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Physicist's Reformed Critique of Nonreductive Physicalism and Emergence

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A Physicist's Reformed Critique of Nonreductive Physicalism and Emergence[1]

by Arnold E. Sikkema

For millenia, people have been asking questions such as "What is the world made of?" and "What are its most fundamental components?" The Greek philosopher Democritus (c. 470-380 B.C.) postulated an atomic theory which held that indivisible particles constitute all of matter, but it wasn't until the nineteenth century that this theory received any empirical support (even though indivisibility remains unsupported). This support was given in botanist Robert Brown's 1827 observations of apparently random motion of pollen grains in water, as explained in Albert Einstein's 1905 application of James Clerk Maxwell's and Ludwig Boltzmann's 1860 kinetic theory of gases, a clear example of the interplay of observation, theory, and experiment basic to physics. In the hundred years following Einstein's *annus mirabilis*,[2] physicists have learned that most matter is made of nuclei and electrons, that nuclei are made of neutrons and protons, that these are made of quarks, and that quarks and electrons, though possibly indivisible, may "simply" be special modes of oscillations of yet more fundamental "strings." Brown, Maxwell, Boltzmann, and Einstein worked in the context of the success of modern (Newtonian) science, which by means of abstraction and empirical studies optimistically de-mystified much of the world into tidy physical explanations in mathematical language.

While scientific developments of the past few centuries represent significant progress toward obedience to the cultural mandate[3] and the manifestations of Christ's lordship and restoration of life and the cosmos, a dark side has presented itself as well. This was the slow but steady growth of reductionism, as majority elements of both the scientific community and the general public under its influence developed a point of view that brain physiologist Donald MacKay calls "nothing-buttery": there is nothing in the universe but particles and interactions.[4] Among the most vocal and dogmatic is Nobel prize-winning theoretical physicist Steven Weinberg, who rebuts moral philosopher Mary Midgley's claim that statements like "George was allowed home from prison at last on Sunday" cannot be explained in the language of physics by saying,

> apart from historical accidents that by definition cannot be explained, the nervous systems of George and his friends have evolved to what they are *entirely* because of the principles of macroscopic physics and chemistry,

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> which in turn are what they are *entirely* because of the principles of the standard model of elementary particles…. [T]he reductionist world view...rules out other sorts of understanding [such as that] George behaves the way he does because he has a soul that is governed by laws quite unrelated to those that govern particles or thunderstorms…. I can readily believe that at least in principle we will one day be able to explain all of George's behavior reductively, including what he says about how he feels, and that consciousness will be one of the emergent higher-level concepts appearing in this explanation…. Of course, everything is ultimately quantum-mechanical…. [Research] moves us closer to the reductionist goal of finding the laws of nature that lie at the starting point of all chains of explanation.[5]

Weinberg's friend and Oxford chemist, P.W. Atkins, is even more triumphalistic in his views:

> Scientists, with their implicit trust in reductionism, are privileged to be at the summit of knowledge, and to see further into truth than any of their contemporaries....While poetry titillates and theology obfuscates, science liberates....The principal activity of the brain, that of sustaining a sense of consciousness through a lifetime, is open to explanation rooted in its physical structure (as governed by the body's genes being inherited and finding expression through the purposeless workings of the second Law [of thermodynamics], essentially building on the purposeless collapse of sandwiches into chaos) and its chemical activity.[6]

It becomes clear in Atkins' writing that "open to explanation" is meant in the ultimate sense that he considers it simple fact that human thought is, at least in principle, reducible to physics. Atkins actually believes that science is able to achieve an "accounting for the emergence of everything from absolutely nothing." [7]

As seen above, both Weinberg and Atkins believe that mind emerges from matter. Emergence has, in fact, developed into a key concept in the philosophy of mind. In the past couple of decades, however, problems with reductionism have led many philosophers of science to adopt an approach called "nonreductive physicalism," while retaining a revised notion of emergence. In the past decade, this approach has begun to impact the burgeoning field of "science and religion," as a number of influential Christian philosophers and theologians consider it to be in significant concordance with biblical anthropology.

Non-Reductive Physicalism Defined

The clearest definition of nonreductive physicalism articulated in a Christian context is given in a collection of papers[8] whose authors, according to co-editor Nancey Murphy, agree "with the scientists and philosophers who hold that it is not necessary to postulate a second metaphysical entity, the soul or mind, to account for human capacities and distinctiveness [while indicating their] rejection of contemporary philosophical views that say that the person is 'nothing but' a body."[9] After a brief discussion of hierarchies (more on this later), such as physics-chemistry-biology-psychology-sociology, she more precisely defines "nonreductive physicalism" in terms of three other positions.[10] *Ontological reductionism*, which these authors accept, is the position that "no new kinds of metaphysical 'ingredients' need to be added to produce higher-level entities from lower," thus minimizing the number of categories of being. But the two positions rejected are *causal reductionism*, "the view that the behavior of the parts of a system...is determinative of the behavior of all higher-level entities," and *reductive materialism*, which goes beyond ontological reductionism to claim "that only the entities at the lowest level are *really* real; higher-level entities...are only composites of atoms." (Here, Murphy pictures the hierarchy of levels as an extension of a sequence such as physics-chemistry-biology, an improved version of which I will take to be Dooyeweerd's modal aspects of created reality.)[11] Permit me to elaborate a little on these three reductionisms and their respective acceptance and rejection in "nonreductive physicalism."

An important aspect of *ontological reductionism* is the rejection of the ancient Greek dualism of being still dominating western civilization (including Christianity), which postulates that humans are constituted by two types of substance: the physical body plus the spiritual soul. While I don't intend here to enter into a full discussion of the nature of the soul, Genesis 2:7 ("And the LORD God formed man of the dust of the ground, and breathed into his nostrils the breath of life; and man became a living soul" [KJV]) indicates that instead of *having* souls, people *are* souls. While I join the "nonreductive physicalist" in this eschewing of two (or more) types of substance, a Reformed, Christian approach must contest the inherent reductionism of claiming that the one kind of stuff out of which the world is made is the stuff of physics. Before turning to this critique, let me round out this brief explanation of Murphy's definition of "nonreductive physicalism."

It is clear that scientists such as Weinberg and Atkins adhere strictly to *causal reductionism*, which is clearly opposed to the Reformed, biblical teaching that persons cannot legitimately pass all responsibility for their decisions and actions to their constituent parts. While not denying that our members play an important role (consider, e.g., "If your right eye causes you to sin..." [Matthew 5:29]), we are created in the image of God, in relationship with others, endowed with conscience and will. While ions and molecules (etc.) are important in the physical and chemical processes of living things, I join the "nonreductive physicalist" in recognizing that a cat's response to a mouse cannot be strictly due to the physical interactions between the particles of the cat, mouse, and environment. In addition to the argument from will adduced by Murphy, I deny causal reductionism primarily because the biotic and sensitive aspects[12] of the cat are not reducible to its physical aspects, even though these aspects are related to (specifically, retrocipate on) the physical.

Reductive materialism is the form of reduction perhaps simplest to refute both from common experience (we routinely refer to cats, colleges, and concepts as no less real than one another)[13] and from the philosophy of science (which in recent years has largely grown to recognize as valid the critical realism of the working scientist, and especially so in Christian circles).[14] The reminder of the "nonreductive physicalist" to resist the significant temptation to regard cats as "more real" than concepts is important to bear in mind.

Thus, while affirming "nonreductive physicalism" insofar as it rejects reductive materialism and causal reductionism, let me explain in some more detail why I cannot accept its notion of ontological reductionism. Essentially, the problem with "nonreductive physicalism" is that it is, after all, a *physicalist* position: it reduces everything to the physical; it elevates this one aspect of created reality as being fundamental, basic, uniquely essential, primary, foundational. And it claims that the universe is physical, in a certain presumed-unambiguous sense: the warrant for Christian faith to affirm the various things it affirms, such as persons, communities, soul, is supposed to be that these are, at bottom, *physical* in a traditional, modernist sense.

The Limited Fundamentality of Physics

Now it must be conceded that there are certain senses in which the physical is foundational and essential. Thus, it can be argued that the discipline of physics is the most fundamental of the so-called natural sciences and serves as a foundation for other natural science disciplines (especially chemistry and biology). Physics, as the science about the physical aspect of creation (using Dooyeweerd's modal aspects), is a fundamental science because all science by virtue of its being empirical involves interaction with the created world, and *interaction* is the kernel of the physical aspect.[15] That is, we gain understanding about the world by interacting with it,[16] which requires (but is not exhausted by) the receipt of sensory signals, all of which involve physical interaction: light focused by the eye's lens interacts with electrons in the retina; air-pressure waves entering the ear canal are directed to vibrate the tympanic membrane, etc. Much of the instrumentation used in the scientific disciplines can be seen as enhancements to human senses by, in part, objective quantification (e.g., the measurement of mass, which is an improvement of our subjective ability, through the sense of touch [e.g., "hefting"], to compare and estimate masses), increasing resolution (e.g., the optical microscope and telescope), extending ranges (e.g., measuring the electromagnetic spectrum beyond the "visible," and sound waves beyond the "audible"), as well as additional types of interactions (e.g., the measurement of magnetic fields). In addition to the importance of the physical aspect in gaining knowledge in every field, the discipline of physics (specifically the atomic sub-discipline) studies the interactions of the entities (atoms, ions, electrons) that chemistry as a discipline builds upon (molecules),[17] which, in turn, biology builds upon (e.g., organic molecules), which, in turn, physiological psychology builds upon (e.g., neurons). By "building upon," I mean not only in terms of studying the aggregate entities and their interactions but also in that the results and conclusions of physics (and to a lesser degree its methods) are employed and assumed in chemistry, etc. However, it must be kept in mind that there is no sense in which biology *simply* builds upon chemistry or physics, for I agree with Stafleu that from the point of view of Dooyeweerd's modal aspects, "the view that the modal aspects form a sort of 'layer' structure in reality, with each layer built upon the earlier ones, is prohibited."[18] Therefore, this is not meant to be an exhaustive definition of the disciplines of physics, chemistry, biology, and psychology or of their interrelationships, but simply examples of the dependence of the latter on the former. In addition, these disciplines need not build upon only the *one* immediately more fundamental; for example, physiological psychology will deal directly with effects of the electrical impulses of physics.

Furthermore, it is certainly true that everything in creation, whether it be cats, colleges, or concepts, cannot exist without the entities of physics and their interactions. This is perhaps most clear with cats, as they have bodily organs, which have organic tissues, which have organic molecules, which have atoms. Colleges, while not essentially involving bricks and mortar, have people, which have bodily organs, etc. Concepts are conceived in someone's mind, which is intimately related with her brain, or through complex interpersonal dynamics, adding the aspect of a dynamic physical interaction among people above the connection to the physical entities; concepts may be subsequently documented in books or computer files or other storage media, all of which involve chemicals (e.g., ink and paper) and/or electromagnetism (e.g., magnetization patterns on hard drives). It must be noted, however, that this dependence of everything upon physical entities is relative to God's faithful sustaining of all things, by which is meant more than God's sustenance of the physical entities.

Finally, the physical aspect can be considered special in at least one other sense, namely that everything in the universe at large, outside of the earth and the limited human influence within and beyond the solar system, appears to be qualified by the physical aspect and no higher aspects.[19] The next higher aspect on Dooyeweerd's scale of modal aspects is the biotic, and there is no evidence that any living thing has ever existed apart from those whose home is earth.[20] Thus, life and its influences occupy, spatially, an extremely small fraction of the creation, demonstrating that passages such as Isaiah 40:15 ("Surely the nations are like a drop in a bucket; they are regarded as dust on the scales; he weighs the islands as though they were fine dust.") and Psalm 8:3, 4 ("When I consider your heavens, the work of your fingers, the moon and the stars, which you have set in place, what is man that you are mindful of him, the son of man that you care for him?") are clearly not hyperbolic. But perhaps more than the specialness of the physical aspect, these considerations point out the exceptional place of the earth in the cosmos.[21]

Thus, the discipline of physics is fundamental to all empirical sciences: everything in creation depends on physical entities, and most of the universe can be characterized as being physical objects. But none of these senses in which physics is foundational or essential amount to an argument that the physical aspect is the most fundamental aspect. The three modal aspects upon which the physical retrocipates, namely the numerical, spatial, and kinematic, might lay equal claim to fundamentality. For these aspects point out respectively the distinguishability and countability of objects, the spatial extent of and separation between things, and the changes over time; it is impossible for me to imagine a non-trivial universe in which any of these characteristics fail to hold. One could also argue that the pistic aspect is the most fundamental, as it relates to values and commitments, which shape and direct our relationships with all created things.

The "De-Materialization" of Physics in the Twentieth Century

Let me now elucidate the physical reductionism found in "nonreductive physicalism," which, as already stated above, postulates that "no new kinds of metaphysical 'ingredients' need to be added to produce higher-level entities from lower." The basic problem with this claim is that it elevates the *composition* of entities as though what things are made of is of ultimate concern to a discussion of their ontology. In other words, the existence of a thing in creation hinges upon the fact that it is composed of ingredients which are the entities studied in physics. The warrant for "nonreductive physicalism" to affirm the reality of higher-level entities, such as concepts, is essentially and only that these higher-level entities have been "produced from" the lower-level entities that are universally, at least among all types of philosophical and/or scientific realists, taken to be real. An additional problem with this claim, regarding the meaning of "production" of higher-level entities from lower, will be discussed later along with emergence.

Several difficulties with the elevation of composition are apparent from the discipline of physics itself, specifically through the successive developments of the special theory of relativity, quantum mechanics, quantum field theory, and string theory; these theories represent a progression of ideas about the fundamental nature of particles and make it increasingly difficult to retain a notion of there being a substance from which all else is constructed.

Special relativity, among other things, unveils mass as being a form of energy, the equivalence being seen in Einstein's famous 1905 equation $E = mc^2$, which indicates how to find the energy E of a mass m; here c is the speed of light. Energy can be turned into mass (i.e. "matter"), and vice versa, the most familiar examples being nuclear fission and fusion. Thus, one cannot unproblematically regard, for example, a carbon atom (say ^{12}C) as being composed of six protons, six neutrons, and six electrons. There is much more to relate than simply the compositional story: special relativity indicates that energies of interaction between these entities are integral to what ^{12}C is. Assembling the "parts" to produce ^{12}C is not simple; in addition to the detailed sequences of steps that must be followed (and are, in the core of a star), energy must at first be put in, and a little more energy is later given off, and the mass of the product is a little less than the mass of the reactants from which we started. In fact, the same thing happens in any chemical reaction that gives off heat energy: a little bit of mass turns into that energy.[22]

The point here is that special relativity begins to show us that the question of composition is not simply one of the identification of constituent entities, and that what one regards as being "stuff" or "ingredients" must be at least put alongside of energy, which is not easy to regard as material.

Quantum mechanics, touched upon by Einstein in his 1905 paper on the photoelectric effect and then developed (primarily by others) in the 1920s, showed that regarding subatomic entities as particles is complementary to regarding them as probability waves. At first, light, which Newton believed to be composed of "corpuscles" and which was later shown (in 1803) by Thomas Young to be a wave in an unambiguous interference demonstration, was shown to possess both wave aspects (e.g. frequency, wavelength) and particle aspects (e.g. momentum, countability). Louis de Broglie extended this idea to all entities that are normally considered particles, and now, confirming this, large molecules, such as the famous buckyballs (C_{60}), have been seen to undergo wave interference. Certain types of questions are actually incoherent, such as asking which hole something passed through on the way to a screen showing an interference pattern. The interaction between an entity and its observer is such that its wave nature manifests itself when wave-like questions are asked, and its particle nature manifests itself when particle-like questions are asked. However, the more one knows about the wave nature of a specific entity, the less one knows about its particle nature, and vice versa; hence, the "complementarity" of the wave-particle duality. The recognition of the reality of the wave nature of entities is a blow to the idea of composition being fundamental, for we now have the problematic situation of probability waves becoming building blocks!

A further step is taken in quantum field theory, well established since its first implementation as quantum electrodynamics in 1950, which shows that particles are quantizations of omnipresent fields. Interactions between particles are mediated by virtual particles that are constantly being created and annihilated in all possible ways; in fact, it is impossible to separate interactions between particles from the particles themselves.[23] The quantum fields are certainly less "substantial," but no less real, than the particles touted as being the building blocks of matter. Furthermore, the notion of "constituent particles" cannot be carried down to the quantum world unproblematically, given that the entities of which nucleons are said to be constituted, namely quarks, can neither exist independently nor be dissociated from one another,[24] and that not simply in the practical sense but even in principle.

Finally, string theory, slowly developing over the last three decades and not yet firmly established, states that what we regard as the fundamental particles are in fact special modes of oscillation of yet more fundamental "strings."[25] If one listens to the pure musical tones we call C and G without any knowledge of sources of musical sound, one might suppose that these are two different, albeit related, creatures. However, knowing that a given tone is generated by the lowest-frequency resonance of a vibrating clamped piano string of a certain length, mass, and tension allows a deeper connection to be established between these otherwise mysteriously related tones. Quite similarly, string theory claims that the entities we know as the electron and the top quark might in fact "simply" be different resonant modes of a more universal and fundamental entity called a string, or superstring. As a piano-string resonant mode has a characteristic frequency (or pitch) that determines how it will interact with others harmonically or melodically, a resonant mode of a superstring has a particular mass, charge, spin, baryon number, lepton number, etc., which dictate how it will interact physically with others. Furthermore, it is supposed that the superstring extends into multiple higher dimensions beyond our familiar three. And there is no guarantee that this is simply the first step of a series ending in a truly fundamental type of entity rather than an infinite regress.[26, 27] It is clear, then, that a superstring is of a different metaphysical nature than the fundamental particles of physics, calling into question the coherence of the notion of a "metaphysical ingredient" employed by the "nonreductive physicalist" position.

Thus, the twentieth century, which began with what could be regarded as an empirical demonstration of the materialistic atomistic vision of Democritus, saw a progressive "dematerialization" of physics through the succession of special relativity, quantum mechanics, quantum field theory, and string theory. Modern physics, then, has something quite different in view regarding the structure of the universe than the ordinary parlance used by the "nonreductive physicalist."

Instead of maintaining that a certain category of metaphysical substance is foundational, Christianity claims the will of God as the foundation of all that exists, not simply in the sense that he creates the matter from which all else is built, but that he creates and sustains the entire creation as an integral whole with its multifaceted character. It is only one feature of the creation that certain things exhibit the characteristic of having constituent entities (be they planks, rocks, cells, particles, waves, fields, or strings) that interact with one another.[28] That is, the physical is only one aspect among many that are exhibited by any given thing. Thus, there is no need to argue that the mind is not made of a new metaphysical ingredient different from the brain, and that the physical structure of the brain gives rise to mental properties. Instead, we have here a holistic approach: the human brain and the human mind each have the full range of aspects.[29] The human brain, qualified by the biotic aspect, has a certain number of neurons and size, changes over time, and features multitudes of physical interactions between electrons and nuclei, including various biotic processes such as regeneration of damage. Apparently, the human brain (together with the rest of the central nervous system) provides a central capacity of sensation. The human mind, qualified by the next higher aspect, the analytical, is the seat of discernment. Due to its intimate connection with the brain, it shares the brain's sensitive and lower aspects, and both the brain and the mind are objects to the remaining aspects, as they enable humans (and society, for example) to be involved in culture formation, to communicate through language, to interact socially, to discern resource usage, to be creative, and to be just, generous, and committed.

In fact, plenty of things in creation are simply not made (or composed) of anything at all. There is no sense in which one could argue that a "concept," which certainly exists as a real entity in creation, has constituent components ultimately composed of atoms. However, a concept does have a physical aspect. If the concept is held in one's mind, it coheres with certain neuron interaction patterns in the brain; if written down, it is preserved through binding between molecules of ink and paper; if it exists in a brainstorming session in a discussion group, it is manifested by the physically-mediated interactions among the participants. Thus, it is necessary to replace the Aristotelian idea of physical composition with that of physical aspect and recognize its place among the other aspects of creation. Similarly, it becomes clear that this is not a "physical universe" but a universe which, along with everything in it, has a physical aspect.

Several benefits attend this downfall of "nonreductive physicalism" (This "nonreductive physicalism" was accomplished by recognizing the physical as being just one aspect among many). One of these benefits is the acknowledgment of the legitimate ontology of things in creation characterized, or qualified, by the various modal aspects. In addition, this recognition will help reduce the tendency in some fields, especially biology and neuro-psychology, to pass certain questions or issues down to physics. That is to say, in some areas of research where a biologist gets stuck in terms of determining certain causal explanations or structural relationships, he or she might be inclined to relegate the responsibility — often too easily accepted by physicists eager to demonstrate their supposed omnicompetence — of a more ultimate explanation "down" to the discipline of physics. Also, while much of current philosophy of science is based on the philosophy of physics because physics is presumed to be the most basic and foundational, even model, science,[30] recognizing the physical as one aspect among others will help develop a more fully orbed philosophy of science, recognizing the importance of the different methodologies of inquiry that rightfully play roles in the other scientific disciplines, rather than focusing on what some regard as the highly problematic ontology of the entities of mechanics due to their lying so far beyond imagination. Finally, this approach recognizes the limitedness of physics as a discipline and the intrinsic value of the other fields of study. There is one set of laws for, and regularities that apply to, the physical aspect of creation, of which by our scientific approach we can develop verisimilitudinous formulations, but the other aspects also have their own organizing principles. The laws of biology (such as in genetics and ecology) are not identical to, nor can they be derived from, nor even in principle be based upon, the laws of physics.

Emergence

Having surveyed and critiqued non-reductive physicalism, I must now address the closely related topic of emergence, which has already been alluded to at several points above. Emergence is the idea that higher-level entities are produced from lower-level entities. The archetypical example of emergence is that of the mind emerging from the brain, meaning that the physical structure of the brain produces the consciousness and thinking capacity that we associate with the mind. Emergence is a hallmark of so-called *complex systems,* which are those exhibiting behaviours or properties completely new and unexpected on the basis only of the component parts of which the system has been composed and their relations; thus, the essential features of complex systems cannot be comprehended upon piecemeal analysis. Somehow, the assemblage of the interacting bits and pieces possesses qualitatively new and surprising phenomena, which led a theoretical condensed-matter physicist to choose as the title of a seminal paper "More is Different."[31] In considering a theory of brain-to-mind emergence, philosophers of science point to examples of what is called self-organization and spontaneous pattern formation such as that of Stuart Kauffman,[32] who describes an array of light bulbs, each of which in a subsequent iteration are on or off depending, according to any non-trivial rule, on the status of two other bulbs. In a 10,000-bulb array, out of the $2^{10,000}$ possible patterns (this number is close to 1 followed by 3,000 zeros, which by far exceeds the number of elementary particles in the observed universe), the array very quickly settles into repeating a sequence of — very surprisingly — only about one hundred patterns. [33] Two simple examples of self-organization from common experience are the spontaneous formation of sand ripples and of weather systems. A somewhat more unfamiliar but instructive example is that of Rayleigh-Bénard convection found in a fluid between two horizontal plates. When the bottom plate's temperature is raised above that of the top plate by a certain minimum amount that depends on other properties of the liquid such as its viscosity, the motion of the fluid's molecules undergoes a transition from being random (Brownian motion) to a dynamic pattern of convection cells (see Figures 1 and 2).

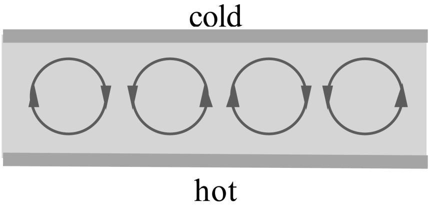

Figure 1. Rayleigh-Bénard convection cells, viewed from the side (schematic).

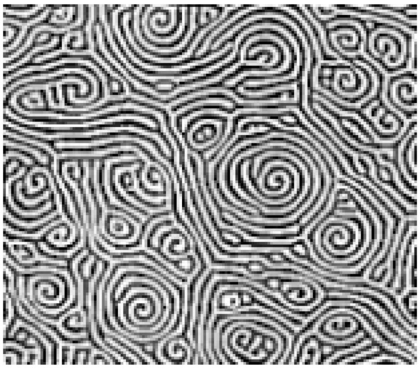

Figure 2. Rayleigh-Bénard convection cells in pressurized carbon dioxide, imaged from above. White and black indicate opposite upward and downward flow respectively. Reprinted with permission from S.W. Morris et al., "Spiral Defect Chaos in Large Aspect Ratio Rayleigh-Bénard Convection, *Physical Review Letters* 71 (1993): 2026-9. Copyright 1993 by the American Physical Society.

Here the motion of individual particles in the fluid is due much less to their microphysical interactions than to the spontaneously established macroscopic patterns.

Other examples of emergence often cited are bulk material properties that are claimed to be quite unconnected to, or at least unpredictable *a priori* from, atomic properties, such as the wetness of water, the hardness of diamond, and superconductivity. These are all demonstrated examples of emergence, which lead philosophers of science, such as Philip Clayton,[34] to speculate that life emerges from organic materials and mind emerges from brain. Hisakazu Inagaki discusses the emergence of human social structures in Karl Popper's "World 3."[35] In fact, Harold Morowitz in his recent book, *The Emergence of Everything*, claims to "present a catalog of 28 observed instances that have emergence in common,"[36] ranging sequentially, and somewhat simplistically, from the big bang to spirituality.

Using Dooyeweerd's modal analysis, we perceive a crucial difference between two different types of emergence, namely that while many examples putatively involve emergence from a system qualified by one aspect to an entity qualified by a higher aspect, emergences that have actually been observed,[37] with possible exceptions in infant development, always begin and end with entities qualified by the same (or even lower!) modal aspect. The speculation that a collection of physical objects emerge into a biotic entity does not follow from having seen emergence occur in collections of physical objects, in which the emerging entity remains a physical entity. That is, it does not follow that life naturally develops from non-living matter, that the brain produces a mind, or that religion will emerge within a society. It is this *production* of a higher-level entity from lower-level entities that is central to "nonreductive physicalism."

Now, physical entities can in fact be combined together to produce items that exhibit a higher aspect, such as the aesthetic. Clearly, when an artist fabricates a painting from various media, this fabrication requires human agency and is therefore not an example of emergence which is supposed to be by *self*-organization. But what about a beautiful pattern of ice crystals spontaneously forming on glass, with its undeniably aesthetic quality? One might argue that this is again not self-organization since the artist here is God. While it is certainly appropriate to recognize the hand of God here, it should be emphasized that there is a vast chasm of distinction between the ways in which the artist and God separately work with physical entities. In the case of the frost pattern, God through his Word and Spirit is at work: he has established, faithfully sustains, and enables the outworking and bringing to fruition of the lawful structures and interactions of water, glass, and air. Granting that this grounding in God's work must in fact be recognized as foundational to anything that one might called *self*-organization, we would categorize the frost pattern but not the painting as self-organization. But most importantly in the context of my argument here, this is still an example of self-organization, which both begins and ends with entities that are qualified by the physical aspect, for the frost pattern is an *object* to the aesthetic aspect, not *subject* to it;[38] clearly it is not alive in any sense (and therefore not even biotically-qualified), even though it demonstrates many of life's qualities such as growth, reproduction, response to stimuli, utilization of energy, etc. (which is a reminder of the value of intuitive recognition of life vis-à-vis defining life[39]). In fact, upon reflection, one can see that pattern-formation found in sand ripples and Rayleigh-Bénard convection cells fits into the same category as the frost pattern: physically-qualified, but having a clear aesthetic aspect. Thus, neither the painting nor the frost pattern is a counter-example to my observation that emergence has not been observed to result in *bona fide* higher-level entities.

One might also raise the following as a counter-example to my claim that the only observations of emergence are those which occur within a single modal aspect: grouping people together results in social group dynamics. This certainly is an example of emergence, as can be seen by the fact that new phenomena are found in a group, phenomena that would not have been predictable based on any study of humans which considered them only as individuals. In this case, however, both the persons and the group of persons are qualified by the full range of Dooyeweerdian aspects, so while new properties emerge, their emergence does not bring us to a higher modal aspect.

In the above examples of emergence, the general phenomenon occurring is that novel properties are seen in a complex system that would not have been expected given the properties of the entities of which the system is composed. For example, water, to the extent that one could describe it as a collection of water (H_2O) molecules, has the property of wetness (roughly definable as a liquid's tendency to cling to surfaces in droplets or sheets, depending on the surface) even though there is nothing about a single water molecule that would lead one to that prediction; in fact, quite a significant collection of water molecules in close proximity is required before the property begins to become manifest. Now, this is not to deny that there is certainly something about the molecules of water (or many other liquids for that matter) to which one can point in an explanation of the wetness, especially in the nature of their weak long-range hydrogen bonds when in the liquid form. But this is a relationship between water molecules whose description required careful studies of liquid water in the first place. That is, wetness is explained *a posteriori*, not *a priori*.[40] The same appears to be true for all of the examples of physical emergence mentioned above, so that one can indeed meaningfully use novelty and unexpectedness of properties as a characterization of emergence as a class of phenomena.[41]

How is it, then, that we find in creation entities that are qualified by the higher modal aspects? It is not that these things are built from, much less produced by, lower-level entities, for this possibility attributes too much autonomy to things in creation, which should be spoken of more passively. God has created the cosmos in such a way that each thing exhibits (when subjected to human investigation) the full range of modal aspects, and he sustains it by his Word of power, and he empowers it by his Spirit to develop, flourish, and unfold. Psalm 104:30 reads, "When you send your Spirit, they are created, and you renew the face of the earth." Citing this verse, Pannenberg writes, "the Spirit of God is the life-giving principle, to which all creatures owe life, movement, and activity. This is particularly true of animals, plants, and humans." A little further, he writes, "The Spirit of God is the creative principle of movement as well as life"[42] Also, in the Nicene Creed, Christians confess that "we believe in the Holy Spirit, the Lord, the giver of life." While all of these claims relate to life, I find it helpful to consider that one aspect of the work of God in the providence and government of the universe is that the Holy Spirit is active in a special way in bringing about any inter-modal emergence that occurs. In fact, a fully Trinitarian approach to emergence is possible, as can be seen especially by considering passages such as Genesis 1:11, "Let the land produce vegetation," in which the *Word* of God goes forth from God the *Father* and, with eyes informed by Psalm 104:30, we see that it is the *Spirit* of God who is at work in a way to enable the land to produce vegetation, and who is at work in the appearance of frost patterns, and also who is at work in the development of consciousness in a human child.

This is, of course, just one of the many ways in which God interacts with the cosmos he has created by his fiat. God is continually known by the "preservation and government of the universe" (Belgic Confession, Article 2), "sustaining all things by his powerful word" (Hebrews 1:3), being faithful to the patterns and regularities he has established in his covenant with creation so that "as long as the earth endures, seedtime and harvest, cold and heat, summer and winter, day and night will never cease" (Genesis 8:22). God acted, and continues to act, in the sweep of redemptive history through covenants with and salvation for his creation and his people. The pinnacle of God's interaction with the cosmos is the incarnation of the second person of the trinity, in which he took upon himself our flesh and blood, our molecules and social structures. And he answers the prayers of those who call to him in faith in the name of Jesus.

Notes

1. I would like to thank Roger Henderson, Charles Adams, and John Zwart for helpful comments on a draft of this paper; Hisakazu Inagaki for many valuable conversations; and the John Templeton Foundation, the Council for Christian Colleges and Universities, and Wycliffe Hall (Oxford University) for the opportunity to study these topics in the John Templeton Oxford Seminars on Science and Christianity (2003-05).
2. The World Year of Physics, 2005, commemorates Einstein's 1905 establishment of a new epoch in physics by explaining the photoelectric effect and formulating the special theory of relativity in addition to accounting for Brownian motion. This paper is published, in part, in celebration of this milestone.
3. This is discussed in a little more detail in Arnold Sikkema, "Science: A Cultural Activity," *Reformed Perspective* 20.3 (January 2001): 289. Of particular interest is that this obedience to the cultural mandate is often done unwittingly by unbelievers.
4. Donald M. MacKay, *The Clock Work Image* (Downers Grove, IL: InterVarsity, 1974), 21.
5. Steven Weinberg, "Reductionism Redux," *New York Review of Books* 42.15 (5 October 1995): 39-42. Vladimir Katasonov has pointed out to me that Nobel-prize-winning physicist Vitaly Ginzburg is similarly active in the Russian context.
6. P.W. Atkins, "The Limitless Power of Science," Ch. 8 in *Nature's Imagination: The Frontiers of Scientific Vision*, ed. John Cornwell (Oxford: Oxford University Press, 1995), 130.
7. Ibid., 131.
8. Warren S. Brown, Nancey Murphy, & H. Newton Malony, eds. *Whatever Happened to the Soul? Scientific and Theological Portraits of Human Nature* (Minneapolis: Fortress Press, 1998); nonreductive physicalism has its origins in the 1916 work of Roy Wood Sellars, as shown in Nancey Murphy, "Supervenience and the Nonreducibility of Ethics in Biology," in R.J. Russell et al., eds., *Evolutionary and Molecular Biology: Scientific Perspectives on Divine Action* (Vatican City State/Berkeley, CA: Vatican Observatory/Center for Theology and the Natural Sciences, l998), 463-89.
9. Nancey Murphy, "Human Nature: Historical, Scientific, and Religious Issues," Ch. 1 in *Whatever Happened to the Soul?* (2).
10. Nancey Murphy, "Nonreductive Physicalism: Philosophical Issues," Ch. 6 in *Whatever Happened to the Soul?* (129f.).
11. Indeed, such hierarchies are found in many writings on critical realism [as reviewed in Alister E. McGrath, *A Scientific Theology, Vol. II: Reality* (Grand Rapids: Eerdmans, 2002), 219-26]; they all lack the generality, comprehensiveness, definitiveness, and interrelatedness of Dooyeweerd's. The relation

between Dooyeweerd's aspect hierarchy and the complexity hierarchy of Nancey Murphy & George F.R. Ellis, *On the Moral Nature of the Universe* (Minneapolis: Fortress Press, 1996) is a topic for future investigation; for example, it appears that increasing structural complexity is merely a by-product, rather than an essential feature, of proceeding through the hierarchy of modal aspects.

12. I refer here to the modal aspects of Dooyeweerd's philosophy of the cosmonomic idea, which need no further explication here due to their familiarity to the Dordt College community. The relevance of the concepts of aspectual anticipation (roughly meaning provision), retrocipation (roughly meaning dependence), and enkapsis (the fractal-like structure of the modal aspects) to emergence is a topic for further study.
13. One way of solidifying this is by defining real as G.F.R. Ellis does: anything that can causally affect other real things, as reported by Karl Giberson, "Princeton Conference Pushes Boundaries," *Research News Online* (May 2002) www.stnews.org/archives/2002/May_features.html (now called *Science and Theology News*).
14. Critical realism explains the growing verisimilitude with which theories represent entities as being due to the interplay between ontology (what is) and epistemology (what we know). For a defense of critical realism from a scientific and Christian point of view, not further explored in this paper, see especially John C. Polkinghorne, "What was happening?" Ch. 21 (158-176) of *Rochester Roundabout: The Story of High Energy Physics* (New York: W.H. Freeman & Co., 1989), John C. Polkinghorne, "Critical Realism in Science and Religion," Ch. 5 (101-24) of *Belief in God in an Age of Science* (New Haven: Yale University Press, 1998), and Alister E. McGrath, *A Scientific Theology, Vol. II: Reality* (Grand Rapids: Eerdmans, 2002).
15. This becomes most clear in M.D. Stafleu, *Time and Again* (Toronto: Wedge, 1980). Stafleu writes, in a section on the measurement problem in quantum mechanics, "we characterize physical systems by their interaction as the basic physical subject-subject relation" (193). My 1998 too-late-for-publication review of this valuable book is at homepages.dordt.edu/~sikkema/StafleuTimeAndAgain.pdf. While some use force and/or energy to characterize the physical aspect, these concepts lose their meaning and relevance at the quantum level, while interaction does not. That other aspects (e.g. social) also feature interaction is an example of the interrelatedness of the modal aspects (e.g. social interaction requires physical interaction).
16. That is not to say that this interaction will be objective or unidirectional, for we are part of the world. In physics this becomes especially important when considering the realm of quantum mechanics, as becomes clear in the measurement problem.
17. A much more nuanced comparison of physics and chemistry, based on a historical analysis, is given in Mary Jo Nye, "Physics and Chemistry: Commensurate or Incommensurate Sciences," in Mary Jo Nye et al. (eds.), *The Invention of Physical Science: Intersections of mathematics theology and natural philosophy since the seventeenth century* (Dordrecht: Kluwer Academic, 1992), 205-24. Of particular interest is her conclusion that "the reductionist program appears not to have been achieved by the founders of quantum chemistry."
18. Stafleu, 17; this is an element of my critique of McGrath's "stratification" of reality.
19. The qualifying aspect of a thing is also called its *leading* aspect, as discussed in Stafleu, 17f.
20. That Christian theology does not rule out extra-terrestrial life, or even extra-terrestrial intelligence, is well argued in C.S. Lewis, *Miracles* (New York: Macmillan, 1947), 59-65.
21. The physical features of the universe necessary for life on earth are thoroughly reviewed in Peter D. Ward & Donald Brown, *Rare Earth: Why Complex Life is Uncommon in the Universe* (New York: Copernicus Books, 2004). Going beyond this the characteristics of earth required for us to develop and satisfy curiosity about the wider cosmos are discussed in Guillermo Gonzalez & Jay Wesley

Richards, *The Privileged Planet: How Our Place in the Cosmos Is Designed for Discovery* (Washington: Regnery Publishing, 2004).

22. Note, then, that the elementary-school concept of "conservation of mass" is only approximately true.
23. Arnold E. Sikkema, "Death of the Watchmaker: Modern Science and the Providence of God," Ch. 5 (97-108) of Hans Boersma, ed., *Living in the LambLight: Christianity and Contemporary Challenges to the Gospel* (Vancouver: Regent College Publishing, 2001).
24. Ernan McMullin, "A Case for Scientific Realism," Ch. 2 (8-40) of Jarrett Leplin, ed., *Scientific Realism* (Berkeley: University of California Press, 1984).
25. A similar point is made in G.F.R. Ellis, "Quantum Theory and the Macroscopic World" in R. Russell et al., eds., *Quantum Mechanics: Scientific Perspectives on Divine Action* (Vatican City State/Berkeley, CA: Vatican Observatory/Center for Theology and the Natural Sciences, 2001), 259-291): "[if] the higher levels of order are in some sense not real…whereas the lowest levels are indeed real [,then given] that we don't even know what the lowest levels of structure are…we don't know what is really real!" (276).
26. Christianity does not resolve this particular dilemma of the "nonreductive physicalist" encountering string theory, as an infinite regress is not outside of the realm of possibilities of an omnipotent creator. Similarly, a universe extending into the infinite past has no less need for or dependency upon a creator, as discussed in William E. Carroll, "Aquinas and the Big Bang," *First Things* 97 (Nov. 1999): 18-20.
27. A related point is made in Philip Clayton, *Mind & Emergence: From Quantum to Consciousness* (Oxford: Oxford University Press, 2004); in Ch. 1, he argues for "monism" rather than "physicalism," writing that "[w]e should not assume that the entities postulated by physics complete the inventory of what exists" while insisting that "[r]eality is ultimately composed of one basic kind of stuff."
28. Andrew Basden, www.isi.salford.ac.uk/dooy/existence.html (1999), summarizes the solution to this problem as being a shift from the western (Greek) focus on entities and existence to a more biblical focus on meaning, quoting Dooyeweerd's famously italicized dictum, "Meaning is the being of all that has been created," consistent with but having a different purpose than my approach here. Thus Dooyeweerd is closer to Wittgenstein, with his over-emphasis on language, than to Aristotle.
29. In what follows, I briefly express a token item for each of Dooyeweerd's modal aspects, namely the numerical, spatial, kinematic, physical, biotic, sensitive analytical, formative, lingual, social, economic, aesthetic, juridical, ethical, and pistic.
30. This observation is due to Ernan McMullin, "The role of epistemic values in science," lecture at Wycliffe Hall, Oxford, 2 August 2004.
31. P.W. Anderson, "More is Different: Broken symmetry and the nature of the hierarchical structure of science," *Science* 177. 4047 (1972): 393-396. See Robert B. Laughlin, *A Different Universe: Reinventing Physics from the Bottom Down* (New York: Basic Books, 2005) for a recent non-technical elaboration.
32. Stuart Kauffman, *At Home in the Universe* (Oxford: Oxford University Press, 1994), Ch. 4: "[A]stonishingly simple rules…suffice to ensure that unexpected and profound dynamical order emerges spontaneously" (74).
33. The relevance of this as a model of a real network is dubious because it depends crucially on having precisely two connections per bulb; L.A.N. Amaral et al. ["Virtual Round Table on ten leading questions for network research," *European Physics Journal B*. 38 (2004), 143-145] note that "the number of elements with *k* links follows a power-law distribution" indicating widely varying connectivities. (I thank Jeff Tseng for identifying this reference.)
34. Clayton*, Mind and Emergence.*
35. Hisakazu Inagaki, "Personhood and Freedom in Religio-Scientific Realism," *Pro Rege* 32.3

(March 2004): 25-38.

36. Harold J. Morowitz, *The Emergence of Everything* (Oxford: Oxford University Press, 2002), 25; like most emergentists, Morowitz links emergence with evolution. (I do not address the physical evolution of the cosmos in this paper, and leave discussions of biological evolution to others.) However, I believe that emergence can be cast in a more ontological, rather than temporal/developmental, framework. A similar insight can be found in George F.R. Ellis, "On the Nature of Emergent Reality," in the forthcoming P. Clayton & P.C.W. Davies, eds., *The Re-emergence of Emergence* (Oxford University Press, 2005): "The existence of higher level complex behaviour, which does not occur at the lower levels, then emerges from the lower level properties both structurally and functionally (at each moment) and in evolutionary and developmental terms (over time)."
37. While philosopher of biology Philip Clayton (private communication, July 2004) claims that my notion of observation is narrow and typical of physicists, and that biologists routinely speak of evolution, and even the origin of life, as being observed, I maintain that such claims of observation tend to conflate theory, observation, and fact in ways that no robust philosophy of science can support.
38. The painting here is similar to the well-known example of the bird-nest, which though it performs a biotic function in providing habitat remains a physically-qualified subject. See Stafleu, p. 19, where subjects and objects are distinguished: "a stone cannot be a biotic *subject*. Only organisms can be subjects to biotic laws. But atoms and molecules, rocks and sticks, may function as biotic *objects* within the sphere of some biotic law. For example, a bird's nest, as a subject, is subjected to only mathematical and physical laws.…As a bird's nest, however, it can be understood adequately only as a biotic 'object'."
39. On defining life, two valuable resources are Aaldert Mennega, "What is Life?" unpublished manuscript (Dordt College, 1971) and Arthur Jones, ed., *Science in Faith* (UK: Christian Schools Trust, 1998), 40f.
40. This *a posteriori* aspect of emergence studies is discussed as "art keyed to experiment" in R.B. Laughlin & David Pines, "The Theory of Everything," *Proceedings of the National Academy of Sciences of the United States of America* 97 (2000): 28-31.
41. An open question in this area is to what degree emergence is related to downward, entropy-reducing, phase transitions in general. The incidences of pattern formation I have discussed all involve an intuitive recognition, *a posteriori*, of an organization of the system at a certain point, and such patterns can be characterized by order parameters whose abrupt changes occur at the same place in parameter space as the intuitively recognized transition. Other similarities with general phase transitions are the importance of interactions at all length scales and the concomitant relative independence of the resulting phenomenon upon microphysical properties and relations. This is an area to which I plan to devote more study.
42. Wolfhart Pannenberg, *Systematic Theology*, trans. Geoffrey W. Bromiley (Grand Rapids: Eerdmans, 1994), Vol. 2, Ch. 7 in the section entitled "The Spirit of God and the dynamic of natural occurrence." (I thank LeRon Shults for pointing out this reference.) Pannenberg also cites Genesis 2:7, Job 12:10, 33:4, 34:14f., and Psalm 104:29, to which I would add Isaiah 32:15, "till the Spirit is poured upon us from on high, and the desert becomes a fertile field, and the fertile field seems like a forest."