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Kant, Niels Bohr and Quantum Spontaneity

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ABSTRACT

This paper focuses on absolute spontaneity, first postulated by Immanuel Kant. In the early twentieth century spontaneity entered the domain of quantum physics when Niels Bohr included it as part of his quantum postulate. Later on, David Bohm developed the concept of a quantum potential in his description and interpretation of quantum physics, a concept that can also be understood in terms of spontaneity. A discussion of Kant's influence on the interpretation of quantum physics is followed by a consideration of the inclusion of spontaneity in Niels Bohr's epistemological approach to quantum mechanics and David Bohm's quantum potential as part of his ontological approach to quantum physics. Kant's influence on both Bohr and Bohm is examined as well as the applicability of his critical metaphysics to quantum theory. Critical metaphysics read together with Bohr and Bohm's interpretations of quantum physics is then utilized to make some proposals with regard to the problems plaguing our best theories of physics.

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Introduction

The 300-year anniversary of Kant’s birthday in 1724 coincides with the commemoration of an important discovery made by Niels Bohr 100 years ago in 1924 in his efforts to understand quantum mechanics, namely that the causality which governs all reactions in the classical world, breaks down in quantum physics. This discovery was a direct result of the earlier discovery in 1900 by Max Planck that energy comes in packets called quanta, which also gave its name to quantum physics. These discoveries for the first-time confirmed Kant’s idea that absolute spontaneity could very well be part and parcel of our world.

The implications of spontaneity being an essential part of our world is profound and perhaps one of the greatest and most unexpected discoveries of all time in the natural sciences. It went directly against the generally accepted view of modern times that all interactions in the world are deterministically determined in causal terms. This discovery also underlies one of the great problems on which physicists to this day have not reached consensus, namely the measurement problem.

In this paper I take a closer look at spontaneity as featuring in quantum physics, descriptions thereof in quantum theories as well as the possible application of Kant’s critical metaphysics in which spontaneity plays an important part to quantum physics. I also look into the origins of spontaneous reactions, a problem that goes right down to the most basic and fundamental forces known to us. In this analysis Kant’s critical metaphysics is utilized in an effort to provide insights and even clues for solving other problems in physics, problems like the apparent incompatibility between quantum physics and general relativity and even those pertaining to consciousness.

1. The Inclusion of Spontaneity in Quantum Theory

In 1924 Bohr discovered that in quantum theory a *causal* connection between electronic motion and radiation cannot be exhibited in *space and time* (Pringe, 2009). As a result of this insight, Bohr later on in 1928 published his so-called quantum postulate, a theoretical generalization based on an empirical assumption, in which this discontinuous or spontaneous process resulting from the indivisibility of the quantum is a central feature:

> [Quantum theory’s] essence may be expressed in the so-called quantum postulate, which attributes to any atomic process an essential discontinuity, or rather individuality, completely foreign to the classical theories and symbolised by Planck’s quantum of action. (Bohr, 1928, 580)

The quantum postulate “means that in the case of all atomic processes every energy change result from an indivisible – and because of that discontinuous – transition between different states that cannot be continuously connected” (Valente, 2010, 1). As a consequence of this discontinuous nature of quantum physics, all quantum outcomes are always described in probabilistic terms. Quantum physics is intrinsically probabilistic, that is, non-causal (Bitbol and Osnaghi, 2013,160).

Also in 1924, Louis *de Broglie proposed* a new speculative hypothesis that electrons and other particles of matter can behave like waves, which was confirmed in 1926 by the electron diffraction experiments of G. P. Thomson. During that time, physicists were able to produce the first formulation of the basic principles of quantum physics. In 1925 Werner Heisenberg, Max Born and Pascual Jordan formulated a description of quantum mechanics called matrix mechanics and in 1926 Erwin Schrödinger invented wave mechanics with his formulation of the non-relativistic Schrödinger equation. Schrödinger afterwards showed that these two approaches are equivalent. Then, in 1927, Heisenberg formulated the uncertainty principle.

2. Niels Bohr and Kantian Philosophy

When Bohr made this discovery that causality breaks down in quantum systems, an immediate concern was that this may be in conflict with Kant's transcendental philosophy, which has provided the epistemological grounding for Newtonian physics. As Léna Soler writes:

> At the time, it was more and more said, here and there in philosophical and scientific circles, that the (then just born) quantum mechanics refuted Kantian philosophy, especially the Kantian table of categories and its concept of causality. (Soler, 2009, 330)

In Niels Bohr's formulation of quantum theory, he, however, did use Kantian philosophy to ground the epistemology of this new field of studies. In general, philosophers of science are in agreement that Bohr made use of Kantian philosophy but the extent and the manner in which he did so are not agreed upon. Already in the nineteen thirties did Neo-Kantian scholars like E. Cassirer, G. Hermann and C. F. von Weizsäcker recognized a Kantian influence in Bohr's approach and many other philosophers of science also discuss different parallels, sometimes holding opposing views in this regard (Kauark-Leite 2017; Bitbol, 2017, 2013; Cuffaro, 2010; Pringe, 2009; Chevalley 1994; Kaiser, 1992; Faye 1991; Honner, 1987, 1982; Fano, 1988 & Folse 1985). Whereas most of them base their views on Kant's *Critique of Pure Reason*, Pringe uses the *Critique of the Power of Judgment* in his approach.

Michael Cuffaro (2010, 1, 25) holds that any proper "interpretation of Bohr should start with Kant" and "a Kantian (who does not deny the validity of the uncertainty relations), starting from the principles of Kantian philosophy, would be led to many of the same conclusions as Bohr" (Cuffaro, 2010, 25). Kauark-Leite (2010, 250) holds the view that Bohr "does nothing but extend the Kantian analysis to a totally different epistemic situation." Pringe (2023, 249) emphasizes that the discontinuity of atomic processes enables us to establish a remarkable connection between transcendental philosophy and Bohr's interpretation of quantum theory. And he shows (Pringe, 2007, 2023) how Bohr's view can not only be understood in terms of classical Kantian (critical) philosophy but also provides a detailed exposé as to how quantum observations can be viewed in objective epistemic terms in the framework of that philosophy.

3. The Copenhagen Interpretation and Its Demise

3.1. Bohr's Interpretation of Quantum Mechanics

As a consequence of the spontaneous collapse of quantum states to reduced states, the observer has no way to gain direct empirical access to quantum objects. They only have access to quantum phenomena and that through their measurement apparatuses. In Bohr's view, quantum objects fall outside the possibility of empirical access and we can thus not obtain any real knowledge about them, except for the fact that they exist. He did not attribute any intrinsic and measurement-independent state properties to atomic objects in addition to the classical ones being manifested in measurement (Faye, 1991).

In Bohr's view the quantum mechanical formulation is thus not true in the sense that it gives a literal representation of the atomic world; it only provides a symbolic representation (waves and particles serve as symbols pertaining to quantum objects). Bohr is therefore called an "entity realist" who opposes "theory realism" (Folse, 1986; Faye 1991).

Bohr's interpretation of quantum physics, with the added insights and contributions of Heisenberg, Born and others, later on became known as the Copenhagen interpretation, despite the fact that Bohr and Heisenberg never fully agreed on the way to understand the mathematical formulation of quantum mechanics. "Today the Copenhagen interpretation is mostly regarded as synonymous with indeterminism, Bohr's correspondence principle, Born's statistical interpretation of the wave function, and Bohr's complementarity interpretation of certain atomic phenomena" (Faye 2019). The heyday of the Copenhagen interpretation spanned approximately the period from 1927 to 1952.

3.2. The Measurement Problem

Some interpreters of Bohr, like Don Howard (1994, 2004, 2005), are of the opinion that he believed that the superposition of quantum states is entangled with the measuring apparatus. This view is not generally shared and most interpreters seem to disagree.

Mario Valente (2010, 7), for example, emphasizes that, according to Bohr, not all of the experimental arrangement has to be considered in direct interaction with the quantum system, only the "significant parts of the experimental arrangement" (Bohr, 1962, 92). This explains why the experimental arrangement with its entirely classically described "fixed measuring rods and synchronized clocks" (Bohr, 1955, 90) stands "outside and independent of the object under consideration" (Bohr, 1985, 369). Valete writes: "This reading of Bohr's ideas implies considering the part of the experimental arrangement not directly in interaction with the quantum system as describable by classical physics." After a discussion of the views of Paul Teller, Henrik Zinkernagel and Simon Sanders, Valente comes to the conclusion that they all understand

> Bohr as implying the need for a classical physics account of (at least) part of the experimental arrangement (the one not directly in interaction with the quantum system), stressing in particular the need for a classical account of the reference frame. This view is clearly at odds with Howard's. Howard's reconstruction implies an all-quantum description of the entangled pair instrument & object, giving just a classical description (in Howard's sense), for both the instrument and object, of the property being measured. (Valente, 2010, 13)

In 1932 John von Neumann produced a formulation of quantum physics in his *Mathematical Foundations of Quantum Mechanics* that has often been taken as for the most part being in agreement with the Copenhagen interpretation. In this formulation Von Neumann argues that quantum mechanics can only be described in terms of the Schrödinger equation; in contrast, the measurement process cannot be described by quantum physics. He coined the term "projection postulate" for the reduction of the wave function when a measurement is taken.

In Von Neumann's formulation the quantum object and the measurement apparatus are in an entangled state. When a measurement is taken, the superposition of states collapses to determinate states. As already shown, this view does not agree with Bohr's view (as it is usually understood) that the quantum object is not in a superposition with the measurement apparatus; all atomic processes are discontinuous (spontaneous) and the resulting quantum phenomena stand in relation with the quantum apparatus (as described in the quantum postulate; see Valente 2010, 5 for a detailed discussion). A "cut" is made between the object-system and the experimental context (Bitbol and Osnaghi, 2013, 154). In this case no question arises as to why the superposition collapses.

In Von Neumann's formulation, he stands in need of finding a cause for the collapse which is intrinsically linked with the act of measurement, a problem that does not occur in the Bohr view. In fact, various scholars like Nancy Cartwright (1983) and R. I. G. Hughes (1989) have argued that the reduction of the wave packet should not be understood in terms of measurement; it also happens in other situations such as atomic decay. Von Neumann then postulates that the superposition of states extends to include the actual observer, whose perception (consciousness) somehow causes the collapse.

The extending of the superposition to include macro structures in the classical world was criticized by Schrödinger in his famous thought experiment about the cat being both alive and dead until an observation is made. This image is often presented in all seriousness as being Schrödinger's view whereas he actually uses it to show how Von Neumann misinterpret the theory to include cat-sized objects like the human observer (the cat is either dead or alive but not both). No evidence exists that quantum features apply to the classical world on a macro level (quantum features do appear on a cellular level as shown in quantum biology but that more or less defines the limits of its application).

Even though Bohr's interpretation is not saddled with Von Neumann's measurement problem, it is nonetheless true that in quantum theory the operational notion of continuous time described by the Schrödinger equation stands in glaring contrast with the discontinuity described in Bohr's quantum postulate and the corresponding statistics of outcomes given by the Born Rule.

As a consequence, the measurement problem is usually defined slightly differently, namely that the two kinds of evolution associated with the quantum mechanical description, that is 1) the deterministic evolution in accordance with the Schrödinger equation (that should be generally valid) and 2) the projection postulate (that should be deductible from the dynamic description), are flatly in contradiction with each other (Albert, 1992, 37). The theory of quantum mechanics can apparently not be fully described in one unified mathematical description.

3.3. The Gap Between the Classical and Quantum Worlds

Since the time when quantum theory was first formulated physicists were struck by the strange difference between the classical and quantum descriptions of the world, with quantum entities demonstrating behavior that has never before been observed in the classical world (like superpositions of states, entanglement and non-locality). This difference was in part captured by Bohr's quantum postulate that describes the spontaneous nature of atomic events as a consequence of the ""indivisibility of the quantum of action" (i.e. quanta; Bohr, 1934, 5) that stands in dramatic contrast with the classical world in which only deterministic causality is known.

Many authors have discussed this "gap". For Bohr, the difference is self-evident and differentiates where predicates can be legitimately used and were not. Bitbol writes that "we are faced with a persistent dialectic between two irreducible domains of discourse (objectified and situated)" (Bitbol, 2007, 258; see Hughes, 1989, 312, 316) In the Copenhagen description of quantum mechanics this primarily concerns the difference between the superposition of states and reduced states (a transition process described by the projection postulate). Various other interpretations have tried to overcome this divide by rejecting the projection postulate (believing that the collapse of the wave packet is not a real event).

Among these views are David Bohm's (and De Broglie's) mechanics that uses a guiding equation to define the positions of the particles (or configurations of fields) described by the wave function, Hugh Everett's "relative state" formulation according to which subsystems "branch off" from the state vector of the universe, and Bas van Fraassen's modal formulation (called constructive empiricism) according to which the quantum state delimits what is possible whereas measured properties say what is actual (for discussions of these views, see Healey, 2009, 274, Hughes, 1989, 311, and Earman, 1986, 223). Another theory is that of Giancarlo Ghirardi, Alberto Rimini and Tullio Weber, which modifies the Schrödinger equation by adding stochastic and non-linear effects. Different variations of these theories have been proposed through the years.

These different views introduce new problems of their own, for example "action-at-a-distance" (Bohmian mechanics), many worlds (Everett's view) and an instrumentalist view (Van Fraassen's approach; for those who find it problematic). The Ghiradi-Rimini-Weber (G-R-W) theory turns the Schrödinger equation into a scholastic dynamical law in which the instantaneous (often called "spontaneous") collapses of the system happen as a consequence of background perturbations (Allori et al., 2008, 357; with the "shifty split" being done away with, Bell, 1990).

This introduces the question as to the nature of the spontaneity ascribed to the quantum world. In contrast with the G-R-W theory, Cartwright (1983) argues that Bohr holds to the view that the transition between states is absolutely spontaneous (i.e. no stochastic process in keeping with deterministic causality underlies such motions). When a quantum system makes a spontaneous transition from one state to another, some conserved quantity like energy, momentum and angular momentum will be emitted or absorbed; the exchange of energy activates the detector and some observable quantity is measured (Cartwright, 1983, 179). Michael Redhead (1987) has indeed shown on mathematical grounds based on Bell's theorem that in the case of the Aspect experiment, the collapse is truly spontaneous without any possible stochastic form of determinism involved. And recently the Majorana Demonstrator experiment performed at the Sanford Underground Research Facility has effectively shown the G-R-W theory to be wrong (Donadi et al. 2020).

All the aforementioned efforts try to obtain a unified (mathematical) description of quantum physics. What is important to note is that the shift away from the Copenhagen interpretation at the same time implies a rejection of Kant's transcendental approach that underlies Bohr's view (Bitbol and Osnaghi 2013, 154). From this it seems to follow that the utility of a Kantian approach to quantum physics and even science more generally is closely linked to the prospects of Bohr's view. We will return to this assessment presently.

4. The Metaphysics of Quantum Physics

At this point the inevitable question needs to be asked, namely why Bohr's view and the Copenhagen interpretation of quantum mechanics lost its appeal. This is a very important question that all Kantians have to consider seriously because it also engages with the question about the usefulness and benefit of Kantian philosophy of science within current scientific debate, especially concerning quantum physics.

Even though this is not an easy question to answer, I would like to make some suggestions. There are mainly two reasons for the demise of the Copenhagen interpretation, namely that the physics community is not only interested in quantum mechanics and quantum theory more generally, as a successful theory, they are also interested in the bigger questions about the nature of our universe. They look for metaphysical insights that can *explain* things. As a consequence, it is not strange to find discussions centering on the "metaphysics of quantum mechanics", with the different views basically exploring different metaphysical options pertaining to the true nature of the world.

Another reason is that physicists put a lot of trust in mathematics and often express a belief in mathematical theories that have a certain appeal (such as its "beauty" or simplicity) despite the fact that no substantial empirical evidence has been found to support them. A good example is string theory or the multiverse. As for quantum mechanics, the impulse is to take the Schrödinger equation seriously as a description of what really happens. And this introduces the main problem: the Schrödinger equation describes deterministic motion, with the projection postulate simply an add-on that is not mathematically supported except for the Born Rule. The natural conclusion then seems to be that mathematics cannot be wrong and our world is really deterministic despite Bohr's quantum postulate and his refusal to accept a literal view of the Schrödinger equation.

When all is considered, it seems that the primary problem comes down to what we make of the gap between the classical and quantum descriptions of the world. A central question concerns the ontological status of this gap: is it real or is it simply a gap in our understanding of the workings of the universe. And from a Kantian perspective it needs to be asked what contribution Kant's philosophy can make towards solving this problem.

The question about the ontological implications of Bohr's view has indeed been asked. Mauro Dorato (2017) argues that Bohr's view does imply some form of ontological distinction between the classical and quantum realms. Scholars who regard Bohr as believing that the measuring apparatus and quantum object are in a state of entanglement (and that this entanglement involves other large objects from the classical world) can in this way overcome this distinction. But nothing prohibits those who do not hold this latter view from considering the possibility of such an ontological distinction in all seriousness and thus endeavor to define the cut between these realms in a non-ambiguous way.

4.1. Towards a Kantian Solution

As Kant already introduces absolute spontaneity in his critical metaphysics in the *Critique of Pure Reason* (First *Critique*; edition A 1781, edition B 1789), we can also take a closer look at his formulation thereof. In accordance with Kant's epistemology having been applied to the quantum system, as follows from Bohr's interpretation and other detailed formulations of quantum epistemology in keeping with the Bohrian approach (Pringe, 2007, 2023), it could very well be that

Kant’s broader critical metaphysics also finds an application in the world described by quantum physics.

Even though Kant establishes the limits of pure reason and undoes all “proud ontologies” (A247; and many Kantian philosophers as a consequence stay clear of metaphysics), nothing in his philosophy prohibits the correct use of metaphysics. Contra Bitbol (2008), philosophers like Willem McLoud (2018), Stephen Palmquist (2013) and Robert Hanna (2006) argue that Kant’s realm of regulative ideas allows for the construction of a systematic critical metaphysics that includes ontological distinctions (see also Allais, 2004, Langton, 1998 and Ameriks, 1992 for noumenal/intrinsic properties) which can serve as a hypothesis pertaining to the natural workings of nature. It is especially in the *Critique of the Power of Judgment* (Third *Critique*; KdU 1790) that Kant produces a detailed and systematic metaphysics when he considers the natural products of nature.

Let us for a moment consider a broad outline of Kant’s critical (regular) metaphysics and how quantum physics can be accommodated within it. This will also show how ontological distinctions enter his metaphysical picture. Needless to say, even though this branch of Kant’s philosophy that he first develops in the second part of the First *Critique* follows logically and systematically from the epistemology formulated earlier in this *Critique* and which applies to objects of experience (and experiment) in the classical word (for the most part described by Newton’s laws), it nonetheless also stands apart and is quite distinct from that.

Kant introduces the basic features of his critical metaphysics in the context of the third antinomy (conflict of laws), one of two dynamical antimonies concerned with the *consideration of existence alone* (i.e. no magnitudes of the series of conditions are considered; A536/B564). The transcendental and empirical use of reason (i.e. the thesis and anti-thesis positions) pertaining to the unconditioned in a series of conditions can be extended *to conceptualize* both an intelligible (noumenal) world and a sensible world, with the latter not taken as an accumulative world-whole but as “nature”. As these two ideas concern different modes of existence (Allison, 2012, 17) it follows immediately that the Kantian concepts of “nature” (to be distinguished from our current understanding of nature) and the noumenal realm are ontologically distinct from each other.

The idea/concept of “nature” that Kant introduces does not refer to material nature (as an aggregate) but rather to nature as a systemic whole (A419/B447). All regulative ideas pertaining to world-concepts (i.e. systemic nature and the noumenal world) are “transcendent” to our experience (we can never experience them), with systemic nature taken as a total system of existence (A420/B448) that refers to the world of appearances. As a system, nature is comprised of the totality of causal relations, called mechanism (see Bxxvii-xxx, A419/B447 n., and *KdU* 5, 379). Mechanism is a regulative concept that belongs to the concept of systemic nature and should be clearly distinguished from the causality of the second analogy that is a rule of the understanding which applies to phenomena (Allison, 2012, 202-2033). Both are, however, deterministic concepts of causality.

This brings us to the noumenal world. As follows directly from the fact that the third antinomy is concerned with modes of existence and as Kant also explicitly mentions (A420/B448; McLoud 2018), the realm of noumena "oversteps" the sensible world (nature) *in kind*, that is, it refers to another kind of existence apart from nature. What is more is that the transcendental idea of freedom, which follows directly from the thesis position of the third antimony (the *thought* of the unconditioned suggests absolute spontaneity as an effective cause; Allison, 1990, 24), can without contradiction be ascribed to the noumenal realm (which lies "outside" nature where mechanism rules).

The noumenal realm thus becomes the realm of freedom, often contrasted by Kant with nature. Kant views this absolute spontaneity as the only alternative kind of causality (A532/B560). McLoud (2018) argues that Kant's motivation for introducing noumena in his metaphysical schema is primarily to "save freedom" (see A537/B565). Whereas nature is a system of existence regulated by mechanism, the noumenal realm is a system of existence regulated by transcendental freedom.

In the dynamical antinomies, the anti-thesis position *thinks* the unconditioned in the framework of sensible conditions whereas the thesis position does not merely think the unconditional; it also *thinks it outside sensible conditions in an intelligible (noumenal) world*. Instead of creating a conflict of reason, this represents a *real (logical) possibility*. The outcome of the third antinomy, when viewed in this manner (with the thesis position taken outside possible sensible conditions), is that *existence in two different worlds can be brought into interaction with each other*, i.e., an intelligible (spontaneous) cause can produce phenomenal effects.

Absolute spontaneity as an effective cause of phenomena *has no previous causal links in the structure of causal relations* governed by the second analogy (in the world of phenomena) or even in nature (governed by mechanism); this is why it is viewed as beginning "a series of occurrences *entirely from itself*" (A534/B562, italics in the original). Kant says:

> Accordingly, a causality must be assumed through which something happens without its cause being further determined by another previous cause, i.e., an absolute causal spontaneity beginning from itself. (A446/B474, boldfacing in the original)

As such the grounds for transcendental freedom (that is, noumena) stand forever outside the causal chain of events that constitute nature; it can, however, without contradiction produce outcomes which interact with the causal chains of the phenomenal world. As such it is not "incompatible" with nature (A558/B586).

We can now apply this metaphysical system to the world described by science. The Kantian concept of "nature" (regulated by mechanism) allows for the *concepts* of space, time and causality to be used in mathematical theories pertaining to systemic nature (see also Kauark-Leite 2010, 248). In this regard Mauro Dorato (2002) shows that time and causality as conditions of experience can be related to concepts thereof in the framework of space-time theories like Einstein's theories of relativity.

When it comes to the noumenal realm, numerous scholars have made use of this idea in their efforts to describe quantum mechanics in Kantian terms. Using mere methodological approaches, these scholars typically describe quantum objects in terms of noumena (or "things-in-themselves") because they are not objects of possible experience (Cuffaro, 2010, 16; Pringe, 2007, 157, n. 31; Fano, 1988). This means that the quantum world is being associated with Kant's noumenal world. Some authors have moreover proposed that the reduction of the wave packet should be viewed in causal terms (see Cartwright, 1983, 182; 1989, 249; Bartels 1999, S170 and Pringe 2007), with Pringe even using the Kantian concept of an absolute spontaneous cause (as already described) to describe what he calls quantum causality.

Using a weak ontological approach, McLoud (2018) argues in his monograph, titled "Kant, Noumena and Quantum Physics," that all the conditions for the Kantian noumenal realm (corresponding with Kant's characterization of that realm in the First and Third *Critiques*, which he views as consistent with each other) are satisfied in the quantum realm as described in quantum field theory (which unites quantum mechanics with special relativity), i.e. with quantum entities existing "outside" proper space, time and causality. As a consequence, he applies the ontological distinction that Kant makes between entities belonging to nature and the noumenal realm to the classical and quantum realms respectively.

McLoud (2018) moreover argues that the Kantian conditions for the possibility of an effective absolute spontaneous causality are also satisfied. He identifies this with quantum causality.

When the gap between the classical and quantum worlds is considered in terms of Kant's critical metaphysics, it immediately follows why these can be regarded as an ontological distinction. Bitbol and Osnaghi (2013), however, do not agree with this assessment:

> Bohr's prescription in no way presupposes or implies an ontological distinction between macroscopic and microscopic systems. There is nothing in the physical nature of macroscopic objects that distinguishes them from the microscopic ones, and which rules out the possibility of describing them as quantum systems. (Bitbol and Osnaghi, 2013, 152)

It seems that Bitbol and Osnaghi (2013) argues that since everything in nature is built from elementary particles, they share the same "physical nature". The problem is, however, that quantum entities in the pre-measurement stage cannot be observed as matter. As Bitbol (2007) shows in another paper, it is only quantum phenomena manifest by impacts, bubble chamber tracks and clicks on counters that appear in space-time that can be described as matter. Quantum objects cannot be observed and does not appear in proper space-time.

When the entities in the quantum field description are considered, they cannot even be described as "particles" as noted by Richard Healey: "For a quantum field theory removes even the basic particle ontology, while leaving it quite unclear what is to replace it." (Healey, 2009, 221)

If an ontological gap between the classical and quantum realms really exists, all efforts to ignore and overcome this gap and to negate absolute spontaneity as a real causality found in quantum mechanics will come to nothing.

4.2. Kant's "Productive Cause"

In the Third *Critique,* Kant goes a step further in presenting his critical metaphysics, this time in the framework of his philosophy of science. The noumenal realm, now described as the supersensible substratum of nature, forms a crucial part of Kant's philosophy of science in this *Critique*, especially in the part called Critique of the Teleological Power of Judgment. As a consequence, we can safely assume that Kant regarded this concept as consistent with science. We cannot eliminate it from Kant's philosophy of science without seriously damaging his arguments (McLoud, 2018, 50).

In the Third *Critique*, Kant is especially concerned with the products of nature. In the place of mechanism and spontaneity (introduced in the First *Critique*), he now introduces two similar but more sophisticated concepts, namely mechanism (differently constituted) and teleology (with "natural purpose" as the main feature).

With regard to the internal possibility that things have in themselves to produce their external form, Kant then introduces the relation between the "whole" and the "parts" as well as the particular causal relation which governs them. He distinguishes two conceivable ways in which this could be possible, namely through the "mechanism of nature", when the material whole is explained by the causal relation between the component parts (the parts determine the whole), and through a "natural purpose", when the idea of the whole (located in the supersensible ground of nature) serves as ground and condition for the parts and their internal arrangement (the whole determines the parts) (Allison, 2012, 203; McLaughlin, 1990, 129).

In the Third *Critique* the idea of the "whole", understood as non-aggregated wholes-and-parts that contain the ground and possibility for the production of the products of nature (of the material whole with its parts), effectively supplants the concept of noumena that Kant uses in the First *Critique* (McLoud, 2018, 46-48). What is more is that Kant now introduces a certain potentiality, a "productive cause" (*KdU* 5, 370, 379), also called "the spontaneity of a cause" (*KdU* 5, 411), that the products of nature have in themselves to produce their material forms, an idea based on the more basic one of absolute spontaneity. Kant conceptualizes *the capacity* of non-extended wholes-and-parts in the supersensible substratum of nature to produce extended parts and aggregated wholes in nature (and space/time) in terms of a "formative force" (Kant speaks of "self-organization" in this regard.) (McLoud, 2018, 46-49, 68)

As before, these Kantian ideas can be applied to quantum physics. Even though Kant formulated his ideas for the products of nature, his extensive use of the supersensible realm in the formulation of his view (and his explicit mention of fundamental entities in this regard in the *Metaphysical Foundations of Natural Science*; *MAN*, 507) allows for the application to the quantum world when that realm is understood in such terms. As a consequence, we can take superimposed states as agreeing with Kant's non-aggregated wholes-and-parts, the parts constituting the whole, with the parts referring to fundamental entities. At bottom, in multi-particle systems, it is, in fact, these fundamental entities that are coupled (through their states) into wholes-and-parts as Kant proposed.

The outcomes of measurement can then also be understood in terms of parts and wholes. In contrast with superpositions of states conceptualized in terms of non-aggregated wholes-and-parts, the outcomes of measurement involve aggregated wholes defined in terms of probabilities in accordance with the Born postulate (the individual outcomes form an aggregated whole as in all probability formulations). Since definite values cannot be assigned to pre-measurement states in superposition, the outcomes are accordingly not determined by such values; they are given probabilistically.

As found in the Kantian system, the idea that quantum systems can be described in terms of potentialities goes back to Heisenberg's later writings. He invoked the Aristotelian idea of potentiality, namely that all change consists in the actualization of potentialities, to describe the relation between the quantum state and its outcomes. Henry Margenau also thought in terms of propensities or latent quantities, i.e. that the measurement of an observable converts latent values into possessed values (Redhead, 1987, 48).

Hughes (1989) presents an event interpretation of quantum mechanics in which quantum properties are replaced by "latencies". When a particular latency is ascribed to a quantum system, probabilities are assigned to the values of a family of observables which would be realized in events (Hughes, 1989, 309). Teller (1995), who also understands superimposed (i.e., quantum) properties in terms of propensities, applies such concepts to quantum fields.

4.3. The Quantum Potential

David Bohm's quantum potential also needs to be mentioned, with various authors having observed close similarities between Kantian and Bohmian ideas (Najmabadi et al. 2020; McLoud 2018; Palmquist, 2015). In contrast with Bohr, Bohm was interested in what determines the behavior of an individual quantum system, i.e. the nature of the system's ontology (Van Strien, 2024, 3). This eventually led to the discovery of the quantum potential and the development of Bohm's theory (to be distinguished from Bohmian mechanics in that this is a second order theory, not a first order one; Romano, 2020, 12).

According to Basil Hiley (2002), the quantum potential can be regarded as an "internal" potential energy that belongs to particles in superpositions of states (it has no equivalent in classical mechanics and has no external source). Insofar as multi-particle systems are concerned, the quantum potential is understood in terms of a "whole" that determines the properties of the individual particles and their relationship (and not the other way round). As such it is a non-local energy, different from kinetic and (classical) potential energy, necessary for energy conservation which involves a spontaneous self-organizing process involving a basic underlying field (see Hiley, 1999, 7). As this terminology is remarkably similar to that of Kant, with both Kant and Bohm having been inspired in their views by the processes they observed in nature, a Kantian influence on Bohm can perhaps not be excluded given the exact same terminology.

Quantum field theory also needs to be brought into the discussion. What is quite clear from Auyang (1995), who follows a Kantian approach, is that quantum fields closely mirror the Kantian conception of the supersensible substratum of nature (McLoud, 2018, 62-7). In this framework pertaining to matter fields, the "basic entities or individuals of the physical world" are "extensionless in all four dimensions" (that is, they have no space or time parts) even though they could be indexed in the framework of a "primitive" space-time manifold M (Auyang, 1995, 123, 129).

These quantum entities are called "events" to express the fact that their *indexing* in M involves both space *and time* (as such they have *the potentiality* to be realized in space-time). These "events" should not be confused with what is normally understood by events in space-time. Only once events are actualized in some manner, are they represented mathematically as timelike or spacelike curves which are generated by mapping some part of a real number system onto the manifold M (Auyang, 1995, 171). As far as time is concerned, the manifold M is

> too primitive to confer special meaning on the time dimension... M is… *the condition for the possibility of introducing the time parameter and the notion of being 'in time'...* [It] is independent of temporal concepts. It contains the time dimension as one aspect and makes possible the introduction of the time parameter, but *is itself beyond time and change*. (Auyang, 1995, 170, my italics)

Auyang's description of quantum fields is quite similar to Bohm's implicate order as can be seen from Hiley's comment in this regard, "[T]here is a deep underlying process from which not only particles and fields emerge, but this process is the source of space-time itself." (Hiley, 2010, 14) In this implicit order the quantum particles can be seen as vibrations of a global field existing on the fundamental level (Fiscaletti, 2018, 14).

When the quantum realm described by quantum fields (usually taken as the basic ontology of the world; Auyang, 1995, 45) are contrasted with the classical world with its objects of experience, it follows that quantum mechanics in actually brings these two worlds together. The temporal parameter of the Schrödinger equation allows for the classical description of quantum phenomena (Valente, 2010), whereas the mathematical space that describes the quantum entities are complex vector spaces (Cartwright, 1999, 217) that make their observation in proper space impossible (similar to entities in quantum fields not being observable in space-time). What is more is that the amplitudes associated with these entities are also complex quantities while our instruments can only measure real numbers (Auyang, 1995, 73).

4.4. The Intermediary Role of Quantum Mechanics

Using Kant's critical metaphysics, the quantum field description can be viewed as describing another ontological mode of being than the one found in the classical world, with these two worlds being brought together in quantum mechanics (a possibility not foreseen by Kant but consistent with his metaphysics). Whereas the quantum mode is ruled by spontaneity, the classical world is ruled by determinism. As such, the time parameter actually introduces classical characteristics to the quantum system: the time *evolution* of the superposition of states is governed by deterministic laws which subject the state vector (the inseparability of wholes-and-parts) to given forces and constraints in a manner similar to classical equations of motion (Albert, 1992, 34). One can view the Schrödinger equation as extending the classical time framework into quantum physics.

We can moreover read the time parameter as placing a (classical) constraint on the quantum mode (which is then in some manner constrained to be in time but not in proper space). The dynamic evolution of the quantum system, made possible through the time framework, constrains the superposition of states to evolve in a certain manner in time. When the system is further constrained (disturbed) in accordance with different experimental configurations, the superposition of states collapses to reduced states.

Another way in which this can perhaps be conceived is in terms of Bohm's theory (Bohm and Hiley, 1993) in which the particles are being acted upon by two quantum fields which generate the quantum potential as well as an "Aristotelian" (classical) potential. Instead of Bohm's use of a configuration space, the equations can be reformulated in ordinary three-dimensional space in which these fields become multi-fields that are dynamically coupled (Hubert and Romano 2018). When the quantum potential is negligible, the particles will move according to Newtonian trajectories. As for the quantum potential, it produces a non-local force that acts on the superposition of states simultaneously (Romano, 2020, 21).

When a two-particle configuration is considered (like in the Aspect experiment) the quantum field that generates the quantum potential will operate simultaneously on both particles despite their distance from each other. Even though the "collapse" of the wave packet does not feature in Bohmian theory, it seems reasonable to assume that the non-local collapse of the superposition of states to reduced states needs to be attributed to the quantum potential (given its non-local and spontaneous character). And as measurement of a property on one particle leads to the instantaneous and (absolutely) spontaneous reduction of the state of the other particle, this spontaneous "collapse" can only be attributed to the quantum potential acting non-locally.

It can thus be proposed that whereas in Bohr's interpretation of quantum mechanics the quantum phenomena (properties) are observed without any consideration of the internal dynamics of the quantum system, the Bohm interpretation provides answers as to why the simultaneous collapse takes place: the quantum potential is responsible for the spontaneous collapse. It may be suggested that the way in which the potentiality for collapse is included in the Schrödinger equation (or rather its decomposed formulation) is through the quantum potential.

As the quantum potential describes the non-local entanglement of the particles, namely its potentiality for self-organization, it stands to reason that it also contains the potentiality for actualization though a spontaneous collapse. Even though this does not follow from Bohmian mechanics it does seem to be consistent with Bohm's theory of the implicate order bringing forth the explicate order.

The strange combination of classical characteristics (described by the time parameter in the Schrödinger equation and the "Aristotelian" potential in Bohm's theory) together with the quantum mode of existence (superpositions of states and the non-local quantum potential) in one system in quantum mechanics is reflected in the way in which quantum particles differ from their classical counterparts. They are not situated in space-time like classical particles; they do, however, retain some definite classical characteristics (deterministic evolution) due to their continuous time evolution which disappears in the quantum field description.

This metaphysical picture explains the measurement problem (the need for two different formulations, namely the Schrödinger equation and the projection postulate). The Schrödinger description can now be viewed as bringing two different modes of existence together in one formulation, i.e. the deterministic time evolution that constraints the superposition of states ("wholes-and-parts") from collapsing (despite them having the potential to do so). When the system is further constrained in accordance with different experimental configurations, the superposition of states collapses to reduced states. In the case of the quantum field description, no similar constraints are placed on the quantum system, allowing it to make absolute spontaneous transitions to reduced states (for a detailed discussion see McLoud, 2018, 67-74, 78-81).

This explanation is supported by the work of Mohammad Jamali et al. (2019) who show that the quantum potential (which appears as part of an extra term in a modified Schrödinger equation) can indeed be associated with the collapse of the wave function in standard quantum mechanics. They propose that "because of this extra term, which leads to a nonlinear modified Schrödinger equation, there may be a possibility for the solution of measurement problem in QM (due to its nonlinearity and non-unitary evolution)." (Jamali et al. 2019, 7)

5. Implications for Contemporary Conversations in Physics

When we take the Bohmian quantum potential as the scientific equivalent of the Kantian potentiality or "productive cause" (*KdU* 5, 370, 379), we can apply Kantian metaphysics to an even broader range and array of issues pertaining to contemporary physics and the challenges associated with obtaining a comprehensive understanding of the workings of nature. Even though philosophers of science usually "follow the science", there is no reason why they cannot make proposals guiding the direction of science. And when nature is interpreted though the lens of Kantian metaphysics it is indeed possible to make some proposals with regard to the problems plaguing our best theories.

5.1. Quantum Field Theory vs General Relativity

Perhaps the greatest challenge for physicists is reconciling quantum field theory with general relativity. This problem is about 100 years old and no convincing unifying theory has yet been found. Scientists are divided in their opinions as to where the problem lies, with some thinking quantum theory has to be modified (to include the quantization of gravity), others that general relativity is an incomplete theory (given the singularities in the theory as well as observational discrepancies like the Hubble tension) whereas still others have proposed that a more general theory (like string theory) would be the answer. None of these proposals have thus far provided real solutions.

Can Kant's critical metaphysics provide some clues to better understanding the issue? In the Kantian conception of things, as presented already in the First *Critique*, systemic nature ruled by mechanism has reference to the classical world, with general relativity being a theory that describes the dynamics of "nature". In contrast, the noumenal world ruled by absolute spontaneity can be viewed as having reference to the quantum world described by quantum field theory (McLoud, 2018). I have argued that in the Kantian system, these two worlds are ontologically distinct, being ruled by mechanism (determinism) and spontaneity respectively. This immediately suggests that they are sufficiently different that theories describing these worlds would be incompatible with each other (as we indeed find).

In theoretical descriptions of the quantum world, spontaneity has indeed become an essential element of the theory, especially when the quantum potential is included (also in quantum field theory; Fiscaletti 2018; Licata and Fiscaletti 2014). The most distinguishing feature of the quantum potential is that it is non-local, which means that it operates outside the Lorentzian space-time manifold and can thus (exactly like quantum entities) not be directly observed (Earman 1986, 188). Authors have argued, however, that we have good reasons to believe that the quantum potential is real (Romano, 2020, 17) and many applications to natural phenomena seem to confirm that.

In his discussion of different mathematical approaches to the quantum potential, Davide Fiscaletti (2018) discusses the work of different scholars. Among them counts Valeriy Sbitnev who regards the quantum potential as

> [A]n information channel which emerges from the zero-point fluctuations of a physical vacuum acting as a special superfluid medium… the physical vacuum consists of an enormous number of virtual pairs of particles anti-particles with opposite orientations of spins (thus constituting a Bose ensemble) … (Fiscaletti, 2018, 29)

It may be proposed that the fluctuations of the electromagnetic field in the vacuum (described by quantum electrodynamics (QED), the quantum field theory of electrons and electromagnetic fields) are the source of the spontaneous character of the quantum potential. Jamali et al. (2019) actually shows that extending Bohmian theory to quantum field theory (in a second quantization) produces a modified quantum potential that can explain phenomena like creation and annihilation of particles.

What is quite fascinating is that the same process featuring in Sbitnev's work, namely the constant emergence and interaction of pairs of particles and their antiparticles such as electrons and positrons, has recently been identified as the source of dark energy in the cosmos. According to Alexandre Tkatchenko (2023), his team obtained results that agree well with the measured values for the cosmological constant (in general relativity). It will be interesting to discover what relation exists between the quantum potential and dark energy and if they perhaps refer to the same feature.

Various different theoretical models describing the coupling of general relativity with quantum field theory have been proposed through the years, most recently by Jonathan Oppenheim (2023). From the standpoint of Kantian metaphysics such interaction is possible because of the intermediate role that quantum mechanics plays between quantum fields and general relativity.

Any real unifying theory will have to take the ontological differences between the classical and quantum worlds into account, namely the spontaneous character of quantum fields (described by the quantum potential) and the space-time description of gravity. Oppenheim did in fact use classical gravity (with no need for quantum gravity). For his part, Fiscaletti (2018, 92, 124) writes that Bohm's quantum potential introduces interesting unifying perspectives also as regards the treatment of gravitation.

Kantian metaphysics suggests that the ontological difference between quantum fields and the classical world (general relativity/gravity) implies that the quantization of gravity is not achievable.

5.2. Consciousness

As already mentioned, in the Third *Critique* Kant reworks and refines his concepts of mechanism and spontaneity within the framework of the description of the products of nature, with a potentiality replacing the simple notion of absolute spontaneity. It is this potentially that agrees so closely with the quantum potential. It is therefore to be expected (in accordance with the Kantian insights) that Bohm's theory would be applied to organic life and its self-organizational features.

Quantum coherence consistent with self-organization is observed in many biological contexts, from the selectivity and transport of ion channels through the membranes into cells (Seifi et al. 2022) to the quantum coherence in phase differences of dipole-bound electron oscillations in the brain (Poznanski et al. 2018). Quantum coherence (micro vibrations) is experimentally verified by a bundle of microtubule (EEG waves), with genetic experiments also having uncovered important roles for the quantum aspects of microtubules together with kinesin in the regulation of physiological processes (Levi, 2020, 74).

This brings us to consciousness. What is quite remarkable is that Kant describes apperception (primitive self-awareness or self-consciousness; see Hanna and Thompson 2013) in quite similar terms as the products of nature, namely as being spontaneously produced from the underlying noumenal reality. Robert Peppin (1987) shows that Kant attributes its spontaneity to apperception having its origins in the noumenal self situated in the noumenal realm. Kant for example says that

> The soul in transcendental apperception is *substantia noumenon*, hence it has no permanence in time, since this belongs only to objects in space."
> (Reflexion, 6001, AA, vol. XVIII, 420-1)

In this way Kant ascribes the spontaneity that characterizes apperceiving as having its origin in the noumenal self (soul). It has been suggested that in this Kant contravenes his view on Noumenal Ignorance, but this is not necessarily the case as one can regard Kant's ascription of spontaneity to the noumenal realm not as constituting any real knowledge but simply the only possible way that he was able to accommodate spontaneity within his philosophy (see Peppin, 1987, 272).

The Kantian idea of spontaneous mental activities has also been reworked in contemporary philosophical models of consciousness, such as the Essential Embodiment Theory of Robert Hanna and Michelle Maiese (2009), who view such activities as characterizing complex dynamic living organisms, steering clear of both dualism and materialism. In Essential Embodiment Theory the mind is taken as deeply and inextricably interwoven as well as emergent from an interactive system consisting of brain, body and world.

In accordance with Kant's conception of a spontaneous consciousness (and my identifying his spontaneous potentiality with the quantum potential), theories of consciousness using Bohmian theory have indeed been proposed. In one case, the well-known model of Roger Penrose and Stuart Hameroff is fused with Bohm's metaphysical concepts to develop a Bohm-Penrose-Hameroff model for consciousness and free will (Gallego, 2011).

A mathematical model in which the de Broglie-Bohm wave mechanics is extended to explain macro-quantum phenomena is proposed by R. R. Poznanski et al. (2018) in a paper titled Spontaneous Potentiality as Formative Cause of Thermo-quantum Consciousness. They show that macroscopic quantum coherent states (associated with consciousness) can exist in the brain when the thermo-quantum fluctuations of dipole-bound electron oscillations go through their phase differences, "guided" by the macro-quantum potential energy through "long-range" correlations of phase differences:

> It is the spontaneous phase differences of dipolar-bound electron oscillations that govern 'long-range order' (i.e., high degree of coherence), leading to stability and unitary binding of consciousness. (Poznanski et al, 2018, 372)

The important role of information within quantum potentials is emphasized by David Bohm and his co-worker Basil Haley. They introduced the idea of "active information" to account for the properties of the quantum potential (Bohm and Hiley, 1993). For many-body systems, the self-organization at the heart of the quantum process involves a non-local correlation of the motion of all the bodies in the entangled state, which are all being simultaneously organized by a collective field, implying that they have access to "a common pool of information encoded in the entangled wave function" (Hiley, 1999). When some of these states/packets collapse, they "transport" the information to other states/packets which means that the information is conserved by the quantum potential. This explains how information is conserved and stored in consciousness and memory.

An interesting feature of critical metaphysics is that the "wholes" embedded in the supersensible ground of nature which underlies the self-organizational processes that give form to biological formations correlate with the human noumenon (soul), which implies that the human noumenon is simply a more complex and sophisticated "whole" that evolved in nature. When it comes to consciousness, lower order biological organisms thus share this feature even though that of humans reaches the more advanced level of self-awareness (apperception).

It may be asked what happens to the information encoded in consciousness when biological organisms die. In quantum physics information is regarded as being conserved but that need not imply that the "wholes" (taken as ensembles of quantum potentials closely integrated with their bodies) continue to be preserved as *single united entities* apart from bodies. For humans, however, an ancient view found all over the world (also in Platonic philosophy) insists that the soul survives death as an immortal entity. Is it plausible that this possibility can be established in science?

When the link between the soul and apperception in critical metaphysics is taken as point of departure, it may be suggested that the coherent, complex and integrated nature of the information stored in the framework of human self-consciousness in the brain (serving as the guiding operative for the collective human ensemble of quantum potentials in the body), can provide it with a permanence that lower order beings lack. This agrees to some extent with a proposal made by Stuart Hameroff (2012), namely "[When] the patient dies, it is possible that this quantum information can exist outside the body, perhaps indefinitely, as the soul". Even though this proposal takes us beyond the reach of current science, this is to be expected. In the words of Roger Penrose (2022):

> [Consciousness] must be beyond computable physics… a theory that we do not know yet.

The Kantian ontological distinction between nature and the noumenal realm may again be relevant in this regard. As for the noumenal realm, it can be proposed that Bohm's idea of a non-local (beyond space-time) and thus unobservable "quantum field" consisting of a universal network of quantum potentials intersecting with each other (and forming the implicate order), provides for an underlying manifold enabling existence in an invisible world to which souls and other spiritual beings might belong. This invisible world stands in contrast with but not entirely apart from our space-time manifold in which all material things and beings exist.

Such a view is very similar to the Platonic conception of a realm of forms in which souls exist (*Phaedo,* 78b-79) that stands in contrast with the world of becoming and material existence, with the realm of forms also later on in the *Timaeus* serving as the substratum of nature. Both these worlds thus belong to one cosmos.

Conclusion

In this paper the role of spontaneity in our understanding of the world is taken under consideration, since the time when Immanuel Kant first included absolute spontaneity in his critical metaphysics and also after its discovery in nature in the form of quantum spontaneity. On the one hand I give an overview of the way that spontaneity is included in the formulation of quantum physics, from Niels Bohr's quantum postulate (and his epistemological approach) to David Bohm's quantum potential (and his ontological approach). On the other hand, I engage with Kant's critical metaphysics in search for clues as to how quantum physics need to be interpreted within the broader framework of our understanding of the workings of nature.

I then use critical metaphysics together with our current understanding of science to make some proposals with regard to the problems plaguing our best theories, including the problem of reconciling quantum field theory with general relativity and those concerning the essence of consciousness. The state of our current knowledge makes proposals possible that would have been impossible a few years ago, proposals that align with Kantian metaphysics. In the final instance, I think it is reasonable, on this anniversary of Kant's birthday, to come to the conclusion that his critical metaphysics is remarkably encompassing, relevant and accurate in the light of our current knowledge of science. As such it may be expected that other aspects of his metaphysics which are not yet within the reach of science, will also in the progress of science turn out to be correct.

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