

# New Physics

The reader may wonder why the subject of physics arises at all in a book about brain function. If we were advocating a new physics of life and mind simply because we cannot devise an explanation of brain function within the framework of conventional physics, it would appear to reveal a fundamental flaw in the paradigm that we are discussing. If cognition is a physical process, should the entailments of physics not be sufficient to entail it? In fact, avoiding such an appearance of being “unscientific” motivates many brain scientists to find a way at all costs to couch their explanations of brain behavior in terms of the traditional concepts of physics. Curiously, they do so while failing to appreciate that *the fundamental need for new physics is postulated* not by the students of the processes of life and mind, but rather *by some of the world’s most renowned physicists*.

## Premises of old physics

Old physics is not to be confused with or limited to Classical Physics. At minimum, old physics includes 19<sup>th</sup> century Classical Physics, General and Special Relativity, traditional Quantum Mechanics, and chaotic dynamics. There are common presuppositions that run through all these ideas, and some of those presuppositions constitute a common flaw. As we will see later, that common flaw renders old physics insufficient to portray a coherent description of reality.

### *Isn't everything physical?*

The old physics is based on several fairly powerful claims. One is that the world is physical after all. If we understand the laws that govern physical processes we should be able to bend the world to our will by judicious application of those laws.

The concept has been accepted as mainstream science for the past 400 years, and the events of those 400 years seem to provide a spectacular vindication of it. The world has been lifted from grinding poverty to a level of material prosperity unprecedented in all of human history. The fear, want and superstition that dominated the lives of ordinary people in the agricultural era have given way to the optimism and seemingly endless opportunity of the industrial and information economies.

Despite the laments of contemporary critics, the technology that arose from applying the premises of the old physics has literally delivered the goods. There might still be misery in the world, but it is almost invariably the result of unwise choices rather than genuine scarcity. The power of the ideas that lay the foundations for Newtonian mechanics is genuine and cannot be denied.

## **Reductionism**

One of the most fundamental of those ideas is reductionism. In philosophical circles there are a number of different concepts that are characterized as reductionism. In the discussion of physics, the most relevant of these concepts are those identified by Ayala. [Ayala] One is *methodological reductionism*, a strategy for studying wholes, such as systems, in terms of their subsystems. More relevant to this discussion is *epistemological reductionism*, or the reduction of knowledge, the notion that the descriptions of large processes can be fully explained in terms of the descriptions of the components of the process.

Less appreciated, but nevertheless relevant to this discussion is Ayala's third concept, *ontological reductionism* or the reduction of reality, the notion that the actual behaviors and properties of large processes are the result of nothing but the behaviors and properties of the components of the process. "A whole is explained by being shown to be nothing but the parts interrelated in a certain manner." [Scharf, p. 602]

The presupposition of ontological reductionism is a foundational presupposition of Classical Physics. "I wish we could derive the rest of the phenomena of nature by the same kind of reasoning from mechanical principles; for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards each other, and cohere in regular figures, or are repelled and recede from each other; which forces being unknown, philosophers have hitherto attempted the search of nature in vain; but I hope the principles here laid down will afford some light either to this or some truer method of philosophy." [Newton, preface to first edition]

One of the inconvenient habits of physicists is to ignore the distinction between the ontological and epistemological. [Jaynes 89] For clarity of discussion we cannot afford to do so. Thus, we will need to consider that physics is predicated on both epistemological and ontological reductionism. The essential point is that at the heart of physics is the doctrine of reductionism, both ontological and epistemological. "The programme for the unity of science is a programme for universal micro-reduction." [Scharf, p. 608] "Micro-reduction requires that compound elements be explainable in terms of their parts and their interrelations." [Scharf, p. 602]

Reductionism is a deep and fundamental presupposition of physics. "The truth of part-whole reductionism, in either version, would fully justify the claim that physics, or more properly microphysics, is complete." [Silberstein, p. 183] It is so widely accepted because it has been so effective. "It is this metaphysical doctrine of atomism [mereological supervenience] that seems to underlie and support the enormously productive research strategy of micro-reduction in modern theoretical science, and, conversely, the success of this research strategy reinforces our belief in mereological supervenience." [Kim 93, p. 77]

## ***Absolute determination***

“We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes.”

-Marquis Pierre Simon de Laplace [cited in Young, p. 29]

Depending on the commentator, either the entire preceding statement or the “vast enough intellect” to which it refers is called Laplace’s Demon. It subsumes all of the presuppositions of Classical Physics. Explicitly, it is a comment on epistemology. It is a claim, in principle if not in practice, that we can construct a sufficiently large differential equation, and constrain it with a sufficiently detailed list of initial conditions, and from it the “vast enough intellect” could know the movement of every particle in the universe for all time.

It is widely agreed that implicit in this statement is the ontological notion that reality is absolutely determined. In other words, it is presupposed (and is indeed one of the primary underpinnings of Classical Physics), that “the state of the Universe” at an instant in time is the effect of “the state of the Universe” at the immediately prior instant, and the cause of “the state of the Universe” at the immediately subsequent instant. More than that, it is presupposed that the causal entailment structure is perfectly unambiguous. Given a specific instance of “the state of the Universe,” one and only one subsequent “state” is possible.

## ***Bottom-up causation***

It is typically not disputed that also implicit in Laplace’s statement is the ontological notion that events in reality are caused from the bottom up. If we have the state of every particle in the universe, we incidentally have the state of larger collections of those parts. Since the state of the parts at one instant fully entails the state of the parts at the next instant, nothing else is needed to bring about the subsequent state. It is fully caused by the action of the parts. This is the essence of ontological reductionism. The whole is nothing more than the sum of the parts.

Bottom-up causation is one of the most profound consequences of reductionism. “Wholes are completely determined, causally and ontologically, by their parts.”[Kim 78, p. 154] In other words, the properties and behaviors of a system are caused *exclusively* by the components of the system. Ontological reductionism excludes the possibility of top-down causation, the idea that the whole might affect the properties of the parts.

The necessity for bottom-up causation and the exclusion of top-down causation are conventions so deeply held among physicists that they seldom see the need to explicitly assert them. Nevertheless, the principle that bottom-up causation is fundamental and that top-down causation is forbidden in traditional physics *is* explicitly stated in the literature on the philosophy of science, for example in Juarrero. [Juarrero, pp. 131, 142-144] From the perspective of physics it is a disturbing fact that discussion about the roles of both bottom-up causation and top-down causation are also readily found in the theological literature, as in Murphy. [Murphy] The fact that theologians refer to top-down causation can be taken as a warning sign that perhaps the concept is seriously unscientific. In the face of such a potent taboo, it is little wonder that physicists seldom mention the subject, even to deny its existence.

It is easy to see why causation of any kind is seldom explicitly mentioned in physics. If the presupposition of physics that aggregates reduce to their components is valid, then a whole is an epiphenomenon, or a byproduct of causation acting on the parts. [Juarrero, p. 21] Thus, as a direct consequence of Newton's paradigm of physics, cause is typically seen as nothing more than collisions of particles. [Juarrero, p. 23] If cause degenerates to an oblique reference to collision, then why not talk about the collisions themselves, and not clutter the discussion with distracting references to cause? Russell is considered to have administered the *coup de grace* to causation, pronouncing it "a harmful relic of a bygone age." [Russell]

Despite Russell's dismissal, causation is at the heart of ontology, addressing the issue of why reality does what it does. If cause, the "why" of ontology, can be dismissed as a harmful relic of a bygone age then the "what" of ontology quickly follows. This is one reason that physicists typically make no distinction between ontology and epistemology. Although Russell gave this kind of thinking a philosophical *imprimatur* less than a century ago, it has been common in physics for several centuries. This is clearly evident in Laplace's quote. He sees no need to explicitly state the ontological points, supposing that reality comes along at no extra cost if he confines his comment to what the "vast enough intellect" can know about reality.

### ***Completeness in principle***

Speaking of that "vast enough intellect" what is the limit on the scope of its epistemology? According to Laplace, there is no fundamental limit preventing the "vast enough intellect" from knowing everything. The knowledge of the "vast enough intellect" is a complete and total description of reality. Thus, in principle, if Laplace is right, it is possible to construct a largest model of reality.

Since the model is complete, it should be isomorphic to reality. Mathematically, that means that it would be possible to construct a one-to-one onto map,  $\phi: R \rightarrow M$ , where in the most general sense  $R$  is the set of all the events in reality and  $M$  is the set of all the propositions in the model,  $\phi$  carries events in  $R$  to corresponding propositions in  $M$ . If the map is one-to-one then every event in reality would map to a different proposition in

the model. If the map is onto then the model would contain no propositions that are not the image of some event in reality.

Furthermore the map would be operation preserving. Suppose event A maps to proposition P, event B maps to proposition Q, and event C maps to proposition S. (Symbolically,  $\phi(A) = P$ ,  $\phi(B) = Q$ , and  $\phi(C) = S$ .) Suppose event A causes event B causes event C. (Symbolically, the unary operation  $\Rightarrow$  on events signifies “causes”, or the transformation of one member of the set of events into another member of the set of events, and it is represented  $A \Rightarrow B \Rightarrow C$ .) Suppose (as is done in composition of permutations) we compose two unary “causes” ( $\Rightarrow$ ) operations to obtain a binary causal operation. (Symbolically,  $((A \Rightarrow B) \Rightarrow C) = (A \_ B=C)$ ) Suppose proposition P implies proposition Q implies proposition S. (Symbolically, the unary operation  $\Rightarrow$  on propositions signifies “implies”, or the transformation of one member of the set of propositions into another member of the set of propositions, and it is represented  $P \Rightarrow Q \Rightarrow S$ .) Suppose we compose two unary “implies” ( $\Rightarrow$ ) operations obtain a binary implication operation. (Symbolically,  $((P \Rightarrow Q) \Rightarrow S) = (P \_ Q=S)$ ) It follows that  $\phi(A \_ B) = \phi(C) = S = P \_ Q = \phi(A) \_ \phi(B)$ , or the map preserves the operation.

If a map is one-to-one, onto, and operation preserving, it is isomorphic. Isomorphism is a powerful property. If two processes are isomorphic, one can just as easily refer to one or the other with no loss of understanding. If reality and the largest model of reality are isomorphic to one another, one can just as easily refer to one or the other. The presumed existence of a largest epistemological model of reality lends legitimacy to Russell’s advice that we might just as well ignore causation.

It is worth mentioning that the largest model that Laplace had in mind would “condense” the entire epistemology to “a single formula.” That single formula is a map  $\sigma: R^m \square R^n$ , where  $\sigma$  carries members of  $R^m$ , the set of m-dimensional vectors of irrational numbers to members of  $R^n$ , the set of n-dimensional vectors of irrational numbers. This idea that the whole world is reducible to numbers goes back at least as far as Pythagoras. [Guthrie, p. 230] and remains at the heart of physics. As Lord Kelvin reminded the Institution of Civil Engineers in 1883, “When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the state of science.” [Thompson 1883]

It was Lord Kelvin who also articulated the notion of the completeness of the largest model. In a lecture to Royal Institute in 1900 he expressed the commonly held belief among physicists of the time that not only was physics complete-in-principle but was very close to being complete-in-fact. He did note that two small clouds remain over the horizon, the experiments of Michelson and Morley, and blackbody radiation. [Thompson 1900]

## ***Recapitulating the foundational premises of old physics***

To summarize the situation, when we speak of old physics, we mean the various descriptions of real-world processes that do not contradict the following common axioms.

- 1) The behavior of the whole is the sum of the behaviors of its parts and nothing more.
- 2) The state of the Universe at a given instant in time is the effect of the state of the Universe at the immediately prior instant in time, and the cause of the state of the Universe at the immediately subsequent instant in time.
- 3) Causation is unambiguous; one and only one state can be caused by a specific immediately prior state.
- 4) Events in reality are exclusively the effect of bottom-up causation.
- 5) There is, in principle, a complete or largest model isomorphic to reality.
- 6) Considering the largest model epistemologically, and implicitly ignoring the causal entailment structure and ontological effects being modeled, results in no loss of understanding.
- 7) The largest model is a differential equation whose solution is a map,  $\sigma: \mathbb{R}^m \rightarrow \mathbb{R}^n$ .

## **Why did the old physics evolve?**

It is widely supposed that the “clouds over the horizon” of which Kelvin spoke led to a revolution in physics. In fact, they left only slightly changed the premises listed above. At the foundation level, modern physics is startlingly similar to Classical Physics. Although the fundamental premises of the old physics have been left mostly intact by 20<sup>th</sup> century innovations, those innovations did seem quite radical at the time they occurred. Why should radical innovations arise in a science that was previously backed up by centuries of successful prediction? What drove these innovations were the seemingly inescapable paradoxes that arose in physics, and the elegance of the ideas that resolved them.

### ***The universal speed limit***

The first major paradox in physics was the discovery of the “universal speed limit.” Although popularly attributed to Einstein, the phenomenon was actually discovered several decades earlier. Einstein’s invaluable contribution was that he resolved the seeming paradox that arose from the discovery.

The phenomenon first arose as a theoretical consequence of Maxwell’s Equations. Those equations describe the relationship between electric and magnetic fields. The two fundamental equations are known as the “curl” equations:

$$\begin{aligned}\nabla \times \mathbf{E} &= -\partial \mathbf{B} / \partial t \\ \nabla \times \mathbf{B} &= \mu(\mathbf{J} + \partial \mathbf{E} / \partial t)\end{aligned}$$

**E** represents the electric field, and **B** represents the magnetic field. Textbooks on electromagnetism often list two more equations, known as the “divergence equations.” However, they are not fundamental. The “divergence equations” are easily derivable from the “curl equations.”

It is a straightforward homework problem for third-year engineering students to substitute either curl equation into the other, manipulate a few vector identities, derive a relationship known as the “wave equation,” demonstrate that “traveling waves” satisfy the wave equation, and compute the velocity of the propagating wavefront. The resulting solution is astoundingly simple. [Hecht, pp. 39-43]

$$c = (\mu_0 \epsilon_0)^{-1/2}$$

What this says is that  $c$ , the velocity of an electromagnetic wave (including light) traveling through free space, depends only upon  $\mu_0$ , the permeability of free space (the ratio of magnetic flux to magnetic field), and  $\epsilon_0$ , the permittivity of free space (the ratio of electric flux to electric field), **and absolutely nothing else.**

The solution is not merely astoundingly simple; it is frighteningly simple. The quantities  $\mu_0$  and  $\epsilon_0$ , are universal constants. This means that the speed of light in free space is a constant. It is independent of location in space, direction of propagation, frame of reference, or anything else. What was most disturbing to 19<sup>th</sup> century physicists was discovery that  $c$  is independent of the motion of any platform from which the propagating light wave might be launched.

To appreciate how bizarre this result is, compare it to two motorcycles. Suppose that motorcycle A is on a railroad embankment and moving 60 miles/hour in a straight line parallel to the railroad. Suppose motorcycle B is on a flatcar in a train and moving 60 miles/hour in a straight line along the bed of the car toward the engine. Suppose that the train is moving 80 miles/hour in a straight line along the railroad in the same direction as motorcycle A. If we ask how fast motorcycle B is moving relative to the ground, the answer is 140 miles/hour, and 80 miles/hour faster than motorcycle A, exactly the difference in speed induced by the moving platform. This is the common sense answer, fully in accord with Newton’s laws of motion, and if it is tested with real motorcycles and a train, the test would validate the answer.

However, if Maxwell is right, the same experiment will not work if spotlights are substituted for motorcycles. Suppose that spotlight A is affixed to the embankment and the light wave emanating from it is moving 186,000 miles/second in a straight line along the railroad. Suppose that spotlight B is affixed to the flatcar and the light wave emanating from it is moving 186,000 miles/second toward the engine. Suppose that the train is moving 93,000 miles/second (half the speed of light) in a straight line along the railroad in the same direction as the lightwaves emanating from spotlight A. If we ask how fast the light emanating from spotlight B is moving relative to the embankment,

Maxwell says that the answer is 186,000 miles/second, exactly the same as the light emanating from spotlight A; the motion of the platform makes no difference.

This answer flies in the face of common sense, defies Newton's well-tested laws of motion, and seems to point to a fundamental flaw in Maxwell's equations. To understand the character of light propagation, Maxwell devised a very clever experiment that many people expected would debunk his bizarre prediction. The speed of the Earth's movement in its orbit is approximately 1/10000 the speed of light. If light speeds add directly like those of a motorcycle and a truck, then the speed of light propagating in the direction parallel to the movement of the Earth should be about 1.0001 times faster than the speed of light propagating in the direction perpendicular to the movement of the Earth. The experiment was carried out by Michelson and Morley using an apparatus that was capable of measuring the difference in the speeds of the light beams with a resolution on the order of than 1 in 10,000,000. Measuring the speed light beams moving parallel and perpendicular to the movement of the Earth, they found no difference. Maxwell's prediction that the speed of light is independent of the motion of the platform from which it is launched was observed in reality. [Hecht, pp. 382-385]

### ***Relativity is not new physics***

What Kelvin had dismissed as a small cloud was a genuine paradox. Newton and Maxwell seemed to contradict each other, and their seemingly contradictory predictions were confirmed by well-founded experiments. Einstein's contribution to the problem was to identify the false premise and so resolve the paradox. To do so he asked, "Can we conceive of a relation between place and time of the individual events relative to both reference-bodies, such that every ray of light possesses the velocity of transmission  $c$  relative to the embankment and relative to the train? This question leads to a quite definite positive answer, and to a perfectly definite transformation law for the space-time magnitudes of an event when changing over from one body of reference to another." [Einstein 1920, Chapter XI, Paragraph 2]

Notice that he challenges only one premise of the Newtonian/Galilean tradition. He cannot ignore the fact that both theory and experiment do indeed show the speed of light to be independent of the movements of every observer. Since it is fixed, the speed of light does not flex in order to fit into fixed frames of reference that result from assuming that the structure of space and time are rigid. Although an inflexible speed of light is incompatible with the notion of rigid frames of reference, there is nothing sacred about the assumption that the structure of space and time are rigid. Given that the speed of light is fixed, but nevertheless propagating light fits into whatever frame of reference it finds itself, might it be the case that the structure of space and time flex in response to disturbances such as propagating light?

This was Einstein's conceptual breakthrough. Assuming the answer to be yes, that the structure of space and time flex in response to disturbances, and performing some tedious mathematics to trace out the consequences he arrived at a body of thought that came to be called Special Relativity. It must be appreciated that other than reversing the Newtonian

hypothesis that velocities are always flexible and the structure of space and time is always fixed with a new hypothesis that that some velocities are fixed and the structure of space and time is flexible, Einstein suggested no other changes to the Newtonian paradigm. As radical as his idea seemed, it does not merely leave Classical Physics intact, it strengthens it by correcting a mistake that Newton had no practical way of knowing that he had made.

Einstein's other big idea flowed directly from his first. Special Relativity shows that the flexibility of the structure of space and time entails a reality that accommodates the properties of electromagnetism as described by Maxwell's equations, which in turn describe a causal entailment structure that in effect answers the "why" questions about electromagnetic effects. Newton had hypothesized the existence of gravity, and even described it in useful detail, but his description was strictly limited to "what" and not "why" questions. Einstein wondered if the flexibility of the structure of space and time might account for why gravity behaves as it does. [Einstein, Chapter XIX, Paragraph 1]

Although it took a further decade of tensor analysis to uncover the answer, it turned out that he could indeed answer "why" to Newton's "what." The key insight was the observation taken directly and intact from Classical Physics that "the *gravitational* mass of a body is equal to its *inertial* mass." [Einstein, Chapter XIX, Paragraph 5] Einstein did not form a new hypothesis; he reinterpreted an old one given the novel insight that the structure of space and time is flexible. "It is true that this important law had hitherto been recorded in mechanics, but it had not been *interpreted*. A satisfactory interpretation can be obtained only if we recognize the following fact: *The same* quality of a body manifests itself according to circumstances as 'inertia' or as 'weight' (lit. 'heaviness')." [Einstein, Chapter XIX, Paragraph 6] Essentially the presence of a mass warps the fabric of the surrounding space, and the acceleration induced by the warp is experienced as gravity. [Einstein, Chapter XXIX]

Although Special and General Relativity have led to amazing predictions of bizarre behaviors that have been observed in reality against all intuitive expectation, they do not constitute a new physics. Einstein changed none of the seven fundamental premises of physics listed above. In Special Relativity Einstein corrected a logical inconsistency in Classical Physics by introducing the notion that the structure of space and time is flexible. General Relativity amounts to *the reinterpretation of the pre-existing classical insight* of the equivalence of inertial and gravitational mass. Everything else follows inevitably from the mathematical analysis of these concepts.

It must be noted that the theories of Relativity do not constitute not a claim that "everything is relative," as they are often incorrectly characterized. Einstein identified several indispensable absolutes, first, that the speed of light in free space is unconditionally constant, and second, that there is only one kind of acceleration, irrespective of its cause. He then described a coherent reality that could rest upon those absolutes. It in no way diminishes the magnitude or the grandeur of the feat that Einstein accomplished to observe that instead of devising a new physics, he showed what Classical Physics could do if a single incoherent premise were corrected.

## ***The ultraviolet catastrophe***

The other “cloud over the horizon” that Kelvin identified was blackbody radiation. It is a common observation that if solid objects are heated, they emit visible light. It is also a common observation that as the temperature solid objects changes, the perceived color of emitted visible light changes from red hot, through orange hot to white hot. In other words, the spectrum of the light emitted by a hot solid object depends on the temperature. What is remarkable is that the relationship between the temperature and the emitted spectrum is similar for all solid bodies. The idealized relationship between the temperature and the emitted spectrum that is approximated by all hot solid bodies is called blackbody radiation. It is not particularly difficult to construct an object that approximates the behavior of a blackbody to a high degree of precision. [Sproull, pp. 108-112]

Ironically, the difficulty arises from the fact that the properties of blackbody radiation are easy to observe experimentally. The observation raises an unmistakable red flag; only in the deep infrared does the spectrum even remotely resemble what is predicted by Classical Physics. As the wavelength moves toward the ultraviolet, Classical Physics predicts that the blackbody radiation should become more and more intense, seeming to approach infinity. As the wavelength moves toward the ultraviolet, the experiment reveals that the blackbody radiation actually becomes less and less intense, seeming to approach zero. Decades of effort have been spent trying to find an explanation of this behavior within the bounds of Classical Physics. All have failed. This failure to explain blackbody radiation at ultraviolet wavelengths suggests a fundamental flaw in Classical Physics, and is called the Ultraviolet Catastrophe. [Daintith]

Planck discovered a new theory that describes blackbody radiation. The theory from Classical Physics presumes that the light is generated by an assembly of oscillators within the blackbody, with some oscillators at every wavelength throughout the spectrum. Planck retained the presumption that the light is generated by an assembly of oscillators, but hypothesized that the oscillators operate at a discrete sequence wavelengths throughout the spectrum with oscillations at any other wavelengths being disallowed. That presumption of quantization of wavelengths led to an equation that agree with the observed data astoundingly well, and thus began the radical new field of Quantum Mechanics.

The problem is that there is no physical reason for the hypothesis of quantization of wavelengths other than the fact that it produces a curve that fits the empirical data. Planck very inventively answered the “what” question, but totally ignored the “why” question. This was to become the paradigm for Quantum Mechanics. Starting from Planck’s concept of quantization, Schrödinger subsumed the entire theory of Quantum Mechanics a single equation describing the location of a particle in an energy field. In normalized units it has the following form.

$$\nabla^2\Psi - P\Psi = \partial\Psi/\partial t$$

In Schrödinger's equation,  $t$  represents time,  $P$  represents energy as a function of location, but what is  $\Psi$ ? It turns out that  $|\Psi(x, y, z)|^2$  is the probability that we will find the particle at the coordinates  $(x, y, z)$ . [Sproull, pp. 140-141] However,  $\Psi$  itself is typically considered to have no physical meaning. It is a "wave function" with the mysterious property of "collapsing" if we measure the coordinates,  $(x, y, z)$ . However, does the act of measuring  $(x, y, z)$  cause some physical aspect of the particle to collapse, or is it simply a bit of our ignorance that collapses once we have an estimate of the position of the particle?

## ***Quantum Mechanics is not new physics***

Clearly, Quantum Mechanics, is not Classical Physics, and there is no *a priori* physical justification for the hypothesis of quantization that leads to Planck's or Schrödinger's equations. However, this is a difference in detail, not in the fundamental presuppositions. The presuppositions of Quantum Mechanics are strikingly similar to Classical Physics. This is most apparent in the seventh presupposition. The entire model of Quantum Mechanics is subsumed in Schrödinger's equation, a differential equation whose solution is a map,  $\Psi: \mathbb{R}^m \rightarrow \mathbb{R}^n$ .

The sixth presupposition of Classical Physics considers its model epistemologically, and *implicitly* ignoring the causal entailment structure and ontological effects being modeled. The corresponding presupposition of Quantum Mechanics is nearly identical. It also considers its model epistemologically, but *explicitly* ignores the causal entailment structure and ontological effects being modeled. This is obvious from the meaning of  $\Psi(x)$ ; it is the complex square root of the probability of finding a particle between the locations  $x$  and  $x+\delta x$ . In Classical Physics, Maxwell's Equations are fundamentally ontological, making a comment on the electromagnetic field itself. In Quantum Mechanics, Schrödinger's equation is fundamentally epistemological, making a comment on *our knowledge* of the location of a particle.

The fifth presupposition of Classical Physics asserts that there is, in principle, a complete or largest model isomorphic to reality. Clearly, the Uncertainty Principle implies that a map between events in reality and propositions in the model cannot be assured of being 1-to-1 or onto, and the isomorphism breaks down. However, this turns out not to be a difference between Quantum Mechanics and the physics of the world of macroscopic sizes.

It is a little-appreciated fact that both theories share the Uncertainty Principle. It is well known that Heisenberg formulated the principle that  $\Delta x \Delta v = \text{constant}$ , meaning that *we can know* either the position or momentum of a particle with as much precision as we like, at the expense of our knowledge of the other. [Sproull, pp. 122-129] What is less well known is that various researchers have discovered that the same principle applies at the macro scale; Gabor's development of a macro-level uncertainty relationship has had a significant impact on recent strategies for signal processing. [Gabor]

It is worth mentioning that in either case, the Uncertainty Principle is a comment on epistemology and not ontology. It states a limit on how much we can learn about a particle or a signal by taking a measurement. It is *not* a description of a constraint on the actual dynamics of the particle or signal. Since the Uncertainty Principle is a comment on knowledge, and not on the physical process that is the subject of that knowledge, it is not a denial of the causality of the process.

Heisenberg's comment on the Uncertainty Principle was a declaration that causation is irrelevant rather than non-existent. "In view of the intimate connection between the statistical character of the quantum theory and the imprecision of all perception, it may be suggested that behind the statistical universe of perception there lies hidden a 'real' world ruled by causality. Such speculation seems to us—and this we stress with emphasis—useless and meaningless. For physics has to confine itself to the formal description of the relations among perceptions." [Heisenberg, p. 197] Notice how he frames the argument; "physics has to confine itself to the formal description." In other words, he asserts that physics is confined to epistemology. If an ontological argument can show that causation is necessary for the relations among those imperfectly calibrated perceptions to make sense, then no matter how compelling the argument might be, it is nevertheless to be dismissed as a useless and meaningless speculation, for the overarching reason that it is not within purview of physics as Heisenberg defined that purview.

The fourth, third and second presuppositions of Classical Physics, are all concerned specifically with causation. As it clear from Heisenberg's comment, Quantum Mechanics ignores causation, and suggests that such self-imposed ignorance has the same force as denial. However, none of these ontological presuppositions are explicitly overturned by Quantum Mechanics; instead they are explicitly ignored.

The first presupposition of Classical Physics is reductionism; whole is the sum of the parts and nothing more. The difference between Classical Physics and Quantum Mechanics on reductionism is trifling. Classical Physics is concerned with epistemological reductionism, and *implicitly* ignores ontological reductionism, on the supposition that the two forms of reductionism are isomorphic. Quantum Mechanics is concerned with epistemological reductionism, and *explicitly* ignores ontological reductionism, on the supposition that ontology is outside the scope of physics.

Like Special and General Relativity, Quantum Mechanics has led to amazing predictions of bizarre behaviors that have been observed experimentally against all intuitive expectation. However, at the fundamental level, like Relativity, it does not constitute a new physics. The only one of the presuppositions of 19<sup>th</sup> century physics that is actually invalidated by a 20<sup>th</sup> century insight is the notion that there exists a model isomorphic to a physical process. However, this is not an instance of Quantum Mechanics striking at the heart of Classical Physics. Gabor derived the Uncertainty Principle on the macro scale from Classical principles, thereby showing that the possibility of a complete model is not one of those principles. In Quantum Mechanics, the other six presuppositions of Classical Physics are either simply ignored or are recast into strictly epistemological terms.

## Chaos theory

One other idea that has been trendy in recent years is chaos theory. It is important to appreciate what chaos theory involves. Both Classical and Quantum physics share the explicit claim that all the description worth mentioning can be captured in a differential equation. Until about 20 years ago, both Classical and Quantum Physics implicitly shared the even narrower claim that *everything that matters* can be captured in a *linear* differential equation.

The distinguishing feature of a linear system is the principle of superposition. If  $O$  is a linear operator,  $a$  and  $b$  constants,  $f$  and  $g$  functions then  $O(a f + b g) = a O(f) + b O(g)$ . If  $O$  is not linear, then this does not hold. For example,  $O(a f + b g) = h$  where  $h$  can have all sorts of strange dependencies on  $a$ ,  $b$ ,  $f$ , and  $g$ . An example is  $h = a^2 + a b f^3 \sin(a b f g)$ . Linear systems are popular among engineers and scientists because the differential equations that characterize them are readily convertible into much easier to solve algebraic equations.

Within a particular range of properties of the system, even in response to a single periodic input, the output will have a broadband Fourier spectrum; this is deterministic chaos. [Thompson 86, p. 25] There is nothing particularly remarkable about a non-linear system producing chaotic response to a periodic input. It is as fully determined as the periodic response of a linear system to a periodic input. The constraint entailed by that determinism is seen in the fact that “For Hamiltonian, energy-conserving systems, the Liouville Theorem states that the volume occupied by any ensemble of states (points) in phase space remains constant as the ensemble evolves in time.” [Thompson 86, p. 221]

A chaotic response exhibits extreme sensitivity to initial conditions. This has a specific mathematical definition. For a given system, and two slightly different initial conditions, the average separation between the responses increases by a fixed multiple for any given interval of elapsed time. [Thompson 86, p. 4]. In other words, there is exponential divergence between the responses. Nevertheless, as long as the initial conditions are the same for every trial, exactly the same chaotic output is obtained every time.

More importantly, extreme sensitivity to initial conditions does not mean that chaos is to be equated with blithering confusion. The differing responses to different initial conditions occupy a bounded region of phase space. [Thompson, p. 94] This means that *we do not* require an infinitely precise knowledge of initial conditions to make a reliable prediction about the state of the chaotic system. For an arbitrary time in the future, to limit the prediction error within a specific bound, there is another specific bound on the range of initial conditions that we can specify.

This is a severe restriction, and one that is practical to meet only under certain conditions. If we linearly decrease the bound for the allowable error of the prediction, then we must improve the precision of our estimate of the initial conditions exponentially. However, the key point remains. The only circumstance under which we would require infinitely

precise knowledge of initial conditions would be if we were trying to estimate the state of the system into a limitless future.

It is widely supposed that extreme sensitivity to initial conditions overturns Laplace's Demon. [Gleick, p. 14] It does not. All it means is that the Demon cannot look infinitely far into the future. Since only a finite amount of time remains until the Big Crunch, the "vast enough intellect" may take a finite look into that future as far as it likes. Since it must know the initial conditions with a precision that increases exponentially with the distance it looks into the future, the intellect may need to be vaster than Laplace envisioned. Nevertheless, as long as the look is to a time finitely far into the future, if the intellect is vast enough it can get the job done.

An intellect might be vast enough in principle, but not in practice. Man-made processes must be safe and reliably controllable without the necessity for an impractically vast intellect. To assure that this happens, much of the work of engineering is concerned with the design and fabrication of components with unnaturally precise dimensions, extreme material purities and narrow operating ranges, all with the specific intention that they should closely track the description afforded by linear differential equations, and thus be relatively easy to predict and control.

In contrast, processes that can be adequately characterized by linear differential equations seldom actually occur in nature. [Gleick, pp. 67-69] What is remarkable about chaos theory is that the non-linear equation of motion predicts, as an inherent consequence of the entailment structure of the process, many bizarre effects that had been previously dismissed as noise or experimental error. The fact that these predicted effects turn out to be real and inherent properties of natural systems was only grudgingly admitted after it became clear that they were too important to be ignored.

### ***Chaos is not new physics***

Chaos is the old physics done with the decision not to ignore those equations that are hard to solve. There is no new physics here. This is most apparent in the seventh presupposition. The entire model of a chaotic system is a differential equation whose solution is a map,  $\phi: \mathbb{R}^m \rightarrow \mathbb{R}^n$ . Chaos theory simply imposes the perfectly reasonable restriction that the non-linearities in the equation not be ignored.

The sixth presupposition of Classical Physics considers its model epistemologically, and *implicitly* ignores the causal entailment structure and ontological effects being modeled. The corresponding presupposition of chaos theory is identical. This is seen in the widespread lamentations over the fact that there is a limit to what we can know about a process. However, as Gabor shows in the Uncertainty Principle for macroscopic processes, there is a limit to what we can know even about linear systems.

The fifth presupposition of Classical Physics asserts that there is, in principle, a complete or largest model isomorphic to reality. Chaos theory does not challenge that claim. The non-linear differential equation is claimed to be the complete description of the causal

entailment structure of the chaotic system. The requirement for an exponentially precise estimate of the initial conditions if we wish to use that differential equation to make a reliable prediction about the chaotic system is more restrictive than the precision required for linear systems, but is no different in principle.

The fourth presupposition of Classical Physics is that events in reality are exclusively the effect of bottom-up causation. This is unchanged by chaos theory. The non-linear differential equation is a description of the effect of the parts on the whole. As a typical differential equation in Classical Physics it ignores the effect of the whole on the parts.

The third presupposition of Classical Physics is that causation is unambiguous; one and only one state can be caused by a specific immediately prior state. The fact that a chaotic attractor does not intersect itself in phase space is simply a restatement of this very principle.

The second presupposition of Classical Physics is that the state of the Universe at a given instant in time is the effect of the state of the Universe at the immediately prior instant in time, and the cause of the state of the Universe at the immediately subsequent instant in time. As a comment on ontological reality, this is the same for both linear and non-linear processes. Extreme sensitivity to initial conditions does not change the principle. The present state is the exact initial condition for the one and only one possible next state. The fact that there are limits on the precision of our knowledge of both states does not change the underlying reality.

The first presupposition of Classical Physics is reductionism; the whole is the sum of the parts and nothing more. Contrary to comments sometime found in the literature, chaos theory overturns neither epistemological nor ontological reductionism. The non-linear differential equation of chaos is derived from considering the parts and excluding the whole, and is merely a more detailed description of the ontological interaction of the parts than one obtains by approximating the non-linear process by a linear equation. Any seeming whole is nothing but the epiphenomenal aggregation of the interactions of the parts. This is precisely the reductionist paradigm of Classical Physics. Chaos simply considers more of the interactions between the parts than linear systems theory does.

Like Special and General Relativity and Quantum Mechanics, chaos theory has led to amazing predictions of bizarre behaviors that have been observed experimentally against intuitive expectation. Nevertheless, at the fundamental level, like Relativity and Quantum Mechanics, it does not constitute a new physics. None of the presuppositions of Classical Physics are overturned by chaos theory. In fact, it is nothing but Classical Physics with the non-linearities taken into account.

## **Paradoxes from the ontology/epistemology confusion**

Newton published *Principia* in 1687. His concepts underwent two hundred years of rigorous philosophical and experimental validation. Kant, despite his criticisms of rational inquiry, held that Newton's theory was "true and irrefutable," a view shared by

Poincaré, one of the most respected philosophers living at the turn of the 20<sup>th</sup> century. [Magee, p. 187] Although Lord Kelvin noted “clouds over the horizon,” they clearly impressed him as insignificant because he also observed, “There is nothing new to be discovered in physics now. All that remains is more and more precise measurement.” [Wolfram]

Nevertheless, despite the fact that almost all of Newton’s presuppositions continue to serve as the foundation of physics even to the present day, at the turn of the 20<sup>th</sup> century two of Newton’s time-honored assumptions were being undermined. In 1901 Planck found it necessary to challenge the notion of continuity of states. “Moreover, it is necessary to interpret  $U_N$  not as a continuous, infinitely divisible quantity, but as a discrete quantity composed of an integral number of finite equal parts.” [Planck] Likewise, in 1905 Einstein replaced a classical absolute, “...the view here to be developed will not require an ‘absolutely stationary space’ provided with special properties...” with an alternative absolute. “Light is always propagated in empty space with a definite velocity  $c$  which is independent of the state of motion of the emitting body.” [Einstein 1905] Within about two decades Quantum Mechanics was derived from the first insight, and Relativity from the other, and both became widely accepted as part of mainstream physics.

Why was there such an abrupt turnabout? Why had concepts that had withstood centuries of scrutiny lost their power seemingly overnight? Clearly, concepts that had stood the test of time could only be swept away by the severest of challenges. Quantization was the answer to the “ultraviolet catastrophe,” and the flexure of space-time was the answer to the “universal speed limit.” In other words, the paradigm shifts arose because Planck and Einstein discovered compelling concepts that resolved seemingly overwhelming paradoxes.

It is a little-appreciated fact that paradoxes continue to arise in physics. [Jaynes 89] Most, if not all, arise from the failure to distinguish the ontological (statements about processes in reality) from the epistemological (statements about our knowledge of processes in reality). As already noted, this failure to distinguish the model from the process being modeled has its roots in the Newtonian/Laplacian notion that a complete description of reality is possible in principle, and if the description is isomorphic to reality we can save a great deal of difficulty by focusing on the model and ignoring the reality.

It is a 20<sup>th</sup> century discovery that the isomorphism breaks down. The Uncertainty Principle, as discovered in Quantum Mechanics by Heisenberg and in macroscopic processes by Gabor, precludes the possibility of a one-to-one correspondence, and consequently isomorphism, between events in reality and propositions about them. There two ways to respond to this limitation. One is to realize that the inferential entailments of any given model constitute an informed guess about causal entailments in the underlying reality and that if a model fails to explain an observed event in reality, that failure should cause us to seek more information in order to make a more informed guess. The other response is to ignore the breakdown in the isomorphism, and continue to *assume* that the properties of our models are properties of reality.

Consider the common interpretation of the Uncertainty Principle. The indeterminism of the Quantum Mechanical model implies that our *knowledge* of reality is unentailed. Heisenberg asserts that “physics has to confine itself to the formal description,” or is strictly epistemological. Because of that, he dismisses questions about causal entailments in reality as “useless and meaningless.” From there it is a small step to suppose that if causal entailments in reality are meaningless, then they do not exist. This seems to put the *imprimatur* of physics on Russell’s philosophical claim that causation is “a harmful relic of a bygone age.”

The problem is that the interpretation does not stop with Heisenberg’s admonition to refrain from asking questions about causal entailment because they are beyond the scope of Quantum Mechanics. All that the Uncertainty Principle tells us is that *our knowledge* of the position,  $x$ , and momentum,  $p$ , of a particle dances about willy-nilly inside a window whose size is  $\Delta x \Delta p$ . The common interpretation says that our uncertain knowledge somehow drives a particle in reality to behave just that way. “Heisenberg’s Uncertainty Principle asserts that a similar frantic shifting back and forth of energy and momentum is occurring perpetually in the universe on microscopic distance and time intervals.” [Greene, p. 119] Heisenberg asserted no such thing; if such a “frantic shifting back and forth” were occurring inside a boundary described by a window of uncertainty, Heisenberg said that physics would be powerless to recognize it.

The error in thinking reflected in the quote from Greene is typical of a class of errors that Jaynes calls the “Mind Projection Fallacy.” The fallacy is the supposition “that one’s own ignorance signifies some kind of indecision on the part of nature.” [Jaynes 89] Greene’s quote illustrates Jaynes’ observation that “the current literature of quantum theory is saturated with the Mind Projection Fallacy.”

One might be tempted to ask if this is really a problem. If as [Haldane] suggests, “the Universe is not only queerer than we suppose, but queerer than *we can* suppose,” is it too much of a stretch to suppose that the indeterminism of our knowledge projects a disentanglement onto the structure of reality, “as if one were to control Nature by psychokinesis?” [Jaynes 89] It *is* too much of a stretch, because as Jaynes points out, even in dealing with simple physics problems, it leads directly to paradox.

Jaynes’ simple example of diffusion is instructive. Suppose one pours a spoonful of sugar into a big pot of water. The sugar falls into the pot in a concentrated cluster of crystals and dissolves, quickly resulting in a high concentration of sugar molecules near the location of the pour, but no sugar molecules near the edges of the pot. If the pot is left to sit for long enough, the sugar diffuses, resulting in a near-uniform concentration of sugar molecules throughout the water in the pot.

Observing the process raises the question of how quickly the diffusion occurs. One common strategy to answer the question is based on the observation that from early-on in the diffusion process, each sugar molecule is completely isolated from all the other sugar molecules and that its movements are all the result of its collisions with neighboring water molecules. That movement has two parts, a small but rapid vibration riding on a

slow but inexorable drift. Over all but the smallest of drift times the small vibrations cancel each other out and can be ignored. Therefore the diffusion rate should be easily determined from the average drift velocity.

Since the sugar molecules are isolated from each other, the average drift velocity is computed from the interaction of an isolated sugar molecule with its neighboring water molecules. The drift velocity is computed by assuming that the particle is located at position  $x$ , and asking what is the probability that it will be at position  $y$  at a given small interval of time,  $\tau$ , in the future. This explicit assumption is constrained by a hidden assumption that this *probability is a property of the molecule*, and that this property is unaffected by knowledge of the prior location of the molecule or the density of sugar molecules in the ambience at that prior moment. Consequently, the prior concentration of sugar molecules in the region surrounding the molecule of interest is ignored. A straightforward calculation shows that the average value  $\langle y \rangle = x$ . The effects of all the collisions with all the neighboring water molecules cancel out. On-average, it is predicted that the sugar particles do not move and that diffusion never occurs.

The hidden assumption that the probability of future movement is an ontological property of the molecule is the point at which the Mind Projection Fallacy intrudes upon the development. That intrusion gives rise to paradox. The prediction resulting from the hidden assumption, that diffusion should fail to occur, contradicts observed fact. Diffusion is seen to occur.

The paradox is resolved by recognizing that the probability of future movement is not an ontological property of the molecule, but rather is an epistemological comment on what we can expect from the information that we decide to take into account. The movement of the sugar molecule is *not* unaffected by its prior location and density simply because we choose to ignore them. If we consider the probability of movement to be our best guess based on what we know, we can add more information and improve the guess. In the case of diffusion, we have the prior information that the concentration was  $n(z)$  when the molecule was located at  $z$ . The drift velocity is computed by assuming that the particle is located at position  $x$ , and asking what is the probability that it was position  $z$  at a given small interval of time,  $\tau$ , in the past, and given the fact that the concentration was  $n(z)$  at that moment in the past. By a straightforward application of Bayes' theorem, the drift velocity is found to be  $v = -(\delta x)^2 / 2\tau \nabla(\log(n))$ , exactly as observed in experimentally. Eliminate the intrusion of the Mind Projection Fallacy, and the paradox vanishes.

How are we to keep the Mind Projection Fallacy from confusing our thinking? This is difficult since often intrudes upon the reasoning process by means of hidden assumptions, premises tacitly hypothesized but not acknowledged (or even suspected). To keep our thinking clear, we must keep the proper perspective on both our need and capacity to make decisions on the basis of incomplete information. "We are hardly able to get through one waking hour without facing some situation (*e.g.* will it rain or won't it?) where we do not have enough information to permit deductive reasoning; but still we

must decide immediately what to do.” [Jaynes 2003, p. 1] Jaynes says that we reach such necessary but partially-informed decisions by *plausible reasoning*.

Most crucially, he sees the proper role of probability as a tool for facilitating the process. He starts with three desiderata of plausible reasoning: 1) Degree of plausibility is represented by an irrational number. 2) Plausible reasoning should correspond qualitatively to common sense. 3) It should be consistent. From these desiderata, following the work of Polya, Cox and others, he derives the principles of probability theory. Speaking of the quantities  $p$ , in his calculations, he says, “They define a particular scale on which degrees of plausibility can be measured.” In other words, a probability is a measure of what we know. [Jaynes 2003, p. 37]

Plausible reasoning is a generalization of logic. He notes that “Aristotelian deductive logic is the limiting form of our rules for plausible reasoning.” [Jaynes 2003, p. 31] That limit is complete information. In the absence of complete information, plausible reasoning served as an algorithm for making the best possible guess with whatever information is available.

For simple problems he gets the same formulas as Bernoulli and Laplace got from counting balls in urns. However, how he arrived at those formulas was significantly different; it was not based on counting ontological events. “The important new feature was that these rules were now seen as uniquely valid principles of logic in general, making no reference to “chance” or “random variables.” [Jaynes 2003, p. x]

This has significant consequences for reasoning about physical processes. There is no requirement that probability be correlated with random outcomes in ontological reality. Probability is a measure of the plausibility of our description of a situation. We are not justified in assuming that our ignorance of a process implies random behavior in the process. When we make that assumption, it frequently leads to paradoxes.

This has a profound implication for new physics. At both quantum and macro scales the Uncertainty Principle invalidates the fifth premise of traditional physics, the notion that there is, in principle, a complete or largest model isomorphic to reality. Jaynes’ discoveries about the role of probability invalidates the sixth premise, the notion that considering a model epistemologically, and implicitly ignoring the causal entailment structure and ontological effects being modeled, results in no loss of understanding.

If there is a need for new physics, such a physics must do away with both. Instead it must be based on the notion that there is no largest or complete model of a process in reality, and not even Laplace’s “vast enough intellect” will find one. More crucially, our knowledge, or ignorance, does not drive ontological randomness. Any genuine understanding of reality must ask questions about the causal entailments of reality as well as questions about the inferential entailments of our models of reality. What Jaynes’ resolution of the paradoxes that flow from the Mind Projection Fallacy shows is that it is the dismissal of questions about causation that has now become “a harmful relic of a bygone age.”

## The need for superphysics

The discoveries of Heisenberg, Gabor and Jaynes lead to only a slight revision in the original presuppositions of physics. Taking into account these revisions, we can still say that the strategies of Classical Physics, Special Relativity, General Relativity, Quantum Mechanics and chaos theory either specifically presuppose or ignore (but do not prohibit) the following presuppositions:

- 1) The behavior of the whole is the sum of the behaviors of its parts and nothing more.
- 2) The state of the Universe at a given instant in time is the effect of the state of the Universe at the immediately prior instant in time, and the cause of the state of the Universe at the immediately subsequent instant in time.
- 3) Causation is unambiguous; one and only one state can be caused by a specific immediately prior state.
- 4) Events in reality are exclusively the effect of bottom-up causation.
- 5) All the available information about a physical process can be described by a differential equation whose solution is a map,  $\sigma: \mathbb{R}^m \rightarrow \mathbb{R}^n$ .

Any revision to physics that leaves these presuppositions intact is simply an update of the old physics. Any body of thought sufficiently radical that we might seriously consider it to be new physics must overturn one or more of these presuppositions. Are we particularly keen to do so? These presuppositions have served us amazingly well for many centuries. Any reason for considering the need for a new physics must be as profound as the one that motivated Planck, Einstein and Jaynes to question some of the old presuppositions. We need new physics if and only if the old physics leads to paradox.

The most publicized paradox is that Quantum Mechanics and Relativity contradict each other. “The notion of a smooth spatial geometry, the central principle of general relativity, is destroyed by the violent fluctuations of the quantum world on short distance scales.” [Greene, p. 129] At first glance, this seems a classic illustration of Jaynes’ idea of paradoxes arising from the Mind Projection Fallacy. In predicting the existence of those “violent fluctuations,” Wheeler says, “Because it is the essence of Quantum Mechanics that *all* field histories contribute to the probability amplitude, the sum not only may, contain doubly and multiply connected metrics; it must do so.” [Wheeler, 1955] Clearly, Wheeler is asserting that probability is a physical property of fields rather than a comment on what we know about the fields.

If this were all there were to it, we could dismiss “quantum foam,” whose existence Wheeler presumed to follow from Uncertainty, as a phenomenon *neither required nor forbidden* by the Uncertainty Principle. Indeed, by Heisenberg’s strictly epistemological interpretation of the Uncertainty Principle it is impossible to determine whether or not the quantum foam exists and speculation about it is “useless and meaningless.” However, even if we follow Heisenberg’s advice and confine ourselves to the level of epistemology, there remains a paradox. If we combine the equations of Quantum Mechanics and General Relativity, infinities arise, and they are stronger infinities than

those that are renormalized away in traditional Quantum Mechanical computations. The infinities indicate that an epistemology that contains the equations of both Quantum Mechanics and General Relativity is logically incoherent.

It also turns out that we cannot entirely dismiss the possibility of quantum foam on ontological grounds. It must not be forgotten that the Uncertainty Principle describes a tradeoff in the limits of what we can know about the position and momentum of a particle simultaneously; if we are willing to sacrifice resolution in one dimension, we can observe the property in the other dimension in as much detail as we like. Lamoreaux claims have done just that, reporting the “conclusively demonstrated” existence of a “vacuum stress” that he says is “due to the modification of the zero-point fluctuations of a magnetic field.” [Lamoreaux, 1997] One interpretation (not shared by all physicists) of his results is that he has produced experimental evidence of the quantum foam. If so, the fact that Wheeler predicted it more than 40 years before Lamoreaux saw it, testifies more to Wheeler’s powerful intuitive grasp of physics than to the predictive power of the Uncertainty Principle.

However, we must not lose sight of the essential point. The paradox is evident both ontologically and epistemologically. Quantum Mechanics and General Relativity contradict each other. There is a genuine need, identified by physicists themselves, for a new physics that coherently accounts for both the microscopic effects described by Schrödinger’s equations and the astronomically large effects predicted by General Relativity. It is reasonable to expect that such a new physics would explicitly overturn at least one of the five presuppositions listed at the beginning of this section.

## ***Superstrings***

One of the currently popular strategies for resolving the paradox implied by quantum foam is superstring theory. It started with a successful attempt to explain why the observed properties of the strong nuclear force happen to fit the Euler-beta function, a theoretical mathematical construct discovered in the 18<sup>th</sup> century. [Greene, p. 137] If one hypothesizes that the elementary particles are vibrating one-dimensional strings, the equations that describe their behavior have solutions in terms of Euler-beta functions. Subsequent work led to the prediction of gravitons, a hint that the theory might reconcile Quantum Mechanics and General Relativity.

Since then, superstring theory has suffered from four difficulties. First, it has progressed by fits and starts; superstring hypotheses that solve a specific problem rapidly lead to contradictions when applied to other problems. Although this has progressively led to a sequence of better hypotheses, each resolving all the previous contradictions, there always seems to be a new contradiction just ahead. This paradigm of “discovery by disaster” is unsettling to most physicists and to all of their funding sources. Second, superstring theories inevitably require high-dimensional spaces in order to provide coherent solutions; this concern seems more aesthetic than scientific, but it has proven to be a hindrance to the acceptance of the theory. Third, the theory is based on approximate solutions to approximate equations, and many of its predictions are decades away (if

ever) from experimental testing. This seems a shaky foundation for what some expect to become a “Theory of Everything.” Fourth, the superstring theorists exhibit the same “there is nothing new to be discovered in physics” attitude as Kelvin. Superstring literature abounds with comments like “It may well be that there aren’t other surprises.” [Greene p. 318] The obvious error of this perspective leads one to wonder what other mistakes they might be making.

It remains to be seen how useful or popular superstring theory eventually will become among physicists. Although the idea of fundamental particles with finite dimensionality and the necessity for eleven such dimensions seems radical to mainstream physicists, there is a much more relevant question. Is the theory radical enough? The chief theoretical strategy is the perturbation method, a technique for approximately linearizing non-linear differential equations that has proven fruitful over the years in Quantum Mechanics. In its present form, superstring theory does not appear to challenge any of the five presuppositions listed above. It is not a foregone conclusion that it will fail to realize the expectations of its enthusiasts. However, it is so similar to traditional physics in both its presuppositions and its theoretical strategies that it hardly seems to have the makings of a radical paradigm shift.

## **Bohm**

### **Ontological interpretation of $\Psi$**

Another contradiction between Quantum Mechanics and Relativity arises in quite a different way. Despite Heisenberg’s admonition that it should be good enough, it is deeply unsatisfying to settle for the notion that  $\Psi(x, y, z)$  signifies nothing more than a complex square root of the probability that we will find the particle at the coordinates  $(x, y, z)$ . Bohm departs from this strictly epistemological convention, offering an ontological interpretation of Quantum Mechanics.

To interpret  $\Psi$  as something ontological, first consider that it has a magnitude,  $R$ .  $Q$  is a quantum potential that depends on  $\nabla^2 R/R$ . The entailment of particle motion is described by an updated version of Newton’s Second Law,  $m \, dv/dt = -\nabla V - \nabla Q$ . “This means that the forces acting on it (the particle) are not only the classical force,  $-\nabla V$ , but also the quantum force  $-\nabla Q$ .” [Bohm, p. 30]

$Q$  represents a “quantum field” with some very peculiar properties. Since the amplitude of  $R$  appears in both the numerator and denominator of the definition of  $Q$ , the strength cancels out. The effect of  $Q$  effect depends on the form of  $\Psi$  and not at all on its strength. It has the power to reorganize energy non-locally. “Such behavior would seem strange from the point of view of Classical Physics. Yet it is fairly common at the level or ordinary experience. For example we may consider a ship on automatic pilot being guided by radio waves. Here, too, the effect of the radio waves is independent of their intensity and depends only on their form. The essential point is that the ship is moving with its own energy and that the *form* of the radio waves is taken up to direct the much greater energy of the ship.” [Bohm, pp. 31-32]

In other words,  $\Psi$  is a manifestation of a quantum field that conveys *active information*. “The basic idea of active information is that a form having very little energy enters into and directs a much greater energy.” [Bohm, p. 35] This fundamentally differs from the passive information in Shannon’s information theory. The receipt of passive information merely removes a bit of ignorance from the recipient. Active information entails organized action. More importantly, that entailment operates non-locally. “A very important further implication of the notion of active information is that in a certain sense an entire experiment has to be regarded as a single undivided whole.” [Bohm, p. 38]

## **Non-locality**

To appreciate how this leads to a paradox in the old physics, start by considering a pair of magic coins. [Dress] Individually, each coin is fair. Over many coin tosses, each coin individually comes up heads just as often as tails. Where the magic comes in is that if both are tossed at the same time, the one that lands second always shows the same face as the one that lands first. One can imagine a rigged game, in which one bets on the outcome of the second coin by placing the bet just after the first coin lands, but just before the second. What is the trick? The trick is quantum entanglement.

Nobody has figured out how to do the trick with macro-sized coins, but it is observed in polarized photons. There is nothing in Classical Physics that shows anything like this kind of behavior. If an atom is excited in a process known as an “SPS cascade” it will emit two photons moving in opposite directions with exactly the same polarity. [Peres, p. 155] That polarization is unpredictable, just like the coin toss. Suppose a polarization detector is placed in the path of one of the photons a fixed distance from the SPS source. It will register the polarization of the incident photon. Suppose another polarization detector is placed in the path of the other photon a longer distance from the SPS source than the first detector. The second detector will register the polarization of the incident photon a short time after the corresponding reading is registered by the first detector.

The reading by the second detector will always be the same as the reading by the first, just like the second magic coin always lands with the same face up as the first. Despite the fact that the sequence of readings from either detector looks random, the two sets of readings are perfectly correlated. It is as if the first photon has somehow reaches out and forces the second to take its polarization.

Why should such a reaching out be necessary? The problem is that in quantum mechanics it is presumed that the polarization of a photon is not fixed (and varies randomly) until the act of measurement occurs. The act of measuring the polarization is presumed to fix its value. Suppose the first photon is observed, and thereby acquires the polarization reported by the measurement. The two photons are in a “pure state;” each has the same polarization as the other, whatever that might be. [Jaynes 89] Consequently, the second photon must also have its polarization fixed by the measurement made on the first, even though no measurement is made on the second photon until much later, if ever. If that second measurement is made, it will always report the same polarization as the first.

How is the influence of the first measurement transmitted to the second photon? Recall that the second photon is receding from the first at exactly the speed of light, and the two are already a long distance apart by the time the first observation occurs. Suppose, at the instant of the first measurement, the first photon initiates a message telling the second photon what polarization it must take. If the message moves no faster than the speed of light, then it never overtakes the second photon. If the first photon did influence the second, the influence would need to travel faster than light, in violation of the universal speed limit. *This is the paradox* that arises from entanglement, and it is of the kind suggested by Einstein, Podolsky and Rosen. [Einstein 1935]

Einstein suspected that the influence was the result of the action of “hidden variables.” These describe causal entailments not visible to the epistemology of Quantum Mechanics. [Bohm, p. 19] The wave function that describes the entanglement of the photons is exclusively a comment on the effect. It says nothing about what produced the effect, neither admitting nor precluding the possibility of hidden variables. In fact, the failure of Quantum Mechanics to take notice of the hidden variables is what caused Einstein to pronounce Quantum Mechanics “incomplete.”

Einstein put one more condition on these hidden variables. He insisted that they should act locally. Non-locality is the notion that two particles can be “strongly coupled over long distances.” [Bohm, p. 57] Bohm shows that non-locality violates a key presupposition of the old physics, the behavior of the whole is the sum of the behaviors of its parts and nothing more. In what Bohm calls a “radical departure,” he says “the quantum potential, Q, depends on the ‘quantum state’ of the whole system in a way that cannot be defined as a pre-assigned interaction between all the particles.” [Bohm, p. 58] (Note: In the context of this comment it must be recalled that Bohm is making another radical departure from traditional Quantum Mechanics; he presupposes that the wave function has ontological meaning.)

Bohm does not merely suggest overturning the notion of ontological reductionism. Something more is involved. “The interaction of the parts is determined by something that cannot be described solely in terms of these parts and their preassigned interrelationships.” [Bohm, p. 58] There is an influence of the whole upon the parts. “Something with this kind of dynamical significance that refers directly to the whole system is thus playing a key role in the theory. We emphasize that *this is the most fundamentally new aspect* of the quantum theory.” [Bohm, pp. 58-59]

Bohm is speaking of his ontological interpretation of Quantum Mechanics. The implication of wholeness is fundamentally new. It overturns another presupposition of old physics that says that events in reality are exclusively the effect of bottom-up causation. It is little wonder that Einstein, a believer in the presupposition of exclusive bottom-up causation, dismissed top-down influence as “spooky action at a distance.” [Bohm, p. 57]

Irrespective of its local versus non-local character, there does appear to be a causal entailment structure that is physically real but hidden from the epistemology of Quantum

Mechanics. Experiments with entangled photons indicate its influence. “The perfect correlation of distant and seemingly random events ... suggests that the fundamental laws of physics are deterministic, and that the apparent stochasticity of quantum phenomena is merely due to our imperfect methods of preparing physical systems.” [Peres, p. 158]

Although we do not know the character of these hidden variables, it is possible to construct a model of them and identify some limitations on what properties might be required of or forbidden to them. Bell presupposed that the hidden variables exist, and his inequalities are a statement of a set of requirements that must be met if the hidden variables are to be exclusively local. [Bohm, p. 143] Most crucially, “Bell’s theorem is not a property of quantum theory. It applies to any physical system with dichotomic variables, whose values are arbitrarily called 1 and -1.” [Peres, p. 162]

Two remarkable results flow from the Bell inequalities. First, when applied to Quantum Mechanics, the wave function that describes the effect (while ignoring the causes) of the polarization of entangled photons violates the inequality. In other words, although the wave function ignores the cause of the entanglement, the violation of Bell’s inequality says that irrespective of the details of that causation, it must include non-local causal entailment. Second, and most crucially, “Bell’s inequality has been tested in a large number of experiments and generally speaking the inequality has been found to be violated.” [Bohm, p. 144] In other words, the observed violation of Bell’s inequality says that irrespective of the details of that causation, it must include non-local entailment.

The fact that both the wave function and the experiments violate Bell’s inequalities has provoked a most peculiar response in the physics community. Many physicists interpret the result as proof that “Bohr won; Einstein lost.” [Jaynes 89] After all, the experiment agrees with the Quantum Mechanical description, “proving” that Quantum Mechanics is right, and that if there is a problem, it must be with Relativity.

The fallacy is that this misrepresents Einstein’s claim. Einstein never claimed that one could produce an effect that violates the Quantum Mechanical description. He claimed that he could produce a result that Quantum Mechanics *ignores*. The experiment demonstrates that there exists a causal entailment structure, hidden from Quantum Mechanics, but entailing the effects described by Quantum Mechanics nevertheless. The hidden variables that Einstein affirmed and Bohr denied *are there*. Einstein’s original claim that Quantum Mechanics is not complete is vindicated. For those keeping score, Einstein won; Bohr lost.

However, what Bell shows is not quite what Einstein expected to see. Einstein expected the hidden variables to be strictly local. Since Bell’s inequalities are violated, some hidden variables *must* be non-local. According to Bohm, the non-locality reflects the influence of the whole upon the parts. Thus, reality has top-down as well as bottom-up causation. This is a paradigm shift that Einstein could not countenance; it is far more radical than the one that he made in order to generalize Newtonian mechanics into Relativity.

Despite the fact that non-locality of the hidden variables did not turn out the way Einstein wished, something more important is revealed. It provides a means of resolving the contradiction between Relativity and Quantum Mechanics. “We need a new notion of order that will encompass these different kinds of unbroken wholeness, which could open the way for *new physical content* that includes relativity and quantum theory but has the possibility of going beyond both.” [Bohm, p. 353, emphasis added]

### **Implicate order**

Bohm sees the influence of the unbroken whole of reality as being felt at every point in reality. He calls this enfoldment, and supposes that every point in reality contains some essence of the whole folded into it. “We may call this order implicit, but the basic root of the word implicit means ‘enfolded.’” [Bohm, p. 354] In other words, the enfolded order can be inferred from direct experience, but is not itself directly experienced. As a result, he chooses *implicate order* as the term for the causal entailment structure by which the whole influences the properties of the parts.

Those parts also influence the whole. He calls that entailment process unfoldment or explication. Since this is the opposite of implicate order, he chooses *explicate order* as the term for the causal entailment structure by which the parts influence the properties of a whole. He sees the two entailments operating in a complementary fashion. “Whatever persists with a constant form is sustained as the unfoldment of a recurrent and stable pattern which is constantly being renewed by enfoldment and dissolved by unfoldment. When the renewal ceases the form vanishes.” [Bohm, p. 357] The whole entails the parts and the parts entail the whole.

Curiously, Bohm overlooks the structural similarity between this interaction and impredicativity. The conventional meaning of the term impredicative is given by Kleene. “When a set  $M$  and a particular object  $m$ , are so defined that on the one hand  $m$  is a member of  $M$ , and on the other hand the definition of  $m$  depends on  $M$ , we say that the procedure (or the definition of  $m$ , or the definition of  $M$ ) is impredicative. Similarly, when a property  $P$  is possessed by an object  $m$  whose definition depends on  $P$  (here  $M$  is the set of the objects which possess the property  $P$ ). An impredicative definition is circular, at least on its face, as what is defined participates in its own definition.” [Kleene, p. 42]

In other words, we can imagine the interaction of enfoldment and unfoldment as being analogous to the impredicative relationship. The distinguishing property of  $m$  is that it is a member of  $M$ ; this is enfoldment. The distinguishing property of  $M$  is that it contains  $m$  as a member; that is unfoldment. The relationship between  $M$  and  $m$  is defined by the inferential entailment that constrains their influence on each other. In impredicatives, as in Bohm’s dynamic unfolding and enfolding, it is not the objects but the relationship that matters.

An impredicative model of Bohm’s orders would describe many of the properties that he attributes to them. In particular, the interaction of top-down and bottom-up entailment

leads to an internal ambiguity fully in keeping with Bohm's expectation that the world is neither random nor unambiguously determined. "So ultimately our overall worldview is neither absolutely deterministic nor absolutely indeterministic. Rather it implies that these two extremes are abstractions which constitute different views or aspects of the overall set of appearances." [Bohm, p. 324]

### **Holomovement is not a hologram**

Instead of impredicativity, Bohm chooses a less useful analogy. He compares enfoldment to the construction of a hologram from a scene, and unfoldment to the recovery of the scene from the hologram. Since he expects the process to collapse if the dynamics ever halt, he calls the combined interactions of implicate and explicate order the *holomovement*.

It is unfortunate that in trying to describe the properties of these entailments, he compares them to a hologram. The analogy breaks down in at least two particulars. First, unlike Bohm's holomovement, a hologram is not a dynamic process; it is a static object. It is a recording of a 3D scene in exactly the same sense as a pattern of microscopic bumps on a compact disk is a static recording of a 2D scene. In both cases, to unaided human sensibilities the recording suggests nothing resembling the recorded scene. In both cases it requires special equipment to encode the scene to the storage medium and other special equipment decode the scene from the storage medium. However, the medium itself is static, and the encoding/decoding processes are strictly mechanistic.

It is crucially important to realize that *holography is a linear system*. [Goodman, p. 203] Thus, it is not merely a mechanism, but rather it is among the simplest sort of mechanisms. Its operation is easily tractable by the principles of Classical Physics, without the necessity to resort to Relativity, Quantum Mechanics or chaos theory, much less any sort of new physics.

Binocular vision extracts depth information by comparing the slight differences in phase in the light originating from a single scene but reaching two different receptors at slightly different times. This differs from photography, in which the film responds to the intensity of the incident light but ignores the phase. When we look at a regular photograph with our binocular vision, we experience that loss of phase information as the quality of flatness in the picture. [Goodman, p. 198]

Interferometry is a classic linear technique for transforming phase information into intensity information. Without belaboring the details, it suffices to say that holography is a clever way of superimposing the intensity information and the phase-transformed-to-intensity information onto a single photographic plate. More importantly, ability to tease apart the intensity and phase-transformed-to-intensity information is crucially dependent on the linearity of the process. It is this capacity to tease them apart that affords a technique for recovering the 3D scene from the superimposed information on the 2D plate.

There is a great deal of confusion in the non-optical literature over the supposition that if the hologram is broken into pieces then each piece contains the entire scene. “Unlike normal photographs, every small fragment of a piece of holographic film contains all of the information recorded in the whole.” [Talbot, pp. 16-17] This is simply not the case. It is the case that if the hologram is constructed by the method of Leith and Upatneiks, then a piece of the hologram contains information that allows for the *partial* reconstruction of a 2D image of the original 3D scene *from a particular perspective*. [Goodman, p. 220] This is a direct consequence of the ontologically reductionistic character of holography. The reason it works is that the 3D scene is fractioned into many 2D scenes each from a different perspective, and each disjoint fraction is concentrated in a different location on the plate. If and only if *the information from all those disjoint 2D perspectives is combined* is the original 3D scene recovered.

The unbroken (and inherently unbreakable) wholeness of the holomovement is thus fundamentally different inherent disjointness of the parts of a hologram . The same sort of thing happens in a discrete Fourier transform. If a bandlimited signal is sampled faster than the Nyquist rate, the resulting list of numbers is a complete description of the signal, typically called the time-domain representation. A discrete Fourier transform is an algorithm that converts the list of numbers in the time-domain signal into another list of numbers of exactly the same length; that is the frequency-domain representation of the same signal.

Both representations contain exactly the same information fractioned two different ways into pieces of exactly the same size. Every disjoint member of the list in the time-domain representation contributes a little piece of non-overlapping information to each disjoint member of the list in the frequency-domain representation. Likewise, every disjoint member of the list in the frequency-domain representation contributes a little piece of non-overlapping information to each disjoint member of the list in the time-domain representation. It is a classic illustration of the reductionistic idea that if an object is broken into parts, then it can be fully recovered by putting the parts back together, no matter how the object is broken.

Like any other linear system, the entire process of holography is entailed exclusively by bottom-up causation. In this process the property of the whole is nothing but the sum of the properties of the parts. It is inexplicable that the hologram should be mistaken for a paradigm of the influence of the whole upon the parts. In holography, the parts of the scene disjointly entail the parts of the hologram, and the parts of the hologram disjointly entail the parts of the recovered scene.

This is the second and more significant particular in which the analogy between the hologram and the holomovement fails. There is not a hint of top-down causation or of any other non-mechanistic property in the operation of holography. A hologram lacks the key feature that accounts for the remarkable character of the holomovement and the new physics that it signifies; that key feature is its top-down causal entailment structure.

## ***Wheeler***

Whereas the perspective of Bohm, Einstein, and Jaynes is ontological, there is a radically different epistemological perspective that leads to an entailment structure with a startling similarity to Bohm's. Wheeler is best known for describing the gravitational singularity formed by a collapsed star as a "black hole." He is also the originator of the concept of quantum foam.

One might be tempted to dismiss much of what Wheeler has to say as an egregious instance of the Mind Projection Fallacy. For example, in devising the concept of quantum foam he argues from the notion that the Uncertainty Principle implies that phenomena on the scale of the Planck length must be in an endless bubbling frenzy. Nevertheless, we cannot totally dismiss the concept of quantum foam because the first evidence of its existence is beginning to appear in experimental results.

Despite the fact that Wheeler ideas seem to originate from the Mind Projection Fallacy, his intuitions are remarkable, and are often subsequently validated by other means. This fact led Dyson to comment, "The really astounding thing about Wheeler's speculations is that so many of them in the end have turned out to be right." [Dyson] Perhaps it is worthwhile to suspend disbelief and see where Wheeler's ideas lead.

Wheeler starts his discussion of strangeness with a remarkable insight. It is not enough that paradox should drive discovery of new principles. "We need two paradoxes. Only then can we play one off against the other to locate the new point." [Wheeler 80, p. 341] As it happens, two come to his mind. The first arises from Relativity. If the Universe starts with a Big Bang and ends in a Big Crunch, then the laws of physics have a finite lifetime. However, Relativity is based on the presupposition that the laws of physics are forever immutable. The second paradox arises from Quantum Mechanics; the Universe is both dependent on and independent of the act of observer-participancy.

In his thinking, the necessity for observer-participancy arises out of another principle that he attributes to Bohr. "No elementary phenomenon is a phenomenon until it is a recorded phenomenon." [Wheeler 80, p. 356] In fact, this quotation appears over and over again in Wheeler's writings. Its meaning can be seen in the entangled photon problem. There, the phenomenon is the state of the polarization of the photon; that state, and its history, essentially spring into existence at the point that it is registered on the polarization detector.

To illustrate how observer-participancy might work, Wheeler recounts a game of "twenty questions" in which he was the questioner. Upon asking the first few questions, he received rapid answers, but the more questions he asked, the longer it took the participants to come up with simple yes-no answers. After not many questions, he asked, "Is the subject a cloud?" To this the audience unanimously answered, "Yes!" Then they revealed the joke; they had agreed in advance and unbeknownst to Wheeler that there was no subject. They would simply answer the next question in a manner that was consistent with all the answers that arose before. Nevertheless, within an amazingly short round,

both Wheeler's questions and the audience's answers rapidly coalesced into a constraint such that a cloud was the only object that would fit. He argues that "phenomena" are formed in much the same participatory manner.

He is at pains to point out that observer-participancy does not necessitate consciousness. Neither the mind of Man nor of God is necessary in the Universe as Wheeler sees it. "No elementary phenomenon is a phenomenon until it is a registered phenomenon." This summary of the central lesson of the quantum takes its two key words from Bohr. 'Registered' as Bohr uses it means 'brought to a close by an irreversible act of amplification' and 'communicable in plain language.' This adjective, equivalent in most respects to 'observed,' has a special feature as compared to that more frequently seen word. It explicitly denies the view that quantum theory rests in any way whatsoever on 'consciousness.'" [Wheeler 80, p. 359]

He describes the Universe as a "self excited circuit." [Wheeler 80, p. 359] He sees the principle of observer-participancy as a necessary condition. "If the views we are exploring here are correct, one principle, observer-participancy suffices to build everything." [Wheeler 80, p. 359] In other words, his version of new physics overturns all the presuppositions of the old physics.

This self-excited circuit is not merely a loop, but a hierarchical loop. "To endlessness no alternative is evident but a loop, such as: physics gives rise to observer-participancy; observer-participancy gives rise to information; information gives rise to physics." [Wheeler 90] In this instance, the hierarchical relation is "gives rise to." Although he does not use the word, such a structure of entailment is the same as an impredicative construct in mathematics. Impredicativity has several properties that satisfy Wheeler's requirements. It entails its own entailment structure, and revises it as the context changes. Most crucially, its ambiguities provide the flexibility that Wheeler supposes to be randomness in the observer-participancy world.

Although Bohm's ontological quantum fields and Wheeler's epistemological observer-participancy registration appear utterly different from one another, they are strikingly similar on the level of entailment. Bohm says that implicate order entails explicate order entails implicate order. Wheeler says, "Physics gives rise to observer-participancy; observer-participancy gives rise to information; information gives rise to physics." In both cases the entailment structure is entailed by an impredicative loop, and the impredicativity entails the bizarre behaviors in both paradigms. "Causation" is a word that Wheeler avoids. Nevertheless, the real world corresponding to Wheeler's epistemology is, like Bohm's, a world entailed by simultaneous bottom-up and top-down causation. There is nothing like this in any version of the old physics.

## ***Schrödinger***

From yet another perspective, one of the earliest and perhaps the most compelling calls for new physics arose from no less a light than Schrödinger. What motivated his call was the question, "How can events *in space and time* which take place within the spatial

boundary of a living organism be accounted for by physics and chemistry?” [Schrödinger, p. 3] It was clear to him that the old physics was not up to the task but a new physics might be. “The obvious inability of present-day physics and chemistry to account for such events is no reason at all for doubting that they can be accounted for by those sciences.” [Schrödinger, p. 4]

He observes a glaring difference in scale and asks why organisms are so much bigger (on the order of ten thousand to ten billion times longer) than atoms? His answer is that individual atoms in any physical medium make large oscillations compared to their size, and that a structure made up of a few atoms lacks the stability needed to support the degree of organization observed in an organism. In contrast, in a structure consisting of many atoms, the effect of the vibrations of individual atoms cancels out, causing large structures to have more overall stability than small ones. However, he then notes that this point turns out to be comparatively insignificant.

Nevertheless, it provides crucial background for a question that does matter. He notes that genes are on the order of a few hundred atomic lengths. The size is “much too small to entail an orderly and lawful behavior” according to the laws of physics. [Schrödinger, p. 30] Nevertheless, genes are both “highly ordered” entail a high degree of permanence on the phenotypic properties of an organism. Why does the high order of a small molecule arise, and how does it entail a highly stable phenotype? More perplexing, how do they achieve this feat when the number of atoms in the genes “represent only a very small fraction of the sum total in every cell?” [Schrödinger, p. 77] Contemporary physics provides no answer. Even worse, the phenomenon appears to violate the laws of physics.

Schrödinger does not explicitly say “paradox,” but he has identified one. The idea that the gene itself possesses negligible energy, but nevertheless entails the massive energies of an organism to become organized in a form that depends on the form but not the energy of the gene. It is worth noting that Schrödinger is pointing at the same sort of phenomenon as Bohm’s active energy, in which the form of one process entails the properties of a much more energetic process.

Reasoning from Quantum Mechanical principles, Schrödinger develops a model of the entirely counter-intuitive properties that he says the genotypic aperiodic crystal must have. Although Schrödinger himself dismissed the description as “general,” it turned out to be specific enough to lead to the discovery of DNA within a decade of his publication of it. In his own mind, the model entailed “just one general conclusion,” which Schrödinger confesses, “was my only motive for writing this book.” That conclusion is “that living matter, while not eluding the ‘laws of physics’ as established up to date, is likely to involve ‘other laws of physics’ hitherto unknown.” [Schrödinger, pp. 67-68]

He sees a “striking contrast” between the order in mechanistic processes and the order in living processes. For example, in radioactive decay, there is no law of physics for identifying when a specific atom will disintegrate. [Schrödinger, p. 78] The lifetime of individual seemingly-identical atoms varies wildly. In contrast to the wild variations in the behavior of individual atoms, Schrödinger characterizes the order entailed by the

genome to present a situation that is unprecedented, and “unknown anywhere else except in living matter.” [Schrödinger, p. 79] In “striking contrast,” in an organism “a single group of atoms existing only in one copy produces orderly events, marvelously tuned in with each other and with the environment according to the most subtle laws.” [Schrödinger, p. 79] The context dependency of events observed in organisms directly violates the first presupposition of traditional physics that the behavior of the whole is the sum of the behaviors of its parts and nothing more.

In pondering the question of how an organism might maintain its order, he notes that “we witness an event that existing order displays a power of maintaining itself and of producing orderly events.” [Schrödinger, p. 77] He explains that he gets the idea from social organization rather than traditional physics. He is speaking of top-down causation. In so doing, he is suggesting a genuinely radical idea, that the new physics might overturn the presupposition that permeates conventional physics, namely that all events in reality are exclusively the effect of bottom-up causation (presuming they are caused at all).

Remarkably, four decades before the hyperset theorists proved the logical coherence of impredicativity, Schrödinger anticipates that top-down causation might arise, from an impredicative entailment structure. “It might seem that something like a vicious circle is implied.” [Schrödinger, p. 77] Russell equated the vicious circle with impredicativity, a fact probably well known to Schrödinger. Thus, although the paradigms of Bohm, Wheeler and Schrödinger are all underpinned by a structure that looks like impredicativity, only Schrödinger comes close to actually using the word.

He considered living processes to be “too involved to be fully accessible to mathematics.” [Schrödinger, p. 3] Clearly, he considered organisms to be material processes within the scope of rational understanding that would be afforded by the new physics. Just as clearly, the new physics that he envisioned must do away with the presupposition all the available information about a material process can be described by a differential equation whose solution is a map,  $\sigma: \mathbb{R}^m \rightarrow \mathbb{R}^n$ .

We listed five presuppositions that are shared (or ignored, but not overturned) by all the currently accepted theories of physics. It is remarkable that by the observation of “fundamental differences in structure” in organisms in “striking contrast” to that of mechanisms, Schrödinger explicitly overturned three of them. By noting the context dependency of organismic behavior, he overturned ontological reductionism. By noting the impredicative character of the organism’s imposition on the order on its parts, he overturned the presupposition of exclusively bottom-up causation. By noting that the description of living processes is “too involved to be fully accessible to mathematics” he overturned the presupposition that everything worth knowing is expressible in numbers.

Schrödinger does not discard the old physics. He sees it as a degenerate case of the new physics. Nevertheless, by explicitly overturning three of the five fundamental presuppositions of the old physics, the revolution in physics that Schrödinger proposed is far more sweeping in its scope than the paradigm shifts that followed either Relativity or

Quantum Mechanics. Given the genuinely breathtaking scope of his proposal, it is little wonder that speaking of the process of living he said “we must be prepared to find a new type of physical law prevailing in it. Or are we to term it a non-physical, not to say a super-physical, law?” [Schrödinger, p. 80]

## Conclusion

From three different perspectives Bohm, Wheeler and Schrödinger, three of the most seminal thinkers in the history of physics, all make the same point. We need a superphysics, a coherent physical law in which the descriptions of effects currently explained Relativity, Quantum Mechanics and Classical Physics all fall out as degenerate cases. The reason they say it is needed is that contemporary theories of physics are incoherent. Relativity and Quantum mechanics contradict each other, and the observed structural relationships in living processes violate the laws of contemporary physics.

The specific laws that constitute the new physics remain to be discovered. As with prior paradigm shifts in physics, resolution of the paradoxes and discovery of a coherent physics will require that some of the most cherished presuppositions of the old physics be overturned. Based on the discoveries of Jaynes, Bohm, Wheeler and Schrödinger we anticipate that the laws of new physics will be consistent with presuppositions akin to those in the following list.

- 1) The Gestalt is an understatement; the behavior of the whole is greater than the direct product of the parts. [Dress]
- 2) Reality is characterized by inherently dynamic relationships rather than a progression through states.
- 3) Causation is ambiguous; more than one outcome might be coherent with a given entailment structure in a given context.
- 4) Events in reality are the effect of both bottom-up (the influence of the parts on the whole) and top-down (the influence of the whole on the parts) causation.
- 5) There is, neither in practice nor in principle, a complete or largest model isomorphic to reality.
- 6) To avoid paradoxes, reality, our partial models of reality, and the relationship between reality and our models of it must be considered.
- 7) Although there is no largest model, we can construct models such that we can gain insight about the process being modeled by asking questions about the model; we expect many of those models to be category-theoretic maps of the form,  $\sigma: Y \square Y$ , where  $Y$  is the set of impredicative maps. (Differential equations are a degenerate instance of this more general map.)

The claim of a need for a new physics, based on presuppositions similar to the above, arises from within the physics community. It is not an instance of life scientists trying to tell physicists how to do their job. In fact, there is lesson here for life scientists. Despite the fact that the processes of life and mind unfold on a physical substrate, and must be consistent with the laws of physics, there is no need to try to shoehorn theories of life and mind into the narrow constraints of the old physics. The physics community is beginning

the process of replacing the old physics with a radical new physics, and it affords a much richer milieu in which to understand the processes of life and mind.

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