Kantian Causality and Quantum Quarks: The Compatibility between Quantum Mechanics and Kant's Phenomenal World *

Stephen R. PALMQUIST

Received: 14.03.2011
Final version: 08.11.2011

BIBLID [0495-4548 (2013) 28: 77; pp. 283-302]

ABSTRACT: Quantum indeterminism seems incompatible with Kant's defense of causality in his Second Analogy. The Copenhagen interpretation also takes quantum theory as evidence for anti-realism. This article argues that the law of causality, as transcendental, applies only to the world as observable, not to hypothetical (unobservable) objects such as quarks, detectable only by high energy accelerators. Taking Planck's constant and the speed of light as the lower and upper bounds of observability provides a way of interpreting the observables of quantum mechanics as empirically real even though they are transcendentally (i.e., pre-observationally) ideal.

Keywords: Kant; quantum theory; Copenhagen interpretation; indeterminism; perspectives; law of causality; transcendental idealism.

RESUMEN: El indeterminismo cuántico parece incompatible con la defensa de la causalidad que hace Kant en su Segunda Analogía. La interpretación de Copenhague de la mecánica cuántica también considera a esta teoría como evidencia a favor del antirrealismo. Este artículo defiende que la ley (trascendental) de la causalidad se aplica solamente al mundo en tanto que observable, y no a objetos hipotéticos (inobservables) como los quarks, detectables solo mediante aceleradores de altas energías. Tomar la constante de Planck y la velocidad de la luz como límites inferior y superior de la observabilidad nos ofrece un modo de interpretar los observables de la mecánica cuántica como empíricamente reales, incluso aunque estos sean trascendentalmente, es decir, preobservacionalmente, ideales.

Palabras clave: Kant; teoría cuántica; interpretación de Copenhague; indeterminismo; perspectivas; ley de causalidad; idealismo trascendental.

1. The Quantum Challenge to Kantian Causality

When the unsuspecting quantum theorist reads Kant's *Critique of Pure Reason*—or, when the unsuspecting Kantian learns about quantum mechanics (hereafter, "QM")—an apparent conflict soon emerges. QM does not require us to assume that all events in nature are causally determined. Yet in the *Critique's* Analogies of Experience, Kant enshrines causality as one of three transcendental principles that govern how the category of relation *must* apply to the phenomenal world. The overarching principle of all three analogies is: "Experience is possible only through the representation of a necessary connection of perceptions."[1] The three subordinate analogies, specifying what "a necessary connection of perceptions" entails (Kant 1781/1787, 224, 232, 256), are:

* Thanks to Richard Conn Henry and several anonymous referees, for reading previous drafts of this essay and suggesting numerous improvements.

[1] Kant (1781/1787, 218). Page numbers refer to the second ("B") German edition, unless prefixed with "A".

I. *Permanence of Substance*: "In all change of appearances substance is permanent; its quantum in nature is neither increased nor diminished."

II. *Succession in Time (="Law of Causality")*: "All alterations take place in conformity with the law of the connection of cause and effect."

III. *Coexistence (="Law of Reciprocity or Community")*: "All substances, in so far as they can be perceived to coexist in space, are in thoroughgoing reciprocity."

This article examines whether QM contradicts these Kantian principles, especially the Second Analogy.

The nature and validity of Kant's arguments defending the Second Analogy are among the most hotly contested issues in Kant's philosophy. Without delving into interpretive debates that are beyond the scope of this study,[2] I shall begin by addressing three preliminary issues. First, interpreters such as Friedman (1992; see also Buchdahl 1965) present interpretations of Kantian causality that downplay its apparent incompatibility with quantum indeterminacy. They argue that when Kant portrays causality as a transcendental condition for the possibility of experience he intends it to apply only as a general rule of thought guiding us to interpret experience as causally determined, but without denying the possibility that progress in science might someday require non-causal rules to be developed and applied at certain highly refined levels of empirical observation and scientific explanation. Though enticing, this proposal remains problematic: the central claim, that Kant did not intend nature's causal laws to be *deductively derivable* from the transcendental principle of causality, is correct, but fails to explain how *non*-causal rules could coexist with an overarching principle that requires all such laws to be causal. If Kant's Second Analogy must apply to *all* empirical knowledge, then how could *some* empirical knowledge simply dispense with it? Rather than solving the problem of the apparent conflict between Kantian causality and QM, this approach merely transfers it to a problem internal to Kant's system. I shall provide an interpretation of both Kant and QM that solves this problem in either form, without assuming a position on the issue of how Kant thought specific empirical causal laws are related to his transcendental principles. Addressing this latter issue would require examining aspects of Kant's theory that he develops only in later writings (see note 21, below).

In a more recent essay Friedman presents a rather skeptical position regarding the enduring validity of Kant's position: "the more abstract and general synthetic *a priori* principles defended in the first *Critique* are just as subject to refutation by the further progress of empirical science as are the more specific and explicitly mathematical prin-

---

[2] Many complexities still being debated are addressed in Guyer (1987, ch.10, 237-266). Friedman (1992, 193n) lists 15 influential publications on Kantian causality. For a more up-to-date review, see Melnick (2006). Watkins (2005) provides a thoroughgoing historical analysis of Kant's views on causality, but without discussing its relevance to modern revolutions in physics. Kant makes a crucial distinction between pure categories, schematized categories, and principles (i.e., categories as applied to phenomena). The question of the compatibility between QM and Kantian causality relates primarily to the latter. As all three are intertwined, my discussion of the "categories" of relation should be understood as referring to their *applied* form, as *principles* (e.g., of causality).

ciples defended in the *Metaphysical Foundations*" (Friedman 2006, 320-21; see also his detailed account of causal laws in Friedman 2001). In the same volume Melnick (2006, 229) takes as granted the position I shall attempt to refute: "The contemporary view of probable causation, or causation without determination, is of course incompatible with Kant's account."

Buchdahl (1965, 390) makes a number of good points. He observes, for example, that "to say that the Principle of Causality is a transcendental condition of experience is not the same thing as to say that nature is lawlike in general". Referring to Kant (1781/1787, 165), Buchdahl adds: "Special laws, as concerning those appearances which are empirically determined, cannot in their specific character be derived from the categories". Interestingly, the subordinate clause here implies that *some* appearances might *not* be "empirically determined". This suggests (as Buchdahl explicitly mentions) possible parallels between QM and Kant's notion of *noumenal* causality—an issue I plan to address in a subsequent article. However, Buchdahl is mistaken to regard Kantian causality as a "regulative principle of reason" (197), whereby Kant advises scientists merely "to pretend that your task is to fit causes to natural effects" (198). As Butts (1984, 690-693) rightly argues, Kant's principle of causality is significantly more "hard core" than Buchdahl claims: the more "looseness of fit" we acknowledge between empirical laws and the transcendental principles, the more interpretive explanation we must provide for how such compatibility is possible.

A second background issue raised by the debate over how Kantian causality fares in the face of quantum indeterminacy is whether the Second Analogy makes an ontological or an epistemological claim: does causality describe the way nature itself must behave, or the way we must express our *knowledge* of nature? On this question the arguments of Allison (1983, 216-234) have persuaded many Kant scholars that this and all related arguments in the *Critique* must be interpreted epistemologically. While agreeing with the general thrust of Allison's approach, I have argued (Palmquist 1993, ch. VI and appx. VI) that Kant nevertheless does sometimes make ontological claims as well. In accordance with this dual emphasis, my focus here will be primarily epistemological; a follow-up article, dealing with QM and *noumenal* causality, will focus more on ontological issues.

A closely-related third issue typically associated with discussions of the Second Analogy, but outside the parameters of the present study, is what implications Kantian causality has for the debate between realism and anti-realism—an issue also often addressed by quantum theorists. My decision not to frame the present discussion in terms of this debate is justified, in part, by the fact that "the proponents of the Copenhagen interpretation" (see below) "did not have, collectively or even individually, a consistent position on the realism-antirealism issue" (Beller 1999, 203). Even Einstein and Schrödinger were not the radical realists they are often portrayed to be; rather, they regarded "the idea of reality […] as a regulative construct" (182).[3] Though clear,

[3] On Einstein's position, see Palmquist 2010 and 2011. Forrest (1988, 1-14) examines the impact of the realism vs. anti-realism debate on QM. See also Atmanspacher et al. (1999, 273-294), d'Espagnat

Kant's position on this matter is not without interpretive difficulties. He portrays his "transcendental idealism" as the only possible foundation for "empirical realism" (Kant 1781/1787, 44, A371, A375). That is, to explain how the world of ordinary perceptions (governed by the Second Analogy) is *ontologically real*, philosophers must adopt an epistemological background theory that regards *absolute* reality (the world considered apart from our relation to it) as necessarily unknowable (or "ideal"). Müller-Herold correctly states that "Kant's philosophy […] opened classical realism up to question" (1999, 7), while the empirical facts discovered by QM brought the latter a death blow: "If classical realism is true, then quantum mechanics must be empirically wrong. Period." I shall support this claim by demonstrating the deep compatibility between Kant and QM: for both, *phenomena* are empirically real (see below) while *noumena* (as I shall argue in the sequel) are transcendentally ideal.

The apparent conflict between Kantian causality and QM arises because Kant argues in the Second Analogy that we *must* regard all events happening in the empirical world as conforming to the principle of necessary connection. That is, every event must have a cause. Yet this is just what many influential quantum theorists deny. Kant says *uncaused events do not happen*, so the story goes, whereas the results of QM supposedly indicate that *uncaused events do happen*; both positions cannot be true. Since QM has achieved tangible results that cannot be ignored, many take it as a foregone conclusion that the sage of Königsberg was simply mistaken.[4] Since the analogies form the capstone of Kant's philosophical project, the whole architecture of his System crumbles. To understand why this common response to the conflict between Kantian causality and QM is flawed, we must examine (in §3) the proper systematic context for interpreting Kant's defense of the principle of causality.[5] Once the compatibility between QM and Kantian causality is brought into full view (in §4), we shall be in a posi-

(1999), Putnam (1987), and van Fraassen (1989). Putnam (1987, 36) regards his "internal realism" as a modified version of Kant's transcendental idealism.

[4] See d'Espagnat (1995, 5-9), Holmes (1955, 244), and Omnès (1999, 75-76). Swinburne (1981, 83) even alleges that accepting Kant's claims in the first *Critique* "would rule out in advance most of the great achievements of science since his day." Among the most influential philosophers of science to advance such an argument was Reichenbach, who claimed (1951, 44) Kant's "philosophy has nothing to say to us who are witnesses of the physics of Einstein and Bohr." After outlining Reichenbach's argument, Butts (1984, 685f) sidesteps such a negative conclusion by interpreting Kant's synthetic a priori as regulative. I have employed perspectival arguments to refute such claims as applied to both non-Euclidean geometries (Palmquist 1990) and relativity physics (Palmquist 2010 and 2011).

[5] The founders of the Copenhagen interpretation held a far more subtle position. Bohr (1928), for example, says: "The very nature of the quantum theory thus forces us to regard the space-time coordination and the claim of causality, the union of which characterises the classical theories, as complementary but exclusive features of the description, symbolizing the idealization of observation and definition, respectively." Likewise Heisenberg (1930, 65) asserts: "It is only after attempting to fit this fundamental complementarity of space-time description and causality into one's conceptual scheme that one is in a position to judge the degree of consistency of the methods of quantum theory." Pringe (2009) demonstrates that Bohr's repeated references to the *symbolic* nature of quantum descriptions were not accidental, but constituted a direct application of Kant's distinction between schematism (for intuited objects) and symbolism (for non-intuited objects)—a claim that strongly supports the position I defend here.

tion to appreciate (in a subsequent article) some deeper resonances between Kant and QM, including David Bohm's intriguing *quantum* "causality" that is remarkably parallel to certain theories Kant himself defended as *noumenal*.

2. Quantum Mechanics, Quarks, and the Problem of Interpretation

Quantum mechanics is a branch of theoretical physics concerned with understanding the characteristics and functions of the smallest physical objects, the "particles" that make up the atoms that compose everything in the natural world. The theories physicists have developed to explain the results of their subatomic experiments are so strange that Richard Feynman once declared: "I think I can safely say that nobody understands quantum mechanics" (in Wright 1993, 42). Wright claims the twentieth century's revolutions in physics not only preserve plausibility for agnosticism, but render it more scientifically tenable than its more dogmatic alternatives: "the great scientific minds of our era believe that the ultimate questions remain unanswered, that science may be unable to answer them, and yet that science does help us to mull them over" (42). This aptly echoes Kant's view that, although natural science is incapable of answering ultimate (philosophical) questions, they remain relevant to its progress.

Agnosticism such as Feynman's is justifiable because the theoretical presuppositions and experimental results of both relativity physics and QM place *limits* on what we can observe and know about the world. Einstein's relativity theory treats the velocity of light as an *upper* limit for all observations in the phenomenal world (Cassirer 1936, xiii). The value of light's velocity varies slightly between different measurements; but, such variations being relatively minor, the speed of light is treated as a constant in mathematical equations (expressed as c): since 1983 it has been legally fixed at 299,792,458 m/sec (Smith 1991, 3-4). QM employs a corresponding *lower* limit of observation, known as the "quantum of action" or "Planck's constant"—named after Max Planck, who first calculated its numerical value in 1900. Planck's constant (expressed as h in mathematical equations) is approximately 6.626×10^{-34} joule-second (Smith 1991, 8; Matthews 1974, 5-6). Subatomic particles with energy levels below this limit cannot be observed (Bohm 1951, 27). These two values define the absolute upper and lower limits of human observation—though other (less constant) physical limitations normally make the actual range of humanly-observable events much narrower.

The word "quantum" refers to the smallest observable unit of energy. When the microscopic "packet" of light known as the *photon* interacts with electrons or other particles, it produces events that cannot be explained by the laws of classical physics. Early in the twentieth century the physicists studying such events realized the structure of the atom is not as simple as had long been assumed. The Greek word ἄτομος means "indivisible", yet physical atoms *can* be divided: they consist not merely of a heavy nucleus (neutrons and protons) with electrons orbiting around it, but also of smaller particles holding together these basic parts. Although these subnuclear particles have never been found to exist independently in nature, they can be "generated" in high-energy accelerators by causing photons to collide with stable particles in an atom. In this way many mysterious, usually short-lived, particles—with exotic names like "muons", "kaons", "gluons", and "cascade"—have been discovered to exist within the atom.[6] The most basic of these subnuclear particles is called the "quark".

Physicists now regard all hadrons—all particles found in the nucleus of atoms—as consisting of quarks (Crawford and Greiner 1994, 61). Hadrons come in two types: "mesons" are relatively light particles composed of a quark paired with an "anti-quark"; "baryons" are relatively heavy particles composed of three quarks. Particles such as protons and neutrons (the most familiar of all baryons) are distinguished primarily by the differences in their underlying quark structure. Each quark has a fractional electrical charge of either 1/3 or 2/3 and is classified as either "up", "down", or "strange". The six resulting types of quark correspond to six types of lepton; together they form the twelve building-blocks of matter. Three types of charges are thought to be conserved by all these particles: the electric, the baryon, and the hypercharge. Quarks are held together by the "strong nuclear force" (Hawking 1988, 70-73), one of the four basic forces governing the physical universe—the others being the weak nuclear force, the electromagnetic force, and gravity.

The theory of quarks was first suggested in 1964 by Murray Gell-Mann and George Zweig, who won a 1967 Nobel Prize for their idea (Lubkin, 1991, 17). Postulating the existence of quarks soon proved to be an effective tool for analyzing the data collected from subatomic experiments, even though at first no empirical evidence supported this hypothesis (cf. Matthews 1974; Smith 1991). Eventually, a series of experiments performed by a team of physicists at Stanford between 1967 and 1973 "produced convincing dynamical evidence from experiment for the existence of quarks", earning a 1990 Nobel Prize for Jerome Friedman, Henry Kendall, and Richard Taylor (Lubkin 1991, 17). Even more conclusive evidence was then collected by various researchers about all but one of the twelve basic particles, until finally, evidence was announced in 1995 indicating that even the elusive "top quark" also exists (Marshall 1995, 1A).

Determining what implications can be drawn from the experimental evidence regarding quarks remains a matter of significant debate. Some physicists speak loosely as if quarks have literally been *seen* (e.g., Crawford and Greiner 1994, 58-63); nevertheless, such claims are technically inaccurate. Quarks have never actually been *observed*; at most, physicists observe the *effects* quarks have on their super-sensitive measuring equipment.[7] As Smith writes (1991, 2): "quarks […] have never been observed as

---

[6] I here adopt the so-called "Standard Model" of elementary particles. Fermilab (2008) gives a concise summary of the key discoveries constituting this now complete model of the particles constituting the material world; see also Matthews (1974, 193, 198-199), and Redhead (1995, 6-7).

[7] Using sight-related terms when referring to observations of causal events does not imply that causality applies *only* to the sense of sight. Kant similarly employs sight-related terms when discussing such issues. His well-known examples of the connection between different parts of a house and of a ship floating downstream rely explicitly on *seeing* as the mode of observation (Kant 1781/1787, 235-238). Although this preference may be only an accident of human language and/or sensibility, I follow Kant in treating sight as a metaphor for *understanding*, with the latter being what is truly at stake in the Second Analogy. The question is not whether we can literally *see* an effect following from a cause, but whether we can *understand* ("see") their necessary connection.

freely moving particles. There are strong reasons to believe that the nature of the forces which bind the quarks together, prevent their observations as freely-moving particles." Moreover, notwithstanding all the data collected through experiments involving high-energy collisions, the limits of observation imposed by light's lower (quantum) limit would prevent us from observing quarks, even if they could exist *independently* in nature, breaking free from the forces that keep them bound up in higher-level structures. The most prudent (or philosophically sophisticated) physicists therefore recognize that the real existence of quarks is still an open question and that the theory of quarks is properly regarded as *hypothetical*.[8]

How to justify saying quarks *exist*, even though we cannot observe them, is a challenging problem. If an object must have some structure in order to be observable, and if calling a particle *elementary* implies portraying it as having no internal structure, then it would be a merely logical truth that quarks (or any particles regarded as elementary) must exist even though they are unobservable.[9] Alternatively, all subnuclear particles could be "made out of each other", with quarks being nothing but "a mathematical device for making calculations" (Matthews 1974, 198-199). This "bootstrap" theory of particles (see Redhead 1995, 67-68) is not unlike the phenomenalist position held by Kant-interpreters such as Strawson, who reject the First Analogy's argument that a permanent physical "substance" must underlie the empirical world. For Strawson (1997), the concept of a single, permanent substance is merely a philosophical device used for constructing certain transcendental arguments and can be replaced by the less presumptuous hypothesis of many interlocking semi-permanent substances.

The collection of data from quantum experiments and the theoretical explanation of how the data fit together to support a given hypothesis are quite distinct enterprises. The most widely-accepted interpretation emerged from a series of conversations between Niels Bohr and Werner Heisenberg, held in Copenhagen during the 1926-1927 winter, when physicists were still digesting the implications of Einstein's relativity theory. However, their so-called "Copenhagen interpretation" is now only one of several competing interpretations of quantum events. The most noteworthy options[10]

---

[8] Parker (1984, 461) calls quarks "hypothetical" particles: "no experimental evidence for the actual existence of free quarks [i.e. quarks existing in nature, outside the context of laboratory experiments] has been found." As Redhead (1995, 9) puts it, "quarks […] can never be separated from their partners—one cannot experimentally break down a nucleon into its constituent quarks", so direct observation of quarks is impossible. The overwhelming weight of evidence collected since these remarks were penned is irrelevant to the basic fact that the quark is a hypothetical construct based on its observed effects.

[9] This is not the *only* explanation for how something can exist without being observable, nor is it relevant only to quarks. For example, electrons (whether or not they are elementary) are unobservable because their wavelength is so much smaller than that of photons—the empirical fact that makes electron microscopes more powerful than light microscopes.

[10] Forrest (1988, xv-xvi) discusses major trends and their permutations, narrowing them down to three ways of interpreting QM. A substantially different approach, quantum field theory, proposes a mathematical formalism that in some versions rejects the Standard Model of QM, treating the particles themselves as illusions arising out of interactions between fields. However, from its outset quantum field theory has been even more controversial than QM.

can be classified by their different answers to two key questions: (A) Is the quantum world characterized by randomness (i.e. indeterminacy)? and (B) Is the quantum world characterized by nonlocality (i.e., action at a distance)? The possible combinations of yes/no answers to these questions define four major approaches to interpreting QM:

1. *The Copenhagen Interpretation* accepts both randomness and nonlocality. It reconciles these by means of the "projection postulate", whereby the act of measurement (i.e. "observation") randomly projects a particle's original state onto a new "eigenstate". This option is the main focus of the present article.
2. *Bohmian Mechanics* (the most plausible of several "hidden variables" approaches) rejects randomness but accepts nonlocality. As I shall argue in a follow-up article, Bohm's special quantum "causality" essentially transfers the problems of QM to Kant's noumenal world, accepting Kantian causality for the phenomenal world.
3. *Modal Interpretations* typically accept randomness, but reject nonlocality. Those adopting this position assume Schrödinger's equation never collapses, thus interpreting the quantum world in terms of "possibly possessed properties" (i.e., values of the observables). They distinguish dynamical states (the set of all pre-measurement "possible" states) from value states (the actual measured results). Van Fraassen (the first to propose this option) called this the "Copenhagen Variant" approach. While presenting a more realistic picture of the world that quantum measurements are "about", it claims we can go no further than knowing the mode (the possible values). Some versions (e.g., Kochen's) are explicitly "perspectival", treating quantum properties as not existing at all apart from their relations to each other in a system, or the relation of discrete physical systems to each other.
4. *The Many Worlds Interpretation* rejects both randomness and nonlocality by positing the existence of other worlds to explain the results of quantum experiments. This approach, often associated with Hugh Everett (Everett et al. 1973; cf. Forrest 1988, 134-135, 149), upholds the more obviously Kantian (i.e., classical) approach that Einstein also tried to preserve, but only at the price of making metaphysical assumptions that contradict Kant's conception of the phenomenal world as a single, unified whole.

The remainder of this article deals solely with the Copenhagen interpretation: not only is it still among the most commonly accepted theories; it is also the interpretation that is typically regarded as challenging Kantian causality most radically.

3. The Kantian Character of the Copenhagen Interpretation's Two Pillars

For our purposes, the most significant claim defended by proponents of the Copenhagen interpretation is that, at the quantum level, pre-determined causal relations cannot be ascribed to unobserved particles. Quantum events as such, it is claimed, just *happen*. Explaining *what* happens therefore requires paradoxical language that would seem absurd if applied to objects of ordinary experience. According to Herbert (1985, 56), if the quantum world could be observed, it would be characterized by non-

Newtonian laws, a world of "undivided wholeness", a "place without separation", a "mystery" wherein the subject/object distinction itself dissolves, a world wherein any perception "creates a new universe faster than light" (but cf. note 5, above). Beller (1999, 205) traces Bohr's emphasis on this background wholeness to both Kierkegaard and Kant, though Honner (1987, 74) claims "there is no evidence that [Kant] ever had any direct influence on Bohr's work." Honner (68; cf. 210) also notes that "Bohr did not want to stress either the role of the subject alone, or that of the independent object. Rather, he wanted to insist on the wholeness of the interaction between observer and observed." As Bohr himself put it, "The essential wholeness of a proper quantum phenomenon finds indeed logical expression in the circumstance that any attempt at its well-defined subdivision would require a change in the experimental arrangement incompatible with the appearance of the phenomenon itself".[11]

The Copenhagen interpretation rests on two important and interrelated pillars. The first is Bohr's "inseparability" hypothesis, whereby the quantum system is viewed as the totality of the experimental arrangement, including the observed measurements and the measuring apparatus. Though Bohr himself was reluctant to posit a "quantum world", preferring to talk only about quantum *descriptions*, many take his theory to imply that the act of observing a subnuclear particle within the quantum system *affects* it somehow, actually changing the state it was in prior to its participation in the system.[12] We cannot say anything definite about the original (unobserved) state of a subnuclear particle or event (if any!); all we can talk about is the nature of the particles *as measured*. The latter are therefore sometimes called "observables", in contrast to the particles' original "state". In terms of Kant's philosophical vocabulary, the glimpses of matter's deep structure provided by such quantum measurements might more appropriately be called "ideas" (concepts of transcendent reality without sensible grounding) than conventional "judgments" of empirical knowledge.[13]

The notion of an underlying, unknowable reality, whose existence can be inferred only from observations of the way it *appears* to us, is one of the fundamental tenets of

[11] Quoted in Honner (1987, 68). Bohr's statement bears a striking resemblance to Kant's transcendental arguments, whereby a given condition must hold in order for experience to be possible. For similar accounts of the compatibility between Bohr's position and Kant's, see Jammer (1974, 203), Omnès (1999, 219), and especially Pringe (2009, *passim*). Physicists' imaginative descriptions of quantum measurements sometimes sound remarkably similar to the way Kant describes some of the more obscure aspects of his System. For examples of Kant's "quark-like" descriptions of the thing-in-itself or of God's presumed "intellectual intuition", see Palmquist (1993, appx. V, 371-383), and Palmquist (2000a, 86-90).

[12] For assessments of the differences between Bohr's own position and its typical portrayal, see Howard (2004), Petersen (1968), Folse (1985), and Fine (1986). Pringe (2009) goes back to the original texts, demonstrating that Bohr's descriptions of the quantum world are thoroughly dependent on an appeal to *symbols* that is entirely consistent with Kant's requirements for talking intelligibly about objects that cannot be presented in intuition.

[13] I shall explore this theme further in a follow-up article, arguing that this status of quantum measurements (as hypothetical ideas) is what requires their description to take the form of symbols, as Pringe (2009, 34) demonstrates. Palmquist (1993, 206, 228-238), presents a detailed examination of the roles these terms play in Kant's theory of knowledge.

Kant's theoretical philosophy; yet quantum physicists who wax philosophical are often as ignorant of this aspect of Kant's philosophy as philosophers usually are of the mathematical apparatus describing quantum mechanical operations. For example, in Gamow's fanciful popularization, the professor of QM admits his discipline "looks like philosophy" (1967, 89) but adds:

> […] this is the fundamental principle of modern physics—*never to speak about the things you cannot know*. All modern physical theory is based on this principle, whereas the philosophers usually overlook it. For example, the famous German philosopher KANT spent quite a lot of time reflecting about the properties of bodies not as they "appear to us", but as they "are in themselves". For the modern physicist only the so-called "observables" […] have any significance […].

Ironically, the first *Critique* explicitly rejects the position Gamow attributes to Kant, and for essentially the same reasons cited by Gamow's imaginary professor! He again alludes to Kant in making another, equally mistaken claim: "So strong was the belief in the absolute correctness of these classical ideas about space and time that they have often been held by philosophers as given *a priori*" (1967, 9). Kant did not view *classical* (Newtonian) space and time as a priori, but a significant *revision* of Newton's position (Palmquist 1990 and 2010): instead of being absolute "containers" filled with static physical objects, Kantian space and time are formal conditions the mind imposes onto a physical world consisting of dynamic objects whose nature is determined by the mutual interaction between the forces of attraction and repulsion (see note 21, below).

Omnès (1999, 75-76) asserts that because Kant defends the categories of reality and causality, his philosophy is now outdated and obviously mistaken: "the absence of these categories in quantum physics" renders Kant's attempt to provide a philosophical foundation for science no longer relevant. Similarly, d'Espagnat (1995, 5-9) starts his philosophical analysis of quantum concepts by examining their Kantian context and expressing skepticism regarding the abiding relevance of Kant's position (7-8):

> when Kant mentions space he means Euclidean space and when he mentions time he means Newtonian universal time […] Since the advent of relativity theory [the apriority of these concepts], of course, is known to be false, and some serious reservations are thereby justified concerning the details of Kant's philosophical system […].
>
> A similar remark is in order concerning Kant's conception of causality […]. Modern physical theories have made such a view obsolete [… and this] must make us skeptical concerning the details of Kantianism.

Interestingly, d'Espagnat does conclude his study by suggesting that the overall "idealist-Kantian" approach retains greater support from the empirical evidence than the "realist-Aristotelian" approach (431-432). Previously (d'Espagnat 1987, 166), he had opined that QM and its implications for our understanding of reality are "Kantian" in an "*a posteriori*" sense, provided we "make a sharp distinction between empirical reality—the set of phenomena—and independent reality." Such comments flirt with the position I defend below, that properly interpreting the function of Kant's infamous thing in itself is crucial for understanding how Kantian causality is compatible with modern physics.

Quantum theory's first pillar adopts a position strikingly similar to Kant's transcendental perspective, with its appearance/thing-in-itself distinction. Since a quantum system makes empirical assumptions (cf. Pringe 2009, 34), however, Bohr's inseparability thesis is best regarded as a physical application of this transcendental distinction. Bohr himself was keenly aware of such philosophical implications and recognized the *compatibility* of this first pillar with Kantian philosophy. The fact that "Bohr prohibits the description of unobserved systems" is at least "a somewhat Kantian position" (Forrest 1988, 109), because it "amounts to denying that we can know things as they are in themselves" (cf. note 5, above). As Beller puts it (1999, 162), Bohr *agreed* with Kant "about the impossibility of describing physical experience in general by any concepts other than classical ones." Beller later adds (180; see also 194-199): "Bohr's belief in this direct accessibility ["of classical reality to sense perception"] is rooted in the Kantian heritage of space-time concepts as forms of intuition (*Anschauung*) and in his lifelong reliance on visualizable classical space-time models of the atom […]". Only classical/visualizable concepts refer unambiguously to reality; this is why Bohr did not wish to postulate the real existence of any literal "quantum world"—"reality", like "causality", being one of Kant's twelve categories.[14] Instead, as Pringe (2009, 34, 73-74, 92-93 and *passim*) demonstrates in thoroughgoing detail, Bohr adopted a Kantian view of "symbols" as serving a function in understanding quantum theory that corresponds to the function of schema for the ordinary empirical knowledge of classical physics.

Heisenberg's "uncertainty principle" is the second pillar of the Copenhagen interpretation. It requires physicists to choose between: (1) making a precise measurement of either the position or velocity of a particle, thus leaving the one that is not measured completely unknown (and *unknowable*); or (2) attempting to measure both aspects simultaneously, thus obtaining only an approximate (statistically probable) knowledge of each. Obtaining *certain* knowledge of *both* the position and the velocity of a particle at the same time, therefore, is impossible.

A major reason for the lack of consistency between early proponents of the Copenhagen interpretation is their disagreement over what implications Heisenberg's uncertainty principle has for classical causality (Beller 1999, 196, 203). Unlike Bohr, Heisenberg tended to regard QM as opposing Kant, claiming (180) that with respect to causality, "common sense is profoundly mistaken." Seeking to overthrow Kantian causality, "Heisenberg wanted to be the new Kant—in his initial presentations of the uncertainty principle to academic audiences, he always described the abandonment of the 'Kantian category of causality' as a natural continuation of Einstein's overthrow of Kantian space and time as forms of intuition" (195). Beller thinks Bohr was unwise to

[14] Beller objects to Bohr's anti-realism for just this reason (1999, 180): "There is no compelling argument for the reality of classical description as opposed to quantum description, except this alleged Kantian kinship between the visualizability of classical physics and our sense perceptions." Similarly, Honner (1987, 7) proposes that "Bohr can best be understood through a consideration of the character of his fundamental arguments. The kinds of claims that he made are […] 'transcendental'. That is […] he begins his thinking with a reflection on the necessary conditions of the possibility of human experiential knowledge." In discussing Bohr's use of transcendental arguments (9-14), Honner adds (11): "Bohr's 'indispensability claims' are […] precisely equivalent to the manner of approach outlined by Kant. In other words, Bohr tries to articulate that which is indispensably the case in any report of human experiential knowing." See Honner (1987, 209-213) for further discussion of the Bohr-Kant relationship.

associate his position with Kant's "after a full realization of the bankruptcy of Kantian arguments for a priori knowledge (the theory of relativity being the final stroke)" (205); "the quantum overthrow of Kantian causality is a direct continuation of the Einsteinian overthrow of Kantian space-time" (195). (For a refutation of this claim, see Palmquist 1990, 2010, and 2011.)

Kant was at the center of the debate over the relevance of QM to philosophy (and vice versa) from the very beginning (Fano 1988, 385-390). In 1941, C.F. von Weizsäcker, one of Heisenberg's students, published an article (385) attempting "to demonstrate the connection of quantum mechanics with Kant's philosophy." Fano acknowledges that the unknowability of the unobserved particle directly parallels Kant's doctrine of the unknowability of the thing in itself (385-386), but emphasizes the crucial difference (386), that "Kant's gnoseology lacks a principle similar [to] the Heisenberg uncertainty principle." Weizsäcker argued that classical mechanics (and Kant) hold an a priori status in relation to QM. Kant himself, of course, did not create a new approach to physics; but his new epistemological standpoint made available to scientists a perspective Weizsäcker calls a "new freedom" (in Fano 1988, 386). So, Fano concludes (386), "quantum mechanics becomes not only a confirmation of Kant's system, but also a sufficient condition for its further move toward subjectivism." Portraying Heisenberg himself as "completely oblivious of Kant" (390), Fano shows how Italian philosophers responded to this Kantian aspect of quantum mechanics, conclusively demonstrating "the prominence of Kantian interpretations of quantum mechanics in Italian philosophy" (398).

According to Atmanspacher et al. (1999, 247-248): "One of the amazing features of the early quantum mechanics of the 1920s and 1930s is its epistemological proximity to philosophical Kantianism with its turn towards the perceiving subject, whose a priori characteristics constitute the distinguishing features of the world of appearances".[15] In contrast to such occasional affirmations of a Kantian bias among early quantum physicists, an inference commonly drawn from Heisenberg's uncertainty principle is that it conflicts with Kant's causality principle, thus requiring us to abandon the latter. Physicists report, for example, that "the quantum process must be regarded as discontinuous" (Bohm 1951, 27), inasmuch as the quantum state of an atom often undergoes sudden and inexplicable changes, and that because "only the probability of such a process may be predicted" (28), we cannot say of a subatomic particle that it definitely *exists* at a certain place and time.[16] Thanks to Heisenberg, the meaning of "cause" (when the term is retained) has undergone a radical change: in place of the classical Newtonian (mechanical-deterministic) understanding (152; see also 133, 163-164), "a given cause must [now] be thought of as producing only a tendency toward

---

[15] Bohr (1928) presents space-time description and causality as the two sides of his principle of complementarity. Even Heisenberg (1930) grants the possibility of describing quantum events causally through a deterministic evolution of the Schrödinger equation. See Pringe (2009, 21; cf. ch.3) for some relevant details.

[16] Bohm (1951, ch. 4, 81f) presents a formal-mathematical explanation of the probability conditions governing such states.

an effect." Quantum theorists typically describe this absence of causal determinism without making a sufficiently clear distinction between the ontological and epistemological issues at stake. Instead of stating dogmatically that quantum events *have no cause*, we should avoid making definite claims about this unobservable level of physical reality. All we can justifiably say, given Heisenberg's uncertainty principle, is that we are incapable of ever *determining* a definite cause. Physicists may *act as if* an event takes place without any prior cause; but those who adopt this hypothetical perspective of Kantian belief (cf. Palmquist 1993, 139) have ceased to view the world from an empirical (scientific) standpoint. The implications of this alternative, "noumenal" standpoint will be the focus of a follow-up article.

In describing quantum phenomena (i.e., objects or events) physicists often make statements that would appear blatantly self-contradictory, if interpreted from the standpoint of classical physics. Certain particles are described as simultaneously having both upward and downward spin, or as existing yet not existing, prior to measurement. A more cautious way to describe such phenomena, interpreting the data epistemologically rather than ontologically, would be to say such particles simultaneously possess both *tendencies*, but have no *real value* before being measured. As van Fraassen (1991, 109) observes: "From Bohr to Feynman, physicists have expressed similar opinions: an observable (measurable parameter) might not have a specific value outside the context of measurement." The implications of such strange notions, generated by the two pillars of QM, obviously deserve further discussion. But before considering in more detail just how quantum indeterminacy can be compatible with Kantian causality, let us summarize the prima facie parallelism between the two.

Despite Heisenberg's tendency to distance himself from Kant, his principle provides additional support for the claim that *both* sides of Kant's basic phenomenon/noumenon distinction have correlates in empirical science. His distinction between two ways of approaching the empirical task of measurement has a close affinity with Kant's distinction between *substance* and *accident*, stated in the First Analogy (see §1, above). As we shall see in §4, this is *Kant's* way of making an empirical distinction between the knowable and unknowable. Together with the parallel observed (at the transcendental level) when discussing the first pillar, Table 1 summarizes the fourfold distinction that results from comparing Kant's epistemological version of the transcendental/empirical distinction with the physical version implied by the two pillars of QM. Unpacking the implications of this tabular summary will be the primary goal of §4.

Table 1: The Unknowable/Knowable Distinction in Kant and Quantum Mechanics

	Kant's epistemology	*Quantum mechanics*
transcendental perspective	the thing in itself vs. appearances	the particle's original state vs. the "observable"
empirical perspective	substance (the substratum) vs. accidents (alterations)	statistical approximation vs. measurement of particle/wave

4. The Principle of Causality in Perspective

Kant's defense of the Second Analogy attempts to prove not that everything in nature must have some definite, objective cause, but that our *expectation* of everything having such a cause is a necessary component of our "empirical knowledge" of phenomena.[17] This nuance is of utmost importance: it distinguishes a non-perspectival from a perspectival interpretive method.[18] The former would attempt to prove the principle of causality holds *absolutely*, with rational beings having no choice but to view every event *solely* in terms of causally-determined natural relations. Such a claim would make a mockery of Kant's subsequent attempt to defend a coherent theory of human freedom (i.e., "noumenal" causality). The perspectival method, by contrast, leaves open a space, not only for the perspectival shift involved in interpreting a nature-determined event (i.e., an event interpreted via the Second Analogy) as also self-determined (i.e., free, or determined by an uncaused cause), but also for other scientific approaches to nature—approaches that may require less emphasis on the principle of causality.[19] Sundaram makes this point concisely: "Cassirer, like Kant, regards causality as a category of human understanding. For things in themselves this category has no relevance. From this point, the classical or quantum mechanical causality or determinism should not be regarded as a metaphysical constraint upon all forms of being. Freedom, too, is a transcendental principle" (1987, 100-101; cf. Cassirer 1936). This hints that freedom may share an epistemological status similar to that of Bohm's quantum "causality"—a topic that lies beyond the parameters of the present article.

We noted in §2 that relativity theory and QM employ constants that define the upper and lower limits of observation. Both are determined by the nature of light, the very thing that, on a mundane level, human beings need in order to observe (*see*) anything. The key to resolving the apparent conflict between Kantian causality and quantum indeterminacy is to regard these two limits metaphorically, as *empirical* counterparts of the same *transcendental* boundaries of human knowledge that Kant's princi-

[17] Palmquist (1993, ch. VI, 161-193) gives a detailed analysis of the several terms Kant uses to refer to "objects".

[18] Palmquist (1993, ch. II) offers a detailed account of Kant's "principle of perspective". Perspectival readings of Kant should not be identified with pragmatist readings. Pragmatists tend to de-emphasize Kant's (a priori) emphasis on reason's architectonic unity, emphasizing instead the *usefulness* of whichever theories the interpreter regards as having lasting practical applicability. Perspectival interpretations, by contrast, *highlight* Kant's emphasis on architectonic systemization by focusing on the boundary conditions distinguishing each *Critique*, and/or those distinguishing a given *Critique*'s major sections.

[19] Palmquist (2000b, §§21-22; and 1993, ch. VIII) provide an explanation and defense of the perspectival relationship between causality and freedom. Hösle (1999, 311-312) likewise recognizes that for Kant causal determinism on the level of ordinary science is not incompatible with the nonlocal causality of *freedom* on the noumenal level. Hösle gives a concise summary of Kant's perspectival (or "perspectivistic" [311]) solution to the problem of freedom and determinism that results from the apparently absolute necessity of the principle of causality. Buchdahl (1969, 657f) was one of the first to recognize that the problem of how Kantian causality can be compatible with indeterminism in science is intimately bound up with Kant's attempt to make room for the effects of human freedom in the phenomenal world. However, Buchdahl's proposed solution is itself problematic (see §1).

ples establish. Although Kantian philosophy and contemporary physics have very different spheres of application, they are *parallel*: various similarities in the patterns they follow render them complementary rather than contradictory.[20] For just as Kant treats space and time as transcendental conditions establishing the boundary for all *sensible intuition*, so also relativity theory depends on the speed of light establishing the (upper) empirical boundary for space-time perception. And just as Kant treats principles such as causality as transcendental conditions establishing the boundary for all *conceptual knowledge* of objects, so also QM depends on Planck's constant establishing the (lower) empirical boundary for our application of causal concepts.

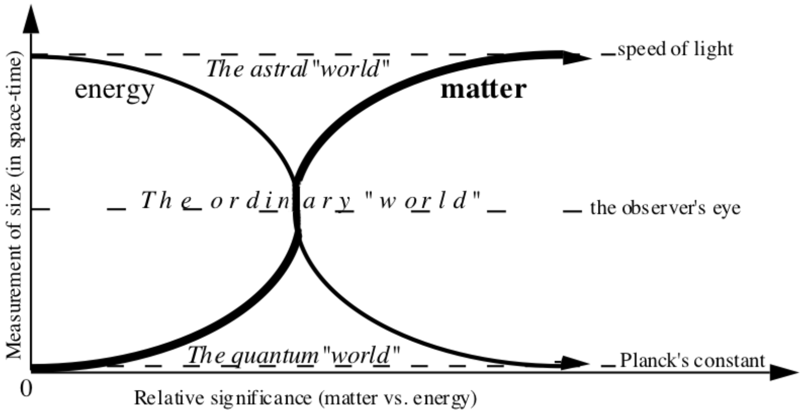

Figure 1: Three Perspectives on the "World"

By depicting the relationships between these three ways of talking about the boundaries of human observation, Figure 1 paves the way for a further elaboration of the perspectival differences summarized in Table 1, above. To interpret Figure 1, first find the size of a phenomenon on the vertical axis, then locate along the horizontal axis the relative significance of matter (the thick line) vs. energy (the thin line) for phenomena of that size. In attempts to talk about Bohr's quantum "world" the significance of energy far outshines that of matter, while for knowledge-claims about Einstein's astral "world" matter outweighs energy in significance, and empirical knowledge of the ordinary "world" exhibits an approximate balance between the two. Of course, the proportions shown in the diagram are inexact, representing only general tendencies.

Kant's "phenomenal world" refers not to physical reality as such, but to physical reality *as observable*. Knowing nothing about high-energy particle physics or high-matter astrophysics, Kant saw the Second Analogy as guaranteeing the certainty of science as it applies to *ordinary* observable experiences, where energy and matter maintain an equilibrium, balanced at the crossroads between submicroscopic (i.e., what is too small to observe, even with a microscope) and super-macroscopic (i.e., what is too large to observe, even with a telescope) extremes. (Recognizing the limited range of Kant's

[20] Kant's aforementioned portrayal of transcendental idealism as the only possible foundation for empirical realism (Kant 1781/1787, 44, A371,A375) suggests that the metaphorical parallelism proposed here does not contradict but *fulfills* Kant's epistemological position.

own focus need not prevent us from applying his principles more broadly, to embrace the quantum and astral "worlds" as well as the ordinary world; but examining his own tentative treatment of unobservable physical objects is beyond the scope of this article.[21]) Regarding these three "worlds" as equally legitimate perspectives on one and the same "reality" obviates the need to reduce them to a single, ultimately valid standpoint. Clearly distinguishing these perspectives reveals how inappropriate it is to argue *from* the truth of QM or relativity physics *to* the falsity of Kant's philosophy of science, for the Second Analogy is necessarily applicable only to knowledge of the ordinary world, and neither of these advances in science calls into question causality at that level.

Before discussing whether "events" at the quantum and astral levels are causally determined, we must reaffirm: nothing discovered by either QM or relativity physics has any significant influence on the applicability of causality to *ordinary* phenomena—the world as (at least in principle) perceivable by the human senses. For even if quantum events *are* radically undetermined, so that statistical approximations must forever replace mechanistic predictions, any margin of error transferred from the quantum world to the ordinary world is so minuscule as to be undetectable: random quantum "events" would still be bound by Kantian causality, when viewed as phenomena in the ordinary world. We therefore should not blame Kant, an eighteenth-century philosopher not a twentieth-century physicist, for focusing on the latter.

We saw in §1 that the principle of causality does not stand alone in Kant's theoretical system, but is one of *three* analogies; taken together, these are themselves but one component of the interdependent set of four categorial principles that constitute the transcendental form of all empirical knowledge. Kant claims not only that we must treat every phenomenon as having a *cause*, but also that all observable *changes* in phenomena must be regarded as *alterations* of a common "substratum" of nature, called "substance". The First Analogy affirms the permanence of substance, the requirement that substance remains the same despite undergoing phenomenal alteration. We must therefore distinguish substance from both the thing in itself and noumena. The latter terms are epistemological constructs referring to a *transcendent* (unknowable) world, considered from the transcendental perspective, as the necessary (but empty) starting-point of all knowledge, or from the empirical perspective, as hypostatized (but illusory) objects, respectively, while "substance" refers to the *physical* world "in itself", viewed from the empirical perspective (cf. Table 1; see Palmquist (1993, §§VI.1-4) for a detailed defense of this explanation of these terms). The Third Analogy then argues that we must regard the cause-and-effect changes observed in the ordinary world as *thoroughly interconnected. Taken together*, these three principles constitute the transcendental foundation that must be presupposed for any science that is to produce legitimate empirical knowledge (cf. Kant 1783, 274-275, 279-280, 294-295).

---

[21]A significant extension of the present article would be to examine Kant's *Metaphysical Foundations of Natural Science* and *Opus Postumum*. These works portray an unobservable material (the "aether") as a clue to the "transition" between transcendental philosophy and physics. While such a study would complement this one in some interesting ways, it is not essential to our main purpose: showing how Kantian causality is compatible with QM.

Understanding the inextricable relationship between Kant's three analogies is important because most interpreters do not regard the First and Third Analogies as posing as great a challenge to the twentieth-century revolutions in physics as does the Second Analogy.[22] QM examines nature's *empirical* substratum in a way that was not possible in Kant's day, revealing it to consist of particles (e.g., quarks) that can be detected only under the extreme conditions of high-energy accelerators. That is, it interprets the world primarily from the perspective of the First Analogy. Recognizing this makes it more plausible to maintain that the inapplicability of Kantian causality to the quantum world does not imply that Kant's arguments in the Second Analogy are invalid, for the latter were never intended to apply to empirical reality *at* the level of substance.

Kantian causality applies mainly to the ordinary world of accidental (phenomenal) changes that characterize the objects of Newtonian science. The qualification "mainly" allows for examples such as Kant's (1781/1787, 273), where he says the "magnetic matter pervading all bodies" is part of the empirical world, and is therefore governed by the categories, even though "the constitution of our organs cuts us off from all immediate perception of this medium." What makes the magnetic property of objects empirical, Kant tells us, is that we *do* have a "perception of the attracted iron filings" when they are in the presence of a magnet. As Aquila (1972, 216) points out, "by an empirical event, [Kant] means a succession of properties in any [observable object in three dimensional space and in time]." Kant therefore concludes that we know the existence of such objects "mediately"—a position he then goes on to portray as standing in stark contrast to empirical idealism. What counts, in other words, is not that we can or cannot "observe" a particular object or event, but that the *evidence* for its existence comes directly from our perceptions and law-abiding inferences based on them (237-238):

> Our knowledge of the existence of things reaches, then, only so far as perception and its advance according to empirical laws can extend. If we do not start from experience, or do not proceed [in] accordance with laws of the empirical connection of appearances, our guessing or enquiring into the existence of anything will only be an idle pretence.

Applying this insight to Heisenberg's uncertainty principle, the primary basis for the common claim that events occur randomly at the quantum level, Cohen (1946, 144-147) rightly affirms that uncertainty

> does not necessarily mean a denial of the principle of causality or an assertion of indeterminism in the objective physical world. It may be explained as a consequence of the fact that any measurement which involves observation of nature through light is itself a physical operation, which disturbs the object observed […].
>
> […] Heisenberg's principle does not mean a lawless world. It means rather that the laws are of a different sort […]. We might venture to suggest that, when the present excitement subsides, it will be found that the permanent results of [Heisenberg's interpretation of] quantum mechanics

[22] Also, interpreters who see Kantian causality in context are less likely to view it as incompatible with QM. As already noted, Pringe (2009) is an excellent recent example, emphasizing the *symbolic* nature of quantum descriptions. See also Cassirer (1936); although Cassirer's work was originally written during the infancy of the Copenhagen Interpretation, Margenau's 1956 Preface argues that subsequent developments would not have changed Cassirer's mind.

> confirm rather than overthrow the classical development in physics, just as the Einstein theory is now seen to be a development and completion of the Newtonian mechanics […].

Does this mean quantum events are *causal* after all? Most quantum theorists agree that these events are at least in some sense random. As we have seen, many philosophically-minded scientists and scientifically-inclined philosophers believe this spells the demise of Kantian philosophy. But it does not, as long as we limit the application of quantum descriptions to a specific, well-defined perspective (that of the submicroscopic world). Thus, without compromising Kant's view of the phenomenal world, we can concur when Smith (1991, 1) says "classical mechanics […] is contained in quantum mechanics as a limiting case." The former fails only when its application is stretched to cover the very small (or very large) "objects" that "exist" at or beyond the observational boundaries of the phenomenal world (see Figure 1). For Kant would readily admit that, once science tries to extend its understanding of the phenomenal world to a realm that transcends the possibility of observable experience, his transcendental principles may not apply. This suggests the possibility of a Kantian critique of conventional interpretations of quantum events: such interpretations tend to be consistent with the First Analogy, yet the philosophical grounds for applying this principle to the quantum world (*as transcending* the ordinary, observable world) are just as questionable as those for applying the principle of causality. Kant's Analogies come as a package, so from the purely philosophical (transcendental) perspective, quantum theorists have no more (or less) justification for treating the quantum world *as such* as "indeterminate" than Bohm does for regarding it as a deterministic realm of "wholeness" governed by hidden causal relationships—a position preferred by Einstein and Schrödinger as well, which I shall explore elsewhere. This debate turns on whether the First Analogy or the Second Analogy properly governs our interpretation of quantum "phenomena".

One reason so many physicists and philosophers fail to see QM and Kantian causality as distinct but *compatible* perspectives is that classical (Newtonian) physicists and philosophers typically viewed causality as the guarantee that, if we know all the variables in a given situation, then we can predict the future with absolute certainty (see Cassirer 1936, ch. 1). Heisenberg's principle destroys such a hope by maintaining the impossibility of *ever* simultaneously knowing all the significant facts about a particle. Yet this ought to be regarded as a denial not of Kant's principle of causality, but of the legitimacy of reductionism. That is, nothing in QM *compels* us to deny the validity of the above "if…, then…" proposition, though many physicists do *choose* to deny it. What it compels us to deny is the possibility of ever *achieving* the "if" side of the equation. QM thereby establishes an area of *physically* necessary ignorance (the quantum "world"), just as Kant's Critical philosophy establishes an area of *transcendentally* necessary ignorance (the transcendent/noumenal "world"). Our further elaboration of the parallels suggested in Table 1 has shown that the two are analogous, though not identical. If this analogy is correct, we should expect to find an alternative way of talking about quantum events, whereby causal language is allowed some form of application. That possibility, as already mentioned several times, will be the focus of a follow-up article, where I shall argue that the language appropriate to the quantum world bears striking resemblances to that of Kant's noumenal world.

REFERENCES

Allison, Henry. 1983. *Kant's Transcendental Idealism*. New Haven: Yale.

Aquila, Richard. 1972. Concepts, Objects and the Analytic in Kant, in L.W. Beck (ed.), *Proceedings of the Third International Kant Congress*. Dordrecht: Reidel, 212-218.

Atmanspacher, Harald, A. Amann, and Ulrich Müller-Herold, eds. 1999, *On Quanta, Mind and Matter*. Dordrecht: Kluwer.

Beller, Mara. 1999. *Quantum Dialogue*. Chicago: UCP.

Bohm, David. 1951. *Quantum Theory*. Englewood Cliffs: Prentice-Hall.

Bohr, Niels. 1928. The quantum postulate and the recent developments of atomic theory, *Nature* 121: 580-590.

Buchdahl, Gerd. 1965. Causality, Causal Laws and Scientific Theory in the Philosophy of Kant, *British Journal for the Philosophy of Science* 16: 187-208.

—. 1969. *Metaphysics and the Philosophy of Science*. Oxford: Blackwell.

Butts, Robert E. 1984. Kant's Philosophy of Science: The Transition from Metaphysics to Science, *Proceedings of the Biennial Meeting of the Philosophy of Science Association* 2: 685-705.

Cassirer, Ernst. 1936. *Determinism and Indeterminism in Modern Physics: Historical and Systematic Studies of the Problem of Causality*, tr. O.T. Benfey; Preface by Henry Margenau. New Haven: Yale, 1956.

Cohen, Morris. 1946. *A Preface to Logic*. London: Routledge.

Crawford, Henry, and Carsten Greiner. 1994. The Search For Strange Matter, *Scientific American* 270: 58-63.

d'Espagnat, Bernard. 1987. Meaning and being in contemporary physics, in B.J. Hiley and F. David Peat (eds.), *Quantum Implications*. London: Routledge, 151-168.

—. 1995. *Veiled Reality*. Reading, Mass.: Addison-Wesley.

—. 1999. Concepts of Reality, in Atmanspacher, et al. 1999, 249-270.

Everett, Hugh et al. 1973. *The Many-Worlds Interpretation of Quantum Mechanics*, ed. Bryce DeWitt and Neill Graham. Princeton: PUP.

Fano, Vincenzo. 1988. How Italian Philosophy Reacted to the Advent of Quantum Mechanics in the Thirties, in Gino Tarozzi and Alwyn van der Merwe (eds.), *The Nature of Quantum Mechanics*. Dordrecht: Kluwer, 385-401.

Fermilab. 2008. Worldwide Discoveries that Led to the Standard Model, http://www.fnal.gov/pub/inquiring/matter/ww_discoveries/index.html. [accessed: Feb. 10, 2011]

Fine, A. 1986. *The Shaky Game*. Chicago: UCP.

Folse, Henry J. 1985. *The Philosophy of Niels Bohr*. Amsterdam: North-Holland.

Forrest, Peter. 1988. *Quantum Mechanics*. Oxford: Blackwell.

Friedman, Michael. 1992. Causal laws and the foundations of natural science, in Paul Guyer (ed.), *The Cambridge Companion to Kant*. Cambridge: CUP, 161-199.

—. 2001. *Dynamics of Reason*. Stanford: CSLI.

—. 2006. Philosophy of Natural Science, in Guyer 2006, 303-341.

Gamow, George. 1967. *Mr. Tompkins in Paperback*. Cambridge: CUP.

Guyer, Paul. 1987. *Kant and the Claims of Knowledge*. Cambridge: CUP.

—, ed. 2006. *The Cambridge Companion to Kant and Modern Philosophy*. Cambridge: CUP.

Hawking, Stephen. 1988. *A Brief History of Time*. London: Bantam.

Heisenberg, Werner. 1930. *The Physical Principles of the Quantum Theory*, tr. Carl Eckart and Frank C. Hoyt. New York: Dover, 1949.

Herbert, Nick. 1985. *Quantum Reality*. New York: Anchor Books.

Holmes, Eugene C. 1955. The Kantian Views on Space and Time Reevaluated, *Philosophy and Phenomenological Research* 16: 240-244.

Honner, John. 1987. *The Description of Nature*. Oxford: Clarendon.

Hösle, Vittorio. 1999. Rationalism, Determinism, Freedom, in Atmanspacher, et al. 1999, 299-323.

Howard, D. 2004. Who Invented the 'Copenhagen Interpretation'? A Study in Mythology, *Philosophy of Science* 71:669-682.

Jammer, Max. 1974. *The Philosophy of Quantum Mechanics*. New York: Wiley.

Kant, Immanuel. 1781/1787. *Critique of Pure Reason*, tr. Norman Kemp Smith. London: Macmillan, 1929.

—. 1783. *Prolegomena to Any Future Metaphysics*, tr. L.W. Beck. New York: Bobbs-Merrill, 1950. (Citations are to the Berlin Academy edition's pagination.)
Lubkin, G.B. 1991. Friedman, Kendall and Taylor Win Nobel Prize, *Physics Today*: 17.
Marshall, Steve. 1995. 'Top Quark' Completes Matter Theory, *USA Today*, 3 (March): 1A.
Matthews, P.T. 1974. *Introduction to Quantum Mechanics*[2]. New Delhi: McGraw-Hill.
Melnick, Arthur. 2006. Kant's proofs of substance and causation, in Guyer 2006, 203-237.
Müller-Herold, Ulrich. 1999. The Primas Effect: On Quanta and Beyond, in Atmanspacher, et al. 1999, 3-8.
Omnès, Roland. 1999. *Quantum Philosophy*, tr. Arturo Sangalli. Princeton: PUP.
Palmquist, Stephen. 1990. Kant on Euclid: Geometry in Perspective, *PhilosophiaMathematica* II 5: 88-113.
—. 1993. *Kant's System of Perspectives*. Lanham: University Press of America.
—. 2000a. *Kant's Critical Religion*. Aldershot: Ashgate.
—. 2000b. *The Tree of Philosophy* [4]. Hong Kong: Philopsychy Press.
—. 2010. The Kantian Grounding of Einstein's Worldview: (I) The Early Influence of Kant's System of Perspectives, *Polish Journal of Philosophy* IV: 45-64.
—. 2011. The Kantian Grounding of Einstein's Worldview: (II) Simultaneity, the Synthetic A Priori and God, *Polish Journal of Philosophy* V: 97-116.
Parker, Sybil, ed. 1984. *McGraw-Hill Dictionary of Physics*. New York: McGraw-Hill.
Petersen, A. 1968. *Quantum Physics and the Philosophical Tradition*. Cambridge, MA: MIT Press.
Pringe, Hernán. 2009. *Critique of the Quantum Power of Judgment: A Transcendental Foundation of Quantum Objectivity*. Berlin: deGruyter.
Putnam, Hilary. 1987. *The Many Faces of Realism*. LaSalle: Open Court.
Redhead, Michael. 1995. *From Physics to Metaphysics*. Cambridge: CUP.
Reichenbach, Hans. 1951. *The Rise of Scientific Philosophy*. Berkeley: UPC.
Smith, Henrik. 1991. *Introduction to Quantum Mechanics*. Singapore: World Scientific.
Strawson, Peter. 1997. Kant on Substance, in P.F. Strawson, *Entity and Identity*. Oxford: Clarendon, 268-279.
Sundaram, K. 1987. *Cassirer's Conception of Causality*. New York: Peter Lang.
Swinburne, Richard. 1981. *Faith and Reason*. London: Clarendon.
van Fraassen, Bas. 1989. The Charybdis of Realism: Epistemological Implications of Bell's Inequality, in James Cushing and Ernan McMullin (eds.), *Philosophical Consequences of Quantum Theory*. Notre Dame: UNDP, 97-113.
—. 1991. *Quantum Mechanics*. Oxford: Clarendon.
Watkins, Eric. 2005. *Kant and the Metaphysics of Causality*. Cambridge: CUP.
Wright, Robert. 1993. Science, God and Man, *Time* (January 4): 38-43.

STEPHEN R. PALMQUIST is a Professor in the Department of Religion and Philosophy at Hong Kong Baptist University, where he has taught since earning his D.Phil. from Oxford University in 1987. He has more than 140 publications, mostly on Kant, and his writings have been translated into at least 12 languages. Among his 10 books are *Kant's System of Perspectives* (1993), *Kant's Critical Religion* (2000), *Kant and the New Philosophy of Religion* (edited with Chris L. Firestone), and *Cultivating Personhood: Kant and Asian Philosophy* (2010).

ADDRESS: Dept. of Religion and Philosophy, Hong Kong Baptist University, Kowloon, Hong Kong SAR.
E-mail: stevepq@hkbu.edu.hk