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:

M. Bitbol et al. (eds.), *Constituting Objectivity,*

> (…) 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

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