Constituting Objectivity

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Constituting Objectivity

Transcendental Perspectives on Modern Physics

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Introduction

Michel Bitbol, Pierre Kerszberg, and Jean Petitot

An appropriate starting point for this introduction consists in providing the reader with a short definition of the adjectives "transcendent" and "transcendental". All too often, these adjectives are mixed up (especially in the English-speaking philosophical tradition), and this leads to many misunderstandings. In a book entirely devoted to transcendental epistemology and its applications to physics, such misunderstandings could easily blur how each idea is perceived. This is why we must try to avoid them from the outset.

"Transcendent" and "transcendental" somehow point towards opposite directions. True, both words share a common component of meaning, which is "exceeding experience". But "exceeding" can be achieved in two antithetical ways. A transcendent *object* exceeds experience insofar as it allegedly exists *beyond* experience, as a remote (and intellectually reconstructed) external cause of experienced phenomena. By contrast, a transcendental structure exceeds experience because it is a *background precondition* of experience. Since transcendental structures concern the methods of access to experience, they have been thought of as pertaining to the *subject* of this experience by the classical tradition. But the latter notion of subject has nothing to do with psychology; it can rather be construed as a precursor of the cognitive notion of "access consciousness" in the sense of Ned Block. So, a transcendent object is supposed to wait for us "out there", and is indifferent to our intervention. By contrast, transcendental preconditions prescribe rules of active definition and selection of phenomena in such a way that one may consider them *as if* they were appearances of an object. This is the difference between merely believing in the existence of objects, and being aware of the procedure through which we *constitute* them. This also accounts for the difference between an ordinary and a critical definition of objectivity: objectivity in the first sense refers to that which possesses transcendent being; whereas objectivity in the second sense refers to what can be *made* valid for any one of us, independently of our situation, but *not independently of the fact of being situated*.

Kant was the primary source of the distinction we have just stressed between "transcendent" and "transcendental". The contrast develops thus:

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> (…) As soon as we posit the unconditioned (…) in what is entirely outside the world of sense and hence outside all possible experience, the ideas become *transcendent*".[1]
> "I call *transcendental* all cognition that deals not so much with objects as rather with our way of cognizing objects in general insofar as that way of cognizing is to be possible *a priori*.[2]

Despite this clear distinction, Kant's own use of the word "transcendental" is sometimes misleading. This is the case when he writes e.g. the expression "transcendental realism", which could roughly be interpreted as "transcendent realism". The reason why he still uses the word "transcendental" instead of "transcendent" in this context is that he wishes to make a distinction between two misuses of our intelligence. The fist misuse consists in extrapolating the application of the principles or categories of pure understanding (a major component of the transcendental preconditions of knowledge) beyond the limits of possible experience; it gives rise to what Kant calls "transcendental illusion". The second misuse consists in manipulating entirely new speculative principles "(…) requiring us to tear down all these boundary posts"[3]; it gives rise to the representation of fake transcendent realms.

To recapitulate, "transcendent" connotes an attempt at breaking up the limits of experience, whereas "transcendental" refers to a reflective move in which one examines the (subjective) conditions of possibility of this experience. "Transcendent" points towards the farthest, whereas "transcendental" brings us back to the closest (which is usually inapparent due to its being too close). Accordingly, elaborating a transcendental epistemology of physics does not mean looking for hidden entities beyond empirical knowledge, but rather undertaking a reflective research about the indispensible preconditions of our knowledge and their relevance to the structure of physical theories.

1 Bringing Transcendental Epistemology Back to Life

As indicated in the title, this book concerns transcendental approaches of *modern* physics. This may seem surprising as it has become commonplace to assume that transcendentalism has been invalidated by the successive developments of physics after Newton. Most philosophers of science think that "transcendental" and "modern physics" are two terms which have long since become incompatible. Their idea is

[1] I. Kant, *Critique of Pure Reason*, B 593, in: *The Cambridge Edition of the Works of Immanuel Kant*, Cambridge: Cambridge University Press, 1999.
[2] I. Kant, *Critique of Pure Reason*, B 25, in: *The Cambridge Edition of the Works of Immanuel Kant*, op. cit.
[3] I. Kant, *Critique of Pure Reason*, B 352–353, in: *The Cambridge Edition of the Works of Immanuel Kant*, op. cit.

that the limits of Kant's philosophy of science indicate the limits of critical philosophy. One may counter this strong prejudice by mentioning three points.

(i) As indicated by the title, the central problem of this book is the *constitution of objectivity*.
(ii) Transcendental approaches therefore intervene as a general philosophy of constitution, not as a special inventory of fixed mental «faculties».
(iii) There is no reason which prevents us from thinking that, in this respect, transcendentalism can be generalized far beyond its kantian version, even if updating it means distancing oneself from a literal reading of Kant. Kant initiated an approach which has many more resources than those he himself developed.

In the same way as the original version of empiricism which came about during the Scottish enlightenment has been generalized and deepened to a considerable extent, well beyond what its founders had envisaged, by modern epistemologies such as the logical empiricism of the Vienna circle or Bas van Fraassen's constructive empiricism, the original version of transcendentalism formulated by critical rationalism can also be generalized and deepened to a considerable extent, well beyond what its founder was able to imagine. True, according to some researchers, this distancing strategy distorts the Kantian perspective so much that it no long deserves the name "transcendental". This pushed them to espouse the advances of physics against a philosophy which nevertheless offers the best epistemology of classical mechanics. But, as this book aims to show, adapting transcendentalism is much more fruitful than rejecting it; and such an adaptation turns out to be very faithful to its Kantian sources, in its spirit and even sometimes in its letter.

As it is well known, the transcendental question arises as soon as one realizes that the central and specific epistemological problem of physics is that of *mathematical* physics. Indeed, fundamental equations are able to generate myriads of precise mathematical models of the variety of observable phenomena, out of universal principles and general concepts. One can express this by saying that these models realize a "computational synthesis" of phenomena. This is a modern form of what Kant called "mathematical construction", when he pointed out in his time (see *Prolegomena*, AK, IV, 272) that Hume empiricism tended to underrate the problem of mathematics.

Actually, there exists a radical contrast between conceptual abstraction (which is a subject for an Analytic) and computational synthesis; a contrast that can be seen as regarding the difference between a direct problem and a *reverse problem*. The direct problem consists in abstracting from the manifold of intuition; it consists in "subordinating" this manifold to what Kant called "the unity of a concept" and what we would call today a categorizing concept. By contrast, the reverse problem consists in *constructing* the referents of concepts by transforming conceptual contents into algorithms for computing these referents. The reverse problem starts from concepts and points towards the manifold of intuition, not the other way around. Mathematics, helped today by methods of numerical simulation, are the essential tool of computational synthesis.

The mere fact that physics involves a computational synthesis of observable phenomena means that physical objectivity cannot be tantamount to an ontology of some independent substantial reality. Indeed, the possibility of a mathematical reconstruction of such an *ontological reality* would ascribe the human mind excessive intellectual capacities which transcend its finiteness. This leaves only two options:

(a) Physics is purely descriptive. It conceptually organizes the empirical manifold by means of an Analytic, and it can thereby pretend it describes an ontological independent reality, but without reconstructing this reality mathematically and without doing any job other than picturing it passively (empiricism + nominalism).
(b) Physics can reconstruct the empirical manifold mathematically, and it must then accept to partake of a "weak" form of objectivity which *de jure* can only concern relations between observable phenomena, namely a reality filtered by ineliminable conditions of experimental or sensory *accessibility*, and by intellectual criteria of selection. The condition of possibility of computational synthesis is the principle of restriction of physical knowledge to laws of observables, and the decoupling between a "strong" ontology and a "weak" objectivity.

The general assumption of this book is that modern physics is dominated by the second attitude, and that it raises an increasing number of questions on the processes of constitution of objects connected with the mathematization of observable data. In our opinion, the term "transcendental" essentially refers to that concern. The use of this term is still justified insofar as it can be shown (see Section 3 of this introduction) that appropriate extensions of Kant's transcendentalism push most of the apparently definitive criticisms which had been formulated against it in the name of the "revolutions" represented by General Relativity and Quantum Mechanics to obsolescence.

This introduction is not the right place to develop the basis of the physical transcendentalism which generalizes Kant's analysis of newtonian mechanics in the *Metaphysische Anfangsgründe der Naturwissenschaft (Metaphysical Foundations of Natural Science, abbrevieted by MFNS*, Kant, 1786). Yet, it is useful to think of it as a generic model for other transcendental readings of mathematical physics. We will therefore outline it by enumerating the following points:

1. Mathematical physics is an objective theory of *observable phenomena*. The conditions of observability are therefore constitutive of the very concept of a physical object. Since the concept of a phenomenon is relational, namely relative to structures of accessibility, to conditions of observations and to measurement results, physical objectivity cannot *de jure* bear on an independent reality. Due to its principle of reduction to observable phenomena, physical objectivity cannot, here again, be an ontology but only a "weak" objectivity.
2. Although it is non-ontological, physical objectivity is not naively subjective-relative either. This is due to the fact that it consists in an act of universal legalization of

phenomena. It expresses a prescriptive law-like order which imposes a norm onto any description of phenomena.

3. Prescribing a law-like order imposes using an apparently paradoxical procedure. This procedure must indeed take the conditions of accessibility to observables into account, but without including the theory of instruments of observation into the theory of physical objects.
4. The categories and principles of physical objectivity - "system", "state", "property", "causality", "interaction", etc. – must then be interpreted mathematically according to the former points. They are not ontological categories, they are prescriptive rather than descriptive, and they incorporate their conditions of accessibility.

In classical mechanics as interpreted by Kant in *MFNS*, point (1) is expressed by the reduction of the scope of physics to sensory phenomena, point (2) is expressed by the Analytic of concepts, point (3) is expressed by the transcendental Aesthetic which explains why mechanics consists of a differential geometry of motions in space–time, and point (4) is expressed by the procedure of schematism, or the construction of categories. But there is no reason to restrict this transcendental analysis to classical mechanics. In quantum mechanics, for instance, one can consider that: point (1) is expressed by Heisenberg's reduction to observables, point (2) remains a transcendental Analytic, but with some alterations, point (3) corresponds to probability amplitudes and operator algebras in Hilbert spaces of states, and point (4) is a reinterpretation of the categorial Analytic in this new framework.

In his *MFNS*, Kant then exposes the following features of classical mechanics, by using a one–one correspondence with his table of categories as described in the *Critique of Pure Reason*:

(i) *Phoronomy (Kinematics)*. The measurement of the phenomena of motion is derived from the metric of space–time. In other terms, space as a form of presentation and manifestation of phenomena (conditions of observability = forms of intuition) becomes geometry (what Kant calls "formal intuition") in the context of physics. Kant discovered that Euclidean space is a background structure for mechanics and that, due to Galilean relativity, this Euclidean structure cannot be dissociated from the principle of inertia (more about this later). The symmetry group of Galilean relativity is therefore expressed philosophically by the transcendental ideality of space. Thus, in his book about Kant's conception of physics, Jules Vuillemin insists on the phoronomic meaning of the transcendental ideality of space: "It is the principle of phoronomy which offers the true demonstration of transcendental aesthetic (…). It is the relativity of motion which makes the subjectivity of space [its transcendental ideality] transcendentally necessary".[4] Kant was the first philosopher who identified – as soon as 1758 with his *New Theory of Motion and Rest … (Neuer Lehrbegriff der Bewegung und Ruhe…)*, and in 1768 with his *Ultimate Foundation of the*

[4] J. Vuillemin, *Physique et Métaphysique kantiennes*, Presses Universitaires de France, 1955, pp. 59–60.

Distinction of the Directions in Space (Von dem ersten Grunde des Unterschiedes der Gegenden im Raume) – the philosophical consequences of the fact that symmetries of space (e.g. chirality) which are irreducibly "non conceptual" exist.

(ii) *Dynamics*. Motion is described by means of intensive magnitudes, such as velocities and accelerations (i.e. "moments"). Therefore, mechanics is *a priori* a differential geometry, and the differential descriptions must be compatible with phoronomic relativity: this is an outline of the concept of covariance. J. Vuillemin also insists on this, and draws a major philosophical conclusion: "that dynamics presupposes phoronomy means the possibility of a Copernican revolution about the concept of substance, a revolution which is likely to be at the heart of Kant's idealism".[5]

(iii) *Mechanics*. By way of temporal schematism which defines it as a principle of permanence, the category of substance is the source of any principle of conservation of physical magnitudes, namely of physical principles of invariance (conservation of energy, momentum, etc.). Besides, causality is expressed by forces.

(iv) *Phenomenology*. Galileo's principle of relativity stems from the fact that absolute motion cannot be an object of experience. In kinematics, this means that the state of motion cannot be a *real* predicate, but only a *possible* predicate. It cannot be interpreted as a real transformation of the real internal state of the system, and of some of its properties taken as intrinsic mechanical properties. Hence, one can both assert and negate motion without any contradiction. In other terms, the relativity of motion invalidates the spontaneous ontological interpretation of statements such as "the body S *has* such and such position and velocity" in terms of a verb "to have" which would mean "to possess (a property)". Neither a spatial or temporal absolute position, nor the absolute velocity (of a uniform motion in straight line) are observable. Dynamics however affords criteria of reality of motion, since forces are real predicates. This reality is ruled by laws of mechanics which are *necessary*. Here, necessity is not to be understood from the standpoint of logic, but from a transcendental standpoint: it is a conditional necessity, relative to the radical contingency of experience.

Another important feature of Kant's approach is the "construction" of categories, when they are applied to a regional object such as motion. It is well-known that, in the *Critique of Pure Reason*, there is a difference between the so-called "mathematical" and "dynamical" categories. Unlike "mathematical" categories (which, by schematization, give rise to the "axioms of intuition" and to the "anticipations of perception" in the *Analytic of Principles*), "dynamical" categories (such as the categories of relation which, by schematization, give rise to the "analogies of experience") *posit* existence and *condition* it, while leaving it *undetermined*. This means that they are *not* constructible. Since they only apply to the object in the most general sense, they are "mere forms of thought", and are therefore only schematizable. But they become "constructible" – and thereby acquire "objective reality", "meaning", and "truth" – when they are applied to an "an additional determination", such as motion, which

[5] J. Vuillemin, *Physique et Métaphysique kantiennes*, op. cit., p. 87.

"contains a pure intuition". This is a crucial point to understand the relation between the *Critique of Pure Reason* and the *MFNS*, between a transcendental theory of knowledge and a transcendental approach of physics.

To sum it up, Kant was the first thinker who developed the heart of modern physics constituted by the correlation between: *relativity, symmetry, covariance, invariance, and conservation* as a philosophical theme. It is precisely this correlation that has been generalized, diversified and deepened in fundamental modern physics (see Section 4 of this Introduction). It is therefore astonishing to see that a philosophy such as transcendental philosophy, which is so relevant to the essence of mathematical physics, has been rejected instead of being steadily improved along with the advances of science.

2 Various Interpretations of Kant's Project for Constituting Objectivity: A Short Historical Outline

We will now briefly focus our attention on the history of Transcendentalism after Kant. This will help us to realize that appropriate generalizations of Transcendentalism were hindered by a combination of over-speculative interpretations and rigidly Kantian interpretations. This unfortunately led to the adoption of other epistemological traditions which were not as well adapted to the essence of mathematical physics as transcendentalism. But, at the same time, this history shows that another path could have been followed. The carefully scientific and flexible version of Transcendentalism advocated by the various neo-Kantian schools of the turn of the nineteenth and twentieth century was a good starting point for this alternative way.

But let's first come back to our basic question. We have just seen that, as many authors from Hermann Cohen to Michael Friedman pointed out, it was his remarkable vision of the scientific theories of his time that enabled Kant to form the project of transcendental philosophy. If contemporary science rejects these theories, is transcendental philosophy bound to collapse as well? One common idea is that the historical limits of Kant's philosophy of science indicate the limits of critical philosophy altogether. The consensus until now has basically been that Kant might have been right in claiming that rules exist ahead of experience, but he was faulty inasmuch as he seems to have believed that some rules are *definitive* as they reflect immutable structures of human reason. A short (and therefore incomplete) outline of the historical development that led to the sciences being disentangled from a Kantian *foundation* will now help us understand why and how some kind of rapprochement between the sciences and Kant's general project can be obtained.

Let us first highlight some of the limitations of Kant's system. Natural science and the theory of knowledge are closely interrelated in Kant. Whereas modern science has progressively disconnected the perceptual object from the scientific object, the whole of Kant's original version of critical philosophy seems to be bound to some fixed balance between perception and cognition. Kant then brought together: (i) a statically conceived metaphysics of nature and (ii) an advance in empirical knowledge of nature, which is in principle endless. As a result, Kant could not give us the means to fully apprehend knowledge in its historical development. He perfectly accepted the idea of a historical evolution of the empirical content of science, but not an alteration of principles. Accordingly, many features of science are missing in his system. He did not make room for leibnizian principles of least action from which Lagrangian formalisms are derived. In his mechanics, Kant also lacks the concept of Work, which is why his epistemology cannot be applied to thermodynamics. Besides, Kant's laws of nature are related to dynamics, and it would appear that they have no bearing on statistical laws. As a result, the allegedly immutable system of categories turns out to be both narrow and false.

This is precisely the challenge Kant faces today: How can we preserve the ideal of unity of knowledge, without ignoring the widening gap between common and scientific experience? Is there a way of vindicating Kant's theories despite the fact that in the present state of physics the *a priori* (normative component of knowledge) is virtually impossible to separate from the empirical?

But this task took time to even be defined as such. The initial phase in Kant's reception was operated by the idealistic movement. Fichte was the first author to emphasize the need for the primacy of practical reason over theoretical reason in his philosophy, and to assert that this reversal made the completion of Kant's system possible. This strategy culminated in German Idealism, particularly through Hegel who argued for a totalizing view of knowledge which includes comprehensive concepts of natural and historical processes. But Kant's views were also supported and reinterpreted by the pioneers of *Naturphilosophie* in Germany. Since mechanistic materialism was commonly taken as a necessary consequence of classical mechanics and mathematical physics in general, there was a search for alternative sorts of natural science which would in turn offer a vindication of the anti-materialist concepts of natural philosophy. Kant's *Critique of Pure Reason* was thus interpreted as opening up the possibility of divorcing classical mechanics from materialistic dogmatism for the first time. As for the *Critique of Judgment*, with its reflection about aesthetics and about teleology in biology, it provided resources for an anti-mechanistic conception of nature influenced not only by physics but also by biology. From Kant's description of the formal *a priori* background of knowledge there arose, as a result of the objective turn which Schelling gives to the Fichtean notion of intellectual intuition, a new metaphysics of nature. The subjective formal *a priori* was converted into a formative power at work in nature. The power of understanding was replaced with a creative force shaping organic development.

After the demise of this metaphysical natural philosophy (which took place around 1830), when this speculation could no longer be taken seriously from the scientific point of view, the fundamental tendency in science can be described as one of partial unification of theories and methods combined with a simultaneous explosion of experimental knowledge. To be sure, the mere idea of a completely unified natural science was unimaginable at the time. But the adventure of metaphysical natural philosophy left its traces: mechanism, as a total explanation of nature, became either a mere program or a philosophical dogma. The theories of heat, optics, magnetism, and electricity were largely independent divisions of physics, with a remote perspective of a unified mechanical interpretation and a more immediate urge for partial unification under appropriate principles. Most of the important innovations then arose as the result of a project of integration of these separate branches of physics; a project in which one can still feel the influence of Kant's philosophical impulse. For instance, the integration of magnetic and electrical phenomena by Oersted was motivated by the application of Kant's metaphysical claim concerning the duality and interaction of two fundamental forces (attraction and repulsion) to physics. This led to the theory of electromagnetism, which Faraday connected to mechanics, and Maxwell and Hertz to optics. The project of innovative integration transcended the limits of physics itself, also affecting chemistry and other disciplines; something that Kant had anticipated in his later *Opus Postumum*.

After Hegel, Schopenhauer rediscovered Kant's need for distinction between phenomena and things in themselves. Accordingly, the vindication of Kant in the second half of the nineteenth century concerned his epistemological contribution as expressed in the *Critique of Pure Reason*, rather than his *Metaphysical Principles of Natural Science*. However, even Kant's epistemology was subjected to intense scrutiny. After all, the key notion for post-idealist, anti-metaphysical philosophy in the nineteenth century was inductivism. From an inductivist standpoint, the Kantian *a priori*, along with all concepts, laws and theories, was conceived as nothing more than the result of empirical generalization. Thus, according to Helmholtz, the point at which natural science and metaphysics come into contact with each other is the theory of human sense-perception. Helmholtz therefore presented the results of enquiry into the physiology of perception in such a way that they fitted perfectly with transcendental philosophy. Science could now be seen as an open system of knowledge: a totality which is constantly growing and changing as a result of experience, so that science as a system of true judgments about the world is projected in the future; instead of delivering truth *via* fixed categories and intuitions, science is understood as a gradual approximation of truth. This is perfectly expressed in the view that came to be called a descriptivist or phenomenological view of natural science. The exclusion of metaphysics compelled physics to confine itself strictly to what is given, and what is given are phenomena. Concepts of substance or force were accordingly eliminated from science (Wundt, Hertz).

According to this view (in good agreement with the spirit of Kant's epistemology), the only concepts which should be used are those which make it possible to express functional connections between phenomena, so that the search for an underlying ontology is abandoned in favor of increasingly abstract mathematical representations of observables. Boltzmann, who supported this view to a certain extent, was convinced that the laws of thought arose by internal ideas' being applied to actually existing objects, so that the existing laws of thought are inherited habits in a Darwinian sense. Current evolutionary epistemology considerably developed this approach. In it, the transcendental basis of knowledge is entirely re-interpreted in terms of the biological preconditions of experience. And the *a priori* is construed as the byproduct of an experience of the human species that became innate in the individual. This is a short step to abandoning the Kantian *a priori* as precondition of experience, since considering the *a priori* as an "organ" (something that resulted from phylogenetic adaptation to the experienced external world) destroys the very concept of the *a priori* in Kant's original sense, namely as a *precondition* of experience. This is also not very easy to reconcile with several of Kant's explicit statements (especially in his *Response to Eberhard)*, according to which *a priori* does not mean "innate".[6] However, those who defend a Darwinian and naturalized conception of transcendental philosophy can still rely on the fact that, even though Kant insists that *a priori* forms themselves are "originally acquired", and therefore not innate, he also considers that the *foundation* of this cognitive process of original acquisition is itself innate.

But it should now be borne in mind that there is more to Kant than his strictly critical system. For instance, the pre-critical *Universal Natural History and Theory of the Heavens* was the first coherent cosmogonical model compatible with suitably revised basic tenets of Newtonian mechanics. This theory can be seen today as pioneering the kind of evolutionary models in natural science, which became fashionable long before Darwin.

The physiological and Darwinian interpretation of Kant's intuitions and categories was countered by neo-Kantianism, even though historicizing the *a priori* seemed from now on to be an inescapable route for any plausible revival of transcendental philosophy. At the turn of the twentieth century, Neo-Kantianism was the most important philosophical movement which developed in the intellectual climate of positivism. Its aim was to forge a new philosophy as an exact science, on the basis of the principles of Kant's theory of knowledge. The central argument was that the essential aim of transcendental philosophy is to identify the fundamental methods and concepts of natural science. Hermann Cohen, who founded the Marburg School (later developed by Natorp and Cassirer), substituted a strictly logical conception of the Kantian program for the physiological interpretation inherited from Helmholtz. Here, intuition must be understood as a source of knowledge rather than as a psychological faculty implemented on a physiological substrate. Insofar as critical philosophy restricts philosophical reflection to the conditions of possibility of *science*, the fall into the psychological or physiological interpretation of the categories is completely avoided. After all, the function of the transcendental subject is to provide the necessary conditions without which "nature", *including the part of nature referred to by the physiological reading of Kant*, means nothing at all. However, the Marburg School replaced Kant's original "static" or timeless version of the synthetic *a priori* with what they perceived as an essentially developmental or "genetic" conception of scientific knowledge. The crucial point is that, in this case, development is represented by the ongoing history of science rather than the past history of our species.

The most famous representative of the Marburg school was Cassirer, who developed his early thesis about the relational-functional character of scientific laws in the

[6] H. Allison, *Kant's Theory of Taste*, Cambridge: Cambridge University Press, 2001, p. 17, AK VIII 221

context of classical physics, and his conception of the functional and historicized *a priori* in light of the then recent developments of the theory of Relativity (see Section 3 of this introduction). Cassirer argued that the genetic process of science is such that general laws at an earlier stage, are exhibited as approximate special cases of the still more general laws at a later stage, one obvious example being the road from Newton to Einstein. This being granted, many features of scientific theories that claim to be representations of things "out there" are reinterpreted as mere tools for this open task of generalization. For instance, non-Euclidean geometry as it intervenes in General Relativity does not express the nature of things themselves, but rather the laws and relations appropriate to a given stage of the systematic organization of science. One should not, says Cassirer, speculate about the *being* of space, but rather inquire into how scientists *use* geometrical structures.

Cassirer also retained from Kant that the meaning of a concept is not tantamount to a mere abstraction out of the variety of its applications; the meaning of a concept must rather be identified ahead of application. Hence the idea, developed by some successors of Cassirer (e.g. G. Buchdahl), that Kant's theories can be salvaged if the locus of the transcendental is not the constitutive dimension of the categories of understanding, but the regulative ideas of reason. In this case, the value of transcendental philosophy has shifted from the laws to the organization of these laws. This was a good way to *go beyond Kant while grounding the move on Kantian premises*, according to Cassirer's famous slogan.

The theme of the flexibility of *a priori* forms, on which the neo-Kantian Marburg school insisted so strongly, was developed in many other ways outside this school. Perhaps the most extreme (yet a-historical) way of advocating flexibility while preserving the basics of Kant's philosophy in light of contemporary mathematics and natural science, was advocated by Poincaré. Poincaré considered that: (i) the idea of a system of fixed categories as a foundation of natural science contradicts the history of natural science; (ii) a conventional (free) choice in the determinations of space and time have to supersede space and time as *a priori* forms of sensibility. In spite of this radical criticism of Kant's foundationalism, Poincaré still perceived his own epistemology as Kantian. Indeed, he merely shifted Kant's issue concerning the synthesis of the objects of knowledge to the problem of whether objective *relations* between objects can be described in terms of subjective capacities (including the visual, tactile and motor faculties that, according to him, underly our notion of space). He also thought that a generalization of Kant's theory of space to spaces of constant curvature is possible provided one replaces Euclid's axioms with a more general principle: the principle of free mobility allowing for the arbitrary continuous motion of rigid bodies.

In another investigation of the structure and function of natural science, Kant's transcendentalism was confronted with history even more brutally than in neo-Kantianism. According to E. Meyerson, stronger than the rational demand for lawfulness, is the demand for *identity*. The development of modern natural science, he says, reflects a perpetual dialectical opposition between: (i) the mind's *a priori* demand for substantiality, and thus absolute identity through time, and (ii) nature's irrational *a posteriori* resistance to such a demand. Interesting developments can be derived from this remark. Indeed, identity is more precisely instantiated by the concept of *invariance*, which is highly relevant for the symmetry groups that have played an increasingly prominent role in contemporary physics (e.g. the Lorentz group in special relativity). In agreement with his neo-Kantian conception of science, Cassirer argued that group theory does not represent “reality”, but is an instrument endowed with transcendental function, insofar as it provides the active link between the demands of the knowing subject and the definition of its object. By and large, invariance posits a new concept of objectivity disconnected from any ontological claim. Here, an object (or a class of objects) of a theory is specified as nothing else and nothing more than a bundle of invariant features.

3 Constituting Objectivity in Relativity and Quantum Physics

The accusation according to which Kant’s epistemology had become irrelevant to modern physics, was developed in intricate details as a reaction to the relativistic and quantum revolutions. Hence the need for a more detailed study of the role of these two theories in the debate about the possibility of a renewed transcendental approach.

To begin with, Relativity seemed to discard Kant’s *Transcendental Aesthetic* with its doctrine of space as an intuitive *a priori* form. Einstein stressed that, in view of the newly established status of non-euclidean geometry in the theory of gravitation, Kant’s thesis that a three-dimensional euclidean space is an *a priori* form of the human faculty of knowledge must be wrong. In Einstein’s own words, «Unlike one is ready to declare that relativity theory is averse to reason, one cannot stick any longer to Kant’s system of *a priori* concepts and norms».[7]

Similarly, quantum mechanics seemed to discard Kant’s *Transcendental Analytic*, with its doctrine of substance and causality as categories, namely as conceptual *a priori*. Heisenberg was especially instrumental in denouncing both concepts as inapplicable to the quantum domain. He first claimed, in his *uncertainty relations* paper of 1927, that «quantum mechanics establishes the final failure of causality». Later, in 1929, Heisenberg became both more nuanced and more accurate. He no longer claimed that there was no room for causality in quantum physics. He rather pointed out that applying the law of causality and locating phenomena in space–time were *complementary* approaches, namely approaches that mutually *exclude* each other. But if causal laws cannot apply to spatio-temporal phenomena, Kant’s theory of knowledge is no longer valid, since his crucial category of causality has no other legitimate domain than appearances in space–time. In his book *Physics and philosophy*, of 1958, Heisenberg then explicitly stated that «Kant’s arguments for the *a priori* character of the law of causality no longer apply».[8]

Yet, at the same time as Kant’s conception of knowledge was thus challenged, several neo-kantian philosophers found many reasons in modern physics to not

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[7] A. Einstein, *Oeuvres choisies, 5*, Seuil, 1991, p. 221.
[8] W. Heisenberg, *Physics and philosophy*, Penguin, 1990, p. 78.

only stick to the basic ideas of transcendental epistemology as formulated by Kant, but to generalize and even to amplify them. The central motivation of this return to Kant was that both relativistic and quantum theories reactualized the basic move of the so-called «Copernican revolution». In both theories, one could no longer focus exclusively on a description of objects, but had to seriously consider the cognitive, or at least instrumental, pre-conditions of this description. In other terms, a reflective attitude, that is typical of transcendental epistemology, was required.

In the theory of relativity, Ernst Cassirer thus noticed that one must: (i) investigate how measurements of length and duration are obtained and coordinated, and (ii) formulate a systematic method of extracting invariants from them.

In quantum mechanics as understood by Bohr, the conclusion to be drawn was even more general. Here, considerations about *contextuality*, about how any micro-phenomenon whatsoever is both relative to and indissociable from an experimental context, are central. Grete Hermann, a German philosopher who had extensive discussions with Heisenberg in 1934, concluded that not only had Kant's philosophy not been refuted by quantum mechanics, it had also been made more *indispensible* and pushed to its most radical consequence in the new physics.

So, at this point, we must list and discuss some strategies for promoting the essential ideas of Kant's theory of knowledge, without sticking to the historical features of the doctrine that were clearly made obsolete by relativistic and quantum theories. We believe that there are essentially three such strategies.

1. The first strategy consists in restricting the validity of Kant's original synthetic *a priori* to the direct environment of mankind, in which classical physics remain a good approximation.
2. The second strategy amounts to formulating new pre-conditions of knowledge that are general enough to encompass the extended domains of phenomena which are accounted for by modern physical theories and, hopefully, any future physical theory as well.
3. Finally, the third strategy consists in «relativizing» the *a priori*, namely making it relative to a certain situation of science that can change from one step to another of its history.

Restricting the domain of validity of Kant's forms of intuition and categories is what Einstein, Bohr and Heisenberg did almost spontaneously after they had formulated their revolutionary theories. All these authors expressed the idea that Kant's *a priori* forms remain unshakable anthropocentric foundations of physical knowledge.

Thus Einstein pointed out in 1921 that Riemannian geometry is grounded on the presupposition that there are rigid bodies which behave as if Euclidean geometry were *locally* valid. But he also warned against any reification of this local validity. As he wrote, "The concepts which proved useful in order to establish a certain order easily acquire for us such an authoritative status that we forget their earthly origin and that we come to construe them as immutable data".[9] So, according to Einstein,

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[9] A. Einstein, *Oeuvres choisies, 5*, Seuil, 1991, pp. 75, 226.

Kant's forms of intuition are nothing else and nothing more than local principles of order which act as minimal presuppositions for any further attempt at extending physics beyond the limited environment of mankind.

As for Bohr and Heisenberg, they promoted the same idea, but applied it to Kant's categories, especially substance and causality, rather than to the forms of intuition. According to both of them, the classical organization of macroscopic experience is a precondition for any further theoretical development, including Quantum Mechanics. But Kant's categories are clearly preconditions for this classical organization. These categories therefore work *de facto* as second-order anthropocentric presuppositions of quantum mechanics, even though they cannot work as general first-order presuppositions that are directly applied to microscopic phenomena. Heisenberg thus remarked that: "What Kant had not foreseen was that these *a priori* concepts can be the conditions for science and at the same time have a limited range of applicability".[10]

Accepting that the constitutive role of the categories of the *Critique of Pure Reason* only applies to the meso-macroscopic domain looks like a partial renunciation of the Kantian project. Yet, one must not forget that Kant's philosophy has enough resources to *also* formulate constructive propositions on what does not directly fall under the joint rule of forms of intuition and categories of pure understanding. Let us take an example. Kant claimed that certain figures of non-euclidean geometry are impossible insofar as the possibility of *constructing* them in *intuitive* space is concerned. But he also accepted that "(…) there is no contradiction in the *concept* of a figure enclosed by two straight lines".[11] It can be inferred from this that Kant did not exclude using such concepts in order to fulfill the need of a systematic unity of the laws of physics according to what is prescribed by the power of judgment.[12]

This resource has recently been used to make sense of Quantum Mechanics in a strictly Kantian framework.[13] The approach here consists in understanding quantum theoretical structures, not as direct expressions of the constitutive function of categories, typical of the *Critique of Pure Reason*, but as a formal transcription of a project of unity of the system of nature, typical of the *Critique of Judgment*. Let us see how this can be done. We know that any prospect of conceptual unity appeared to be blocked in the period of edification of quantum theories, between 1900 and 1924, when one had to accept that using mutually exclusive representations such as the corpuscule and wave pictures, cannot be avoided. Some sort of unity was restored only when Bohr formulated his concept of "complementarity", according to which these two exclusive representations (i) are relative to different types of

[10] W. Heisenberg, *Physics and philosophy*, op. cit., p. 78.

[11] I. Kant, *Critique of Pure Reason*, A 220, Hackett, 1996, p. 284.

[12] S. Palmquist «Kant on Euclid: geometry in perspective», *Philosophia Mathematica II* 5:1/2, 88–113, 1990.

[13] H. Pringe, *Critique of the Quantum Power of Judgment: A Transcendental Foundation of Quantum Objectivity*, De Gruyter, 2007. See also in this volume: H. Pringe, «A transcendental view on correspondence and complementarity».

experimental devices and different types of correlative classical concepts, and (ii) jointly characterize "one and the same object". However, it must be realized that the hypothetical object towards which the two complementary representations are supposed to converge cannot be said to simultaneously *possess* the two corres-ponding properties. No *constituted* object can therefore be said to be "behind" the contextual phenomena. Bohr's "objects" are only *regulative* devices used as unifying *symbols*, with a merely "as if" causal role. In the same way as in Kant's *Critique of Judgment*, one must here use a purely «symbolic analogy», instead of the normal constitutive «analogy of experience» which would only be available for proper objects of intuition.[14]

But this attempt at finding resources in strict accordance with Kant's texts, including the *Critique of Judgment*, is by no means the only way of maintaining and developing the relevance of transcendental epistemology in modern physics. Let us then turn to the second available strategy, which consists in generalizing the synthetic *a priori*. Here, the hope is to succeed where Kant failed, namely finding some *really necessary* preconditions for *any* empirical knowledge at *any* time of history. Along with this perspective, the project aims to show that the basic structures of physical laws essentially express the structures of these very broad presuppositions. Demonstrating that, is what one may call 'giving a transcendental justification' of a physical theory. But these two aims are likely to be conflicting. Indeed, a set of preconditions general enough to be universal and perennial is likely to be so poor in content that very little of the law-like structures can be justified by it. While a reasonably large part of the law-like structure of Classical Mechanics could be transcendentally justified by Kant's preconditions, a much smaller part of any physical theory would be justified by truly general preconditions.

This strategy was especially advocated by C. F. von Weizsäcker,[15] in his most recent work. He formulated two central preconditions for any scientific knowledge, far more general than Kant's. The first precondition is that it must be possible to *discriminate* between at least two phenomena. The second precondition is that one must be able to distinguish between *potential* and *actual* phenomena, namely between future and past, between prediction and possession of information. Undoubtedly one can hardly conceive any item of scientific knowledge that does not rely on a possibility of discrimination and on the prospect of gaining information in the course of time. But, in view of these presuppositions' being so elementary, it is not surprising that Von Weizsäcker's project of deriving modern physics from them failed, except for some very broad features.

Let us then turn to the third strategy for giving transcendental epistemology new relevance in modern physics and recognizing its constitutive features: the strategy of relativized and historicized *a priori*.

Here are first some arguments in favor of the relativized *a priori*.

To begin with, it is clear that the relativized *a priori* is fully compatible with the two previous options. Bringing out specialized relative *a priori* structures does not

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[14] I. Kant, *Critique of Judgment*, section 59, Hackett, 1987, p. 227.

[15] C.F. Von Weizsäcker, *The structure of physics*, Heidelberg: Springer, 2006.

prevent one from extracting more universal preconditions. Indeed, the most general and poorest preconditions of empirical knowledge (such as Von Weizsäcker's) might easily be construed as invariants of the many special and richer preconditions for each region of experience. Furthermore, saying as Einstein, Bohr, and Heisenberg did, that the validity of Kant's forms of intuition and thought is restricted to our mesoscopic environment, can also be taken to mean that Kant's forms are relative to the range of rules and procedures taking place within this environment. They are preconditions for the most familiar region of experience. This being granted, Einstein's, Bohr's and Heisenberg's restriction can be taken by contrast as an incentive to identify new anticipative forms which are relevant to the new range of phenomena and procedures explored by microphysics.

Another point in favor of the relativized *a priori* is that, as we will now see, it is not too difficult to confute the accusation according to which it is empty, arbitrary, and amounts to little more than a restatement of basic scientific methodologies.

This accusation was first formulated by Einstein against Cassirer's reading of the theory of Relativity. According to Einstein, "One can always set up a system of *a priori* elements in such a way that it is not contradictory with a given physical system".[16] If this trend towards relativization is pushed to its ultimate consequences, Einstein concludes, one lands into little more than the hypothetico-deductive method. The only component of Kantianism which still seems to be retained at this point is a recognition of the spontaneity of reason, namely the fact that our reason always tends to anticipate phenomena with a set of constructive hypotheses. Transcendental methodology would then be reduced to Peirce's Abduction, or to Popper's conjecture of regularities.

So, if a transcendental epistemology is to retain any specificity at all, one must not push relativization to a point where it can no longer be distinguished from an ongoing dialectic of conjectures and tests. But is this possible? We think the answer is «yes»: this is indeed possible. There is a key difference between an *a priori* background and a mere conjecture. The difference bears on *necessity*. An *a priori* form is somehow necessary; not a conjecture. But of course, the concept of necessity must here be seriously qualified if we do not want to fall back into the absolute and eternal *a priori* forms of Kant.

Let us illustrate this idea of a qualified necessity with an example.

Hans Reichenbach was probably the first author who formulated, in 1920, the idea of a relativized *a priori* in direct response to modern physics (in his *Theory of relativity and a priori knowledge*). But according to him one must carefully separate: (1) the constitutive components, and (2) the apodictic (or necessary) components, of the *a priori* in physics. Along with point (1), Reichenbach insists: (i) that one can isolate «coordinating principles» which are crucial to any physical theory[17]; and (ii) that these coordinating principles *are constitutive of* the objects

[16] A. Einstein, *Oeuvres choisies, 5*, op. cit. p. 222.

[17] For instance, the Lorentz transformation, which was still an empirical law in Lorentz' physics, became a true background coordinating principle in Einstein's physics.

of this theory, because they prescribe the framework against which some phenomena can be interpreted as fleeting appearances of permanent objects. But, says Reichenbach, they are by no means *necessary*, unlike Kant's categories of pure understanding. The component of the *a priori* referred to in point (2) must then, according to him, be relinquished.

In this version of the relativized *a priori*, there is clearly more than in the hypothetico-deductive method, since the coordinating principles which are genuinely *constitutive* are carefully separated from the connecting principles which only state the relations between the properties of the constituted objects. By contrast, the usual conjecture-refutation method would merge both principles into a single category: that of corroborated conjectures or hypotheses. In spite of this difference, however, the idea that the coordinating principles lack any necessity was taken by Reichenbach, a few years after having written his *Theory of relativity and* a priori *knowledge*, as a good reason to abandon any reference to transcendental philosophy and to revert to empiricism.

Let us now have a closer look at why Reichenbach decided to drop any claim of necessity in his view of the relativized *a priori*. His basic reason was of course that, if the *a priori* is to be historicized, one cannot retain any principle which would be "valid for all times". Since Reichenbach identified "necessary" and "valid for all times", it was obvious to him that the historically drifting constitutive principles are not and cannot be necessary. But we do not have to accept this identification of "necessary" and "valid for all times". Less stringent definitions of necessity are available, and they can be used in the context of transcendental epistemology. One of them is *conditional necessity*: certain constitutive principles are necessary under the *condition* that a certain practice of research is implemented. But practices may evolve and a new network of presuppositions may then become conditionally necessary. Then, surprising as it may seem, a set of constitutive principles can be *necessary* and *provisional* at the same time!

If we accept this, the procedure of transcendental justification can be activated again, though of course not in the same sense as Kant's. Here, a transcendental justification would no longer be a regression from the fact of objective knowledge to certain concepts and principles which are taken to be "*a priori* conditions of the possibility of *all* experience". It would only be a regression from a given historical project of intersubjective knowledge, to a set of preconditions which are necessary *if* this particular project is to be successfully carried out. A transcendental justification of certain general structures of a physical theory is thus possible in such a restrictive acceptation.

In this sense, it now proves quite easy to justify transcendentally a large part of the structure of Quantum Mechanics. One can for instance derive a crucial part of the quantum formalism from assumptions about the limits of accessible experimental information[18]; or from assumptions about contextuality of phenomena, combined with a demand of unity of the mathematical tools used for

[18] A. Grinbaum, The Significance of information in quantum theory, Ph.D. thesis, Ecole Polytechnique, 2004, http://www.imprimerie.polytechnique.fr/Theses/Files/ Grinbaum.pdf

predicting these phenomena.[19] This means a lot for the interpretation of quantum theories. This means that one is no longer compelled to understand quantum theories as a representation of the «external», «independent» world, with all the strangeness and paradoxes that are associated with such a representation. Rather, quantum theories can very naturally be understood as expressing the constraints and bounds of (experimental) knowledge. This is very much in the spirit of Kant, if not in the letter of his original texts.

Now, let us inquire further into how the procedure of constitution of objectivity can be applied to quantum physics.

In everyday life and in using classical physics, considering that objects have been «constituted» may sound superfluous. After all, if such a constitution has taken place, it was in the ontogenic (or, possibly, phylogenic) past of human beings. The basic conditions of the constitution of objects have been permanently available since then, and they do not have to be questioned. Therefore, at present, everything looks as if the material bodies of everyday life and classical physics were given out there.

But in microphysics, things are very different. The basic conditions of the constitution of objects in space–time are no longer available, and this forces us to think afresh about constituting new types of objects. To begin with, what exactly are these conditions of the constitution of objects in space–time? They essentially consist in clauses of active imposition of continuity and reversibility of the temporal sequences of phenomena. These clauses, when they are successfully implemented, give ground to the idea that there is *something* permanent or substantial retaining its own *identity* across space–time[20]: a "something" which is endowed with *properties*, and which can *cause* events. But none of these clauses can be enforced on the micro-scale[21]:

1. The scheme of identity requires the possibility of restoring the continuity of spatio-temporal trajectories in order to follow them; but, in view of Heisenberg's uncertainty relations, no such trajectory is accessible to experience. At most, we can have access to a fuzzy trajectory. The continuity criterion, which defines identity, can then only be used with reasonable efficiency in situations of very low density.
2. The scheme of definition of properties requires reproducibility of phenomena across a large range of variation of perceptive or experimental history. But in quantum physics, when some pairs of measurements (those which bear on conjugate variables) are performed sequentially, the result of each type of measurement crucially depends on the order of the sequence.

[19] J.L. Destouches, *Principes fondamentaux de physique théorique*, Hermann, 1942; M. Bitbol, *Mécanique quantique, une introduction philosophique*, Flammarion, 1996; M. Bitbol, «Some steps towards a transcendental deduction of quantum mechanics», *Philosophia naturalis*, 35, 253–280, 1998.

[20] J. Piaget, *La construction du réel chez l'enfant*, Delachaux et Niestlé, 1977.

[21] M. Bitbol, *L'aveuglante proximité du réel*, Flammarion, 1998; M. Bitbol, *Schrödinger's Philosophy of Quantum Mechanics*, Kluwer, 1996.

3. The scheme of definition of ordinary causality requires free substitution of well-defined antecedent conditions in order to check that a certain effect is determined (or at least probabilistically promoted) by a certain antecedent. But, in quantum physics, this definition cannot be applied to its usual mechanical domain, to wit *motion*. For, here again due to Heisenberg's uncertainty relations, it is impossible to completely specify the spatial and kinematic antecedent conditions of a certain process of motion.

This means that *all the schemes of reversibility which justify our belief in the existence of spatio-temporal objects called material bodies at our scale*, are *missing* at the microscopic scale. What can we do at this point? Return to Kant's method of constituting objectivity, but applying it differently and to a different pattern of phenomena.

Let us first remember what motivated Kant's conception according to which objects of perception as well as objects of science are *constituted*. Kant's primary aim was to take a middle course between dogmatism and empiricism, between the view that objects are real entities independent of us and the opposite view that objects are merely imaginations of the human mind. A constituted object is neither isomorphic to a real object existing *in itself*, nor reducible to a figment of the imagination. So, what is it exactly? Let us read one of Kant's clearest statements about this point. He wrote: " (…) insofar as (…) presentations are connected and determinable (in space and time) according to the laws of the unity of experience, they are called *objects* ".[22] Here, nothing other than presentations, namely appearances, is required. But these appearances are embedded within a structural framework provided in advance by our understanding: the laws of the unity of experience. This structural framework is what *must* be presupposed in order to organize the presentations into manifold complexes made independent with respect to any particular situation or to any particular subjective state. In other terms, the structural framework of our understanding provides us with cognitive invariants. This definition of (constituted) objects needs no reference to exteriority, except in the weaker sense of spatial exteriority; no reference to reality either, except in the weaker sense of empirical reality (a sense that has been revived in a modern version by Putnam under the name "internal realism"). Objects are by no means construed as part of external reality in the strongest sense; yet objects are as independent of particular subjects as one may wish.

A crucial point is that, here, objectivity no longer means complete *detachment* of entities and properties with respect to the cognitive apparatus, but coordination of phenomena into several *strata* of invariants across a variety of subjective and instrumental circumstances. The fact that the usual types of spatio-temporal invariants, namely material corpuscles, are no longer available in quantum physics should not prevent one from attempting some sort of coordination.

This quest of a radically renewed constitution of objectivity can be carried out in two steps. Firstly coming back to classical mechanics in this spirit and analyzing

[22] Kant, *Critique of Pure Reason*, B 522, op. cit. p. 508.

how objects were in fact defined in this theory, beyond the superficial claim that they are merely given to us. Secondly extending this mode of definition to microphysics, with some suitable alterations.

When we perform an analysis of the status of objects in classical mechanics, we find that they are nothing else than the boolean lattice of those experimental propositions that are embedded in a covariance diagram corresponding to Galileo's group. They ultimately play no other role in the theory than an invariant of Galileo's group.[23] Any further statement according to which a classical object is a carrier of properties, beyond the level of these properties, is just a metaphysical addition, without any bearing on the way classical mechanics operates.

How can we transpose this procedure to quantum physics? Peter Mittelstaedt made a very interesting suggestion[24] after Schrödinger. He first noticed that if something holds the role Kant ascribes to a «substance», this something can only be the *state* Ψ itself, because (i) *state* Ψ gathers in its preparation a complete set of commuting observables, (ii) *state* Ψ is *permanent*, in good agreement with Kant's first analogy of experience. He then added that, by contrast, those putative entities that are conceived as carriers of the same spatial and kinematic properties as classical bodies, namely particles, "can only be considered as *fictional* objects".[25] One reason for this is that, given a certain state Ψ, only *commuting* observables can be taken as jointly "objective", in the sense of their being mutually accessible without alteration. In contrast, since the spatial and kinematic observables that are united by the concept of classical bodies do not commute, they are not jointly objective. This is a clear incentive to dispense with the old type of objects called material bodies altogether, and adopt a new type of object instead. We have no need for fictional objects which are only able to generate paradoxes.

However, in spite of this, few people cross the line, and replace the traditional body-like domain of objectivity with a new domain of objectivity such as the Hilbert space. Why is this so? We think this is due to the dominant realist attitude in epistemology. Realist philosophers of science are not content with invariant structures: they want "elements of external reality". Now, the problem with states Ψ is that, although they are indeed abstract invariants (by Dirac transformation) across the whole range of observables, they are quite poor candidates, taken in isolation, to the title of "elements of reality". Indeed, they are little more than mathematical generators of probabilities. And since they are generators of probabilities, they connect only indirectly, by means of Born's algorithm, with genuine experimental invariants such as values of spatial or kinematic observables, whereas good old material bodies are supposed to carry them directly.

But unlike realists, transcendental epistemologists do not care at all whether an invariant represents reality or not. What they require is only that these invariants be

[23] See E. Castellani, «Galilean particles, an example of constitution of objects», in: E. Castellani (ed.), *Interpreting bodies*, Princeton, NJ: Princeton University Press, 1998.
[24] P. Mittelstaedt, *Philosophical problems of modern physics*, Boston, MA: Reidel, 1976.
[25] P. Mittelstaedt, *Philosophical problems of modern physics*, op. cit. p. 129–130.

completely free of any paradoxical feature, as general as possible, and able to unify the largest conceivable domain of knowledge. If those conditions are fulfilled, they feel free to say that they have reached an optimal state of objectivity in the effective sense of maximal independence with respect to any subjective, spatial and instrumental situation. This is more than enough for them.

4 Constituting Objectivity in Contemporary Physics

We will now see how these ideas about constitution of objectivity can be extended to the most recent advances of theoretical physics, from Quantum Field Theories to Quantum Gravity.

As already mentioned in section 1 of this introduction, in the *MFNS*, the "mathematical" categories are specialized into "phoronomy" and "dynamics", whereas the "dynamical" categories are specialized into "mechanics" and "phenomenology". But the constructibility of the latter does not result in a true geometrization of physical contents. In other terms, in this reading of the original version of classical mechanics as formulated by Newton, constructibility does not result in an ascension of the "dynamical" into the "mathematical", nor in what Hermann Weyl called the transformation of kinematical principles into dynamical principles.

Now, it is clear that a large fraction of the subsequent advances of mathematical physics consisted in a "stronger" progressive construction of the dynamical categories by means of stepwise extensions of the field of applicability of mathematical categories, namely by means of stepwise extensions of relativity groups and other symmetries, and therefore of covariance constraints as well as of conservation principles. One can thus give a natural transcendental interpretation of the generalizations of classical mechanics that were developed throughout the nineteenth century.

Lagrangian and Hamiltonian formalisms (underpinned by symplectic geometry) allow two types of advances.

Firstly, they make it possible to reformulate Kant's spatio-temporal synthetic *a priori* (constitutively correlative of Galileo's relativity group and of the principle of inertia which states that geodesics are Euclidean straight lines and that inertial motions are uniform motions along a straight line) by considering that the Euclidean metric of space is a "background structure" of Newtonian mechanics. In a variational Lagrangian formalism, one calls "background structure" a structure that appears in the Lagrangian, but which do not have to be varied in order to obtain the Euler-Lagrange equations.

Secondly, another advance allowed by symplectic formalisms is represented by Noether's theorem which connects relativity principles (i.e. principles of *inobservability* of absolute kinematical magnitudes) and symmetries (invariance of the Lagrangian), with the laws of conservation of corresponding physical magnitudes (principles of *observability* of the latter magnitudes). This theorem is somehow *the* transcendental theorem, which vindicates Kant beyond what he could have hoped, and beyond what he could figure out. Indeed, it develops to an unsuspected extent

Kant's project in the Phenomenology and Mechanics of his *MFNS* (see Section 1): deriving a definition of observable magnitudes from principles of inobservability implied by Galilean relativity.

Thirdly, in General Relativity, the *content* of transcendental principles is changed, but far from being weakened, the architectonic of transcendental philosophy is actually reinforced by this change. The "axioms of intuition" (with the corresponding kinematics) and the "anticipations of perception" (with the corresponding dynamics) are transferred from the global and metric level, which was typical of newtonian mechanics, to the underlying local and differentiable level. The relativity group of the theory then becomes the group of space–time diffeomorphisms. Accordingly, the constraints of covariance become more important. This makes it possible to reduce forces, along with the category of causality, to a generalized principle of inertia. Here, the geometrical synthetic *a priori* is no longer located on a metric level, but rather on the differentiable level; it concerns, e.g. the cohomology of differential forms. This change can be expressed by saying that the metric is no longer a "background structure" (be it Euclidian or Minkowskian), but becomes a *dynamical* element of the theory. This new stage of the geometrization of physics can be interpreted from the standpoint of transcendental philosophy as a chiasm between a generalized "phoronomy" (relativity) which becomes dynamical, and a "mechanics" which becomes kinematical (inertial). An important consequence of this is that diffeomorphism invariance deprives location from any physical meaning.

Fourthly, in quantum field theory (gauge theories) one introduces "internal" degrees of freedom, and this yields broadened symmetry principles which considerably enrich the geometrization of physics by geometrizing interactions. As Yuri Manin (1988) claimed: "From a philosophical point of view, one can speak of a new wave of geometrization of physical thought which for the first time is sweeping far beyond the boundaries of general relativity".

Since the pioneering research of Chen Ning Yang and Robert Mills in the 1950s, two classes of fields were then distinguished in gauge theories:

(i) Matter fermionic fields, which are interpreted as fiber bundles over space–time (the coordinates of fibers are internal degrees of freedom, and the symmetry group of fibers express internal symmetries of particles).
(ii) Bosonic gauge fields, which represent interaction fields mediated by exchanged virtual particles (bosons). These are interpreted as connections over these fiber bundles.

The particles which mediate interactions are therefore the quanta of connection fields over matter fiber bundles. The Yang-Mills Lagrangian is the norm of the curvature of connections. It is an invariant of the gauge group, and space–time contribute to it as a gauge field by means of the scalar curvature of its connection. Covariant derivatives then offer the possibility of expressing interactions geometrically. In this situation, gauge theories were able to "construct" interactions by introducing a dependence of internal symmetries of systems (which are apparently non spatio-temporal global symmetries associated with particles quantum numbers) on space–time. If these internal symmetries are thus localized, and if the invariance