Transcendental Structuralism in Physics
An alternative to Structural Realism

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Abstract:
In physics, structures are good candidates for the role of transparadigmatic invariants, which entities can no longer play. This is why structural realism looks more credible than standard entity realism. But why should structures be stable, rather than entities ? Here, structural realists have no answer ; they content themselves with the mere observation that this is how things stand. By contrast, transcendental structuralism (a byproduct of Kant's transcendental idealism) can easily make sense of this fact. Indeed, it shows that when knowledge bears on phenomena, namely on the emergent byproduct of a relation between the explorer and what is to be explored, this knowledge necessarily bears on relations between such phenomena. After a development on the clarifying power of transcendental structuralism, I turn to an early transcendental structuralist interpretation of quantum mechanics proposed by Jean-Louis Destouches (1909-1980). Destouches, an early French philosopher of physics, was a student of Louis de Broglie. He recasted in the 1940 the very concept of physical theory in the light of quantum physics. According to him, whenever phenomena are inextricably relative to the experimental set-up, a physical theory cannot provide anything beyond a *list of interconnected predictions* for future facts given a relevant class of past facts. In his general mathematical theory of predictions, the Ψ-functions of quantum mechanics do not refer to some "real" waves; they are shown to be nothing but the formal expression of the phenomena's being relative to incompatible experimental contexts. Since the quantization of variables can itself be derived from a wave-mechanical formalism, it becomes clear that the most prominent features of quantum mechanics are a mere consequence of contextuality. Destouches thus proved that it is easy to make sense of quantum mechanics provided a *reflective* attitude is adopted. By contrast, too many difficulties arise when one tries at any cost to make quantum mechanics intelligible within a purely *ontological* framework.

Introduction : structuralism in the atmosphere of transcendental epistemology

My primary aim in this paper is to describe some important features of Jean-Louis Destouches' philosophy of physics, and especially his early version of transcendental structuralism. This is an important task in itself, since the remarkable, ambitious, and strongly argued work of this French forerunner of the studies about the foundations of physics (who worked between the 1930s and the 1950s in the wake of Louis de Broglie's temporary acceptance of the Copenhagen interpretation of quantum mechanics), remains almost entirely ignored nowadays. It is ignored, first of all, by the international community of English-speaking philosophers of physics, which is understandable due to the fact Destouches was almost exclusively writing in French and has never been translated. But his work is also little known of the French-speaking philosophers of science[1], which is more surprising in view of his highly advanced and very accurate reflection.

But before I come to Jean-Louis Destouches, I would like to insist from the outset that a transcendental philosophy of science is more naturally in tune with structuralism than any variety of realism. Whereas structuralism is merely contingent and optional for a realist philosophy of science, it is necessary and inescapable for a transcendental philosophy of science. Moreover, whereas it may be disappointing for a realist philosopher of science to admit that we can only know structures, and not entities with their intrinsic properties (if any), it is obvious for a transcendentalist philosopher of science that objective knowledge is structural by definition. Why is it so?

The main motivation for structural realism is well-documented. A reasonable requirement of scientific realism is that scientific theories converge asymptotically towards a true grasp of the way the world is. Even though one may accept that some sort of instable behaviour occurs during the convergence process, it is usually accepted that this convergence should manifest itself by an increasing amount of historical invariance in the content of

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[1]A philosophy of quantum physics making extensive use of Destouches's ideas has nevertheless been developed by myself: M. Bitbol, *Mécanique quantique : une introduction philosophique,* Paris : Flammarion, 1996 ; M. Bitbol, "Some steps towards a transcendental deduction of quantum mechanics", *Philosophia naturalis,* 35, 253-280, 1998. Besides, a collection of his papers has been published by a major French academic press : P. Février, H. Barreau, & G. Lochak (eds.), *Jean-Louis Destouches physicien et philosophe,* Editions du CNRS, 1994

scientific theories. But the rate of historical invariance is *de facto* very low when *entities* (their definition more than their names, that can remain artificially stable) are concerned. Larry Laudan's impressive list of forgotten entities is quite enough to show this. If scientific realism is to be rescued, it is then clear that the nucleus of stability must be sought elsewhere. Now, structures are good candidates for this role of transparadigmatic invariants which entities can no longer play. Many laws survive across scientific revolutions, as limiting cases for the new theory. And some other structures, such as the global symmetry principles, are even more perennial, since they retain their full generative aptitude irrespective of the paradigmatic changes in concepts and practices.

This sound motivation being granted, structural realism meets several objections, usually formulated by advocates of a more orthodox version of scientific realism. Some of these objections can be found in the work of Stathis Psillos, and I will just summarize two of them, which are especially liable to a transcendental solution.

The first objection is that at no stage of the evolution of science can one be certain that a theory does not leave aside some parts of the structure of the real world. A structural realist can then accept that the theoretical structure does not capture the real structure in its entirety, that it is only *embeddable* within the real structure. But in this case, the orthodox realist is likely to point out that there are many, possibly an infinite number of, ways of selecting embedded structures within a larger structural frame. Isomorphism carries very little information in this case.

The second objection is that one may wonder whether there exist some non-structural features in the real world. If one answers "yes", then either the non-structural features can be known and structuralism is incomplete, or the asserted non-structural features cannot be known and structuralism is caught in the usual conundrum of metaphysics: namely perplexity about the dubious status of a discourse bearing on the unknowable. Another option is to give a negative answer to the former question: "no, there is no non-structural feature in the world". This option is called "*eliminative* structural realism". It avoids the pitfalls of metaphysics, but it raises other problems. The first problem is mere puzzlement: why is the world pure structure? And if this is so, how can the appearance of entities and intrinsic properties arise out of pure structure? The second problem is that (according to robust realists) eliminative structural realism concedes too much to idealism. It comes very close to the proposition Weyl took as the "central thought of idealism": "The objective image of the world may not admit of any diversity which cannot manifest themselves in some diversity of perception"[2].

But once this concession is made, we have every reason to go further and inquire into what transcendental idealism, in a Kantian or neo-Kantian version, has to say about structuralism. We then quickly discover that transcendental philosophies of science have answers in store for some of the former questions, and for other puzzlements as well.

To begin with, transcendental philosophy easily accounts for the core feature of structuralism. I consider that this core feature is relations without (substantial) *relata*. Let me quote Ferdinand de Saussure, the father of structuralism: "For our minds, (relation) entails two positive terms between which the (relation) takes place. But here is the paradox: in language, there are only (relations) without positive terms"[3]. In Kantian or neo-Kantian epistemology, this so-called "paradox" is repeatedly aknowledged. Relations here do not connect two substantial entities, but rather objects which are themselves *nothing else* than focal points of stable networks of relations. According to Kant, the properties of a *substantia phaenomenon* are only relational, and the so-called subtance itself is "totally and fully a set of pure relations"[4]. As for Cassirer, his entire philophy of knowledge is grounded on this leit-motiv. The history of science as a whole, says Cassirer, tends towards relinquishment of substantial concepts and research of "invariant

[2] H. Weyl, *Philosophy of mathematics and natural sciences,* Athenaeum, 1963, p. 117

[3] F. de Saussure, Notes for the "Cours de linguistique générale", quoted by S. Bouquet, Introduction à la lecture de Saussure, Payot, 1997, p. 142. In the text one finds "difference" instead of "relation".

[4] I. Kant, *Critique of Pure Reason,* B321

relations" instead[5]. And if properties are referred to, it is only after the concept of property has been (re)defined in such a way that "it includes in itself the concept of relation"[6].

This universal agreement about relationism and structuralism among transcendental philosophers is not difficult to understand: relationism and structuralism are rooted into their most fundamental assumptions; especially the so-called "copernican revolution" assumption according to which we do not know things in themselves but only *phenomena*. To see this, we must first enquire into what is a *phenomenon* in a kantian context. There are several ways of characterizing phenomena in transcendental philosophy, but the simplest is expounded in the *Transcendental Aesthetics.* In this well-know introductory part of the *Critique of Pure Reason*, phenomena are byproducts of a relation between our faculties of knowledge and whatever we mean when we refer to the "thing in itself". Kant then set up a two-way correspondence between the idea that knowledge bears on pure relations and the "copernican revolution" assumption; between the idea that we can only know relations between objects and the assumption that objects are in turn made out of relations between us and some sort of thing in itself. Thus, in the last part of the *Analytic of Principles,* we find an argument going from the "Copernican assumption" to the core feature of structuralism. There, Kant points out that the items that we know can have no intrinsic foundation *because* they are mere *phenomena;* and since they have no intrinsic foundation, they consist in pure extrinsic relations[7]. Conversely, at the end of the *Transcendental Aesthetics,* the argument goes backwards from structuralism to the "Copernican assumption". Since, in intuition, only relations between phenomena are given, an intuitive representation can only concern a relation between a subject and its objects; it says nothing about a putative intrinsic reality pertaining to the thing in itself[8].

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[5] E. Cassirer, *Philosophie der Symbolishen Formen,* Vol 3, Chapter 5 (III)
[6] E. Cassirer, *Zur Einsteinschen Relativitätstheorie,* op. cit.
[7] I. Kant, *Critique of Pure Reason,* B341
[8] ibid. B67

These well-known arguments were taken over in 1935 by the German Philosopher Grete Hermann[9], and applied to Quantum Mechanics. According to Hermann, Kant's arguments about the relational-structural nature of knowledge are even more compelling in the quantum universe than they were in the classical universe. For, in classical physics, the univocity of the system of relations between phenomena could still accomodate the belief that the "(...) structures of relations are univocally determined by some objective connections of things in space and time". But in quantum mechanics the plurality (and "complementarity" in Bohr's sense) of the structures of relations forces one to realize that they ultimately express the many available cognitive relations between experimental devices and the microscopic "glub" (according to Rom Harré's expression). Kant's reasoning can no longer be evaded. While it was a philosophical luxury in classical physics, it becomes a foundational necessity in quantum physics.

But the resources of transcendental philosophy for structuralism do not stop at this point. Speculations about the way the thing in itself "affects" our senses had very little appeal on the mind of neo-Kantian philosophers. Accordingly, they pushed aside any question about the origin of phenomena. And they only retained the constructive part of Kant's philosophy, namely his theory of the constitution of objectivity by law-like ordering of these phenomena. Such a strategy does not weaken the connection between structuralism and transcendental philosophy; if anything, it makes it even more stringent. Indeed, in this case, the structures which are provided in advance by our understanding, or by our symbolic system, or even by our regulated practices of research, are preconditions for there being objective knowledge at all. No other phenomena than those which are ordered according to these structures can be treated as objective. For our anticipative structures are able to pick out static or dynamic invariants with respect to the various situations of the subjects, whereas the

[9] G. Hermann, *Die Naturphilosophische Grundlagen der Quantenmechanik,* French translation by L. Soler & A. Schell, *Les fondements philosophiques de la mécanique quantique,* Vrin 1996

residual part of the phenomena which does not fall under this structural frame, expresses the specific component of each situation. In other words, *reduction of knowledge to structure is the price to be paid for intersubjectivity or intersituationality.* Even Karl Mannheim, one of the founding fathers of the sociology of knowledge, was aware of that. According to him, coordinating the variety of individual or collective perspectives entails an ever increasing formalization of knowledge[10]. Individuals and social groups can only understand each other at the high stage of abstraction provided by structures.

At this stage, the reason why physical knowledge is structural becomes obvious: this is a condition for its being shared across spatio-temporal, cultural, and individual situations. *Structure is the mark of cognitive universality.* Some structures in physics can almost immediately be understood this way. Not to mention Newton's three laws and their transcendental reading by Kant, I may quote Eugen Wigner according to whom time, space, and rotation invariance, "(...) are almost necessary prerequisite that it be possible to discover, or even catalogue, (...) correlations between events"[11]. The case of many other structures in physics is not so clear, but it is a good programme of research to enquire into whether the so-called internal or local groups of symmetry can be understood as preconditions for coordinating certain classes of experimental situations.

As one now realizes, meeting the objections which have been formulated against structural realism is quite easy in the frame of transcendental structuralism. The reason why knowledge is structural has already been stated, in a Kantian and neo-Kantian version: because knowledge only concerns the phenomenal byproducts of cognitive relations rather than the intrinsic features of reality (Kantian); because structure is the only common denominator of the multiplicity of, temporal, spatial, subjective, or cultural positions (Neo-Kantian). Eliminative structuralism is

[10] K. Mannheim, *Ideology and utopia,* (1936), in: K. Mannheim, *Collected works* volume 1, Routledge, 1997, p. 271
[11]E. Wigner, *Symmetries and reflections,* Ox Bow Press, 1979, p. 29

natural in this case. For if there is some non-structural feature left aside, this is only subjective or qualitative material, not liable to objective knowledge by definition. Moreover, there can be no surplus structure at a given stage of the development of physics. For here structure means structure of (experimental) anticipation or action, and the latter is automatically encompassed by the mature physical theory accounting for the corresponding set of phenomena. New structure may occur, of course, but it does not arise from some stock of preexistant surplus structure; rather from a historical development of the (experimental) modes of anticipation and action.

As for the way appearance of entities and properties may arise from pure structure, this is explained by the procedure of constitution of objects, which consists in extracting a permanent nucleus out of changing configurations. As we will see, the universality of the procedure of constitution of objectivity becomes especially manifest in microphysics where many conditions for defining invariants are not fulfilled at the phenomenal level, but where the procedure of extracting a permanent nucleus is still efficient provided it is deflected towards the predictive formalism itself.

Now, let me come to Jean-Louis Destouches' attempt in this direction.

1-*A short intellectual biography of Jean-Louis Destouches*

Jean-Louis Destouches was a brilliant French physicist and philosopher of physics, and a student of Louis de Broglie. He was born in Paris in 1909, he died in Paris in 1980, and he began his studies at *the Faculté des sciences* of the university of Paris in 1929. There, his teachers of mathematics were Emile Borel and Maurice Fréchet, and his teachers of physics were Marie Curie, Irène and Frédéric Joliot-Curie, Jean Perrin, and, last but not least, Louis de Broglie. He attended de Broglie's first lecture at the *Collège de France* in 1928, one year before he entered at the university, and this gave him a strong motivation to study the foundations of quantum physics. At that time de Broglie had relinquished his early pilot wave (and double solution) theory, and he taught a personal blend of the so-called "Copenhagen interpretation of quantum mechanics". This explains the definitely "Copenhagian" flavour of Jean-Louis Destouches' philosophy of physics, which persisted even after de Broglie's re-conversion to the pilot wave theory.

In 1936, after some preliminary studies on second quantization, Jean-Louis Destouches started elaborating a "general theory of corpuscles and systems of corpuscles" in which he undertook a thorough reappraisal of the very concept of particle, and accordingly worked out a conception of physical theories as pure predictive formalisms. His work culminated in 1942, with the three volumes of his *Fundamental principles of theoretical physics*[12]. Between 1938 and 1942, he also started a fruitful collaboration with Paulette Février, a young philosopher of logic who was to become his wife. Just after the second world war, he obtained a chair of mathematical physics at the university of Paris, and at the same time he taught philosophy of physics and philosophy of science at the Sorbonne. Many institutions of economy and social science also asked him to teach how to apply his powerful and highly general "theory of prediction" beyond physics.

At the beginning of the 1950's a sort of split occured within the intellectual circle of de Broglie. Louis de Broglie himself went back to his pre-1927 attempts, and rehearsed some of his former ideas on wave-particle duality. He was followed by some of his disciples, and he was reinforced by the publication of Bohm's well-known papers in 1952. But J.L. Destouches adopted a critical stance with respect to this radical turn of thought of his master. He did not content himself with making repeated use of Von Neumann's theorem which was still incorrectly interpreted at that time as proving the impossibility of hidden variable theories. In anticipation of Bell's and Kochen's & Specker's theorems, he also elaborated a new set of arguments against hidden variable theories. He found that, if viable theories of this type existed, they would

[12] J.L. Destouches, *Principes fondamentaux de physique théorique,* Hermann, 1942

have two features which are either self-defeating or inacceptable to him: (1) a blend of non-locality and contextualism of properties, and (2) underdetermination of their surplus content by *any* finite or infinite set of experimental phenomena. Contextualism of properties was expressed thus: "(...) there is no hidden parameter description *for the system;* this description only exists for a given couple system+apparatus, not for the system alone". Such involvement of the experimental context is self-defeating because the aim of hidden variable theories was precisely to provide us with a description of the intrinsic features of the objects under investigation. As for the fundamental underdetermination of hidden variable theories, it was strongly criticized by Destouches as follows: "(an objectivist description which would yield the same predictions as quantum mechanics involves processes that are) *in principle* inaccessible to any measurement and which can have no relation whatsoever to experiments. Such inaccessible magnitudes (and processes) can be called metaphysical (for they can undergo a large range of variations without any alteration in empirical predictions)"[13]. The paper where he developed these arguments obtained unconditional approval from John Von Neumann and Pascual Jordan[14], but it met the strong opposition of de Broglie and it then remained unpublished until recently.

In spite of this strong reluctance towards de Broglie's new trend of thought, Jean-Louis Destouches followed very closely the work of his mentor during the 1960's and 1970's. But he ascribed it an original and limited significance. Instead of accepting uncritically that de Broglie's double solution theory somehow picture the intrinsic structure of the world, he considered that it expresses certain relevant functional relations between phenomena, and that it conveys a useful heuristic power. This deflationary construal of

[13] J.L. Destouches, "Retour sur le passé", in: A. George (ed.), *Louis de Broglie, physicien et penseur,* Albin Michel, 1953

[14] P. Février, H. Barreau, & G. Lochak (eds.), *Jean-Louis Destouches physicien et philosophe,* Editions du CNRS, 1994

de Broglie's theories was developed in Destouches' so-called "functional theory of corpuscular systems"[15].

2-*A post-positivist and structuralist philosophy of science*

Now, let me concentrate on Destouches' own views on the philosophy of science and philosophy of physics which were, in many respects, ahead of his time.

Firstly, his general methodological option easily compares with John Bell's. This method consists in transforming all the questions about a theory into meta-theoretical questions, in such a way that it becomes possible to distinguish contingent from necessary features of each given theory, by comparing it with a set of properly defined *virtual* theories. In his own words, the main problem in the foundations of physics is that the physicists "(...) never consider in a systematical way either a set of *possible* theories, or the general conditions which must be met by any acceptable theory (....)". To overcome this problem, "One must rise one step in abstraction, in the same way as one goes from mathematics to meta-mathematics"[16]. He thus undertook systematic 'epi-theoretical' investigations (as he called them) about quantum theories.

Secondly, it is striking to notice that Destouches already upheld in the thirties, approximately at the same time as Popper's *Logic of scientific discovery,* a post-positivist philosophy of science. According to him, it is definitely impossible to verify or even justify a scientific theory. Any conceptual construction in science must be "(...) undertaken knowing in advance that one does not and cannot obtain any permanent basis"[17]. This being accepted, the historical trajectory which has been followed before the physical theory reached its mature state, is almost as important as its final structure.

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[15] J.L. Destouches & F. Aeschlimann, *Les systèmes de corpuscules en theorie fonctionnelle,* Hermann, 1959

[16] J.L. Destouches, "Les thèses fondamentales de l'idonéisme", in: *Etudes de philosophie des sciences en hommage à Ferdinand Gonseth,* Bibliothèque scientifique 20, série Dialectica, Editions du Griffon, 1950.

[17] J.L. Destouches, *Essai sur la forme générale des théories physiques,* Institutul de arte grafice (Cluj), 1938, p. 1

The mark of history is identified by Destouches in axioms. Not of course the abstract axioms which are formulated at the ultimate stage of the elaboration of a theory, and which are likely to eliminate contingent features. But what Destouches calls "an axiomatic in the process of formation"[18], namely a plastic set of assumptions which is provisionally taken for granted by a community of scientists. Destouches described the procedure by which an "axiomatic in the process of formation" is adopted, as an "inductive synthesis". Despite the presence of the term "induction" in it, the expression "inductive synthesis" points toward a method which is akin to Peirce's *abduction*. Indeed, Destouches insisted : "A widespread view is that experimental results are enouth to construct a theory. But this is completely wrong (...); as long as one has not formulated any simple idea, the experimental material remains useless"[19]. In other words, "inductive synthesis" involves *synthesis* at least as much as induction. Now, synthesis here means aggregation of various elements borrowed from previous steps of cognitive orientation, in a renewed ascent from particulars to concepts. In Destouches' words, the inductive synthesis is "(...) synthesis because its aim is to encompass disparate elements of knowledge within a single scheme; and it is inductive because it goes from the particular to the general, from partial to complete, from concrete to abstract, from certainty to conjecture"[20]. Destouches then insists on the fact that scientific concepts do not organize and anticipate an entirely pre-given reality, but rather a reality which has already been shaped out by previous frameworks of thought. As Nelson Goodman would have it, a new anticipation does not rely on previous data only; it also relies heavily on previous successful anticipations[21].This is especially clear when a new theory has to be built in a domain which is partly ruled by a previous physical theory. In this case, "(inductive synthesis has to be) heterogenous; it has to make use of pieces of deductive theories, comparisons with former theories, as well as half-

[18] ibid. p. 76
[19] J.L. Destouches, *Physique moderne et philosophie,* Hermann, 1939, p. 77
[20] ibid. p. 86
[21] N. Goodman, *Fact, fiction and forecast,* Harvard University Press, 1983

formalized and half intuitive explanations"[22]. Its only unifying principle is the *project* of formulating the coherent axiomatic of a presently unknown theory. When he describes this complex and somehow awkward cognitive process, Destouches has in mind the recent process of formation of the quantum theory, with its mixture of operationnally defined classical variables taken over by means of the correspondence principle, and new laws relating these variables. But unlike Bohr, Destouches did not think that, for this reason, one must say that quantum theory still uses classical *concepts*. For, according to him, a concept depends as much on its location within the network of law-like relations in which it is embedded, as on its operational definition. If inductive synthesis is creative of new theoretical structure, then it is creative of new concepts as well, for concepts are nothing over and above the *role* they plays in an integrated web of lateral inter-relations and transversal relations with experimental procedure. This is the first aspect of Destouches' structuralism I wanted to point out.

Also, unlike many positivist philosophers of science, Destouches criticizes the supposed bedrock of scientific work, namely experimental facts. "It is tempting to call the measurement results 'physical reality' (...) But this reality is far from being a primitive given; it rather emerges after a long mental evolution. Measurement results can acquire *meaning* only after the theory in which they can be incorporated has been elaborated, and moreover the measurement apparatus itself can be understood only by means of a theory"[23]. These remarks about the theory-ladenness of facts are almost commonplace nowadays after Popper and the semantic conception of theories. But they still retained some provocative flavour in the thirties. Here again, they displayed Destouches' structuralist trends. Destouches did not ascribe any meaning to isolated items, be they experimental facts or protocol sentences. Each item could make sense, according to him, only relative to a network of highly interdependent experimental practices and preliminary theoretical orientations.

[22] J.L. Destouches, *Essai sur la forme générale des théories physiques,* p. 17
[23] ibid. p. 92

Another topic of Destouches' meta-theoretical reflection bears on the mutual connections between mature physical theories.

One must first bear in mind, Destouches points out, that at any epoch, several theories are used simultaneously. Some theories are quantitatively embedded in one another, which means that it is possible to demonstrate that their quantitative predictions converge approximately in a certain experimental domain. This is the case for classical and quantum mechanics whose quantitative prediction converge in the domain where the Planck constant can be neglected. Now, there are also theories which, at a given time, seem to have completely separate domains of validity. We can think of thermodynamics and classical mechanics in the mid-nineteenth century, or standard quantum mechanics and general relativity in the 1920's. Between these theories, other, non convergent, types of relations may be established, such as disjunctive domain relations. But the most problematic case is that in which the models associated to several theories used at a given time involve *mutually incompatible* pictures and *contradictory* propositions. During the first quarter of the twentieth century, for instance, the corpuscular theory of light proposed by Einstein in order to account for black-body radiation and photo-electric effects was apparently incompatible with the wave picture of electromagnetism, which however was still required in order to account for interference patterns. What kind of relation is there between such types of apparently incompatible theories? Can there be *relations* at all in this case?

Destouches tackled the problem of the relations between incompatible theories by inquiring into nothing less than the prospect of *unifying* them; namely finding a level of description at which they appear as several aspects of a single theory. According to him, we have no reason to be sure that unification of the multiple theoretical strata which are used at a given time is in principle possible, especially when some of their components appear mutually *contradictory*. But as a *project,* unification is part of science. Unification of theories may be artificial, but it is a basic need which underlies the whole scientific endeavour. As

Destouches puts it, unification is "(...) a matter of method, not of reality; it is wanted by us, in us, and for us"[24]. Destouches here agrees with Kant, who wrote in his *Critique of Judgment* that the unity of the laws of nature within an integrated system is a regulative ideal, subjectively necessary for our faculty of knowledge. In other words, the unity of theories is seen by Destouches and by Kant as a kind of transcendental pre-condition for knowledge. This is a weak variety of transcendental condition when compared with the basic conditions of constitution of objectivity, yet very pervasive at the highest level of research. The relevant question, therefore, is not about the *presence or absence* of theoretical unity as a reflection of an *existent or inexistent* unity of nature. It is rather about *how* theoretical unification, taken as a basic *requirement* of the cognitive project of science, can be fulfilled *in any event*.

With this epistemological rather than ontological version of the question in mind, Destouches first demonstrated an elementary meta-theorem about compatible theories. According to this theorem, whenever two theories, with their associated models, "(...) are such that no proposition of the first one contradicts a proposition of the second one, then there exists a unifying theory whose set of primitive terms is the collection of the primitive terms of both theories, and whose set of axioms is the logical product of the axioms of the two theories"[25]. But of course, the interesting case is not this one; it is rather that of theories whose associated models include mutually *contradictory* propositions. In order to unify theories of this type, Jean-Louis Destouches writes, the only possible way is to abstract the basic structures of these theories and to alter the rules of ordinary logic, especially by restricting the scope of the logical product. Once this is done, a new unified theory is obtained; in it, the basic structures of the former theories is articulated within a *non-boolean logical structure*. The unified theory usually entails unexpected predictions which did not follow

[24] J.L. Destouches, *Physique moderne et philosophie,* op. cit. p. 63

[25] J.L. Destouches, *Physique moderne et philosophie,* op. cit. p. 63-64; also J.L. Destouches, *Essai sur l'unité des théories physiques,* Institutul de arte grafice (Cluj), 1938

from the constituent theories. Now, writes Destouches, altering logic is tantamount to restricting the validity of each proposition to a well-defined context of speech, and to ascribe meaning only to those propositions whose relevant context does *not* involve the conjunction of two or more mutually incompatible contexts. In other terms "these modification of logic entail (...) Bohr's complementarity"[26]. Interestingly, thus, quantum mechanics, with its unification of the corpuscle picture and the wave picture in a general formalism which orders contextual propositions and which is underpinned by a non-classical logic, appears as a special case of a much more general situation. The final outcome of this discussion is that, whenever it is meant to absorb two mutually inconsistant theoretical models, the resulting unified theory is bound to make quite explicit the background contexts of experimental investigations. It cannot dispense with a reflective analysis of the instruments of investigation, thus contrasting with other theories which can ignore contexts and concentrate on the description of their object. Thus, in general, according to Destouches, the ideal of unification of theories entail renunciation to another regulative ideal of science: namely the ideal of making scientific propositions so entirely independent of the process of acquisition of knowledge that they can be construed as propositions bearing on intrinsic properties of pre-existing objects.

To summarize:

(i) A prerequirement of unification is identical to the preliminary move of any transcendental philosophy of science: reversing focus from objects to our mode of knowledge of objects[27].

(ii) Part of the contents of theories is determined by constraints of intertheoretical relationship. This is structuralism at a meta-theoretical level.

3-*Transcendental structuralism in the philosophy of quantum mechanics*

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[26] ibid.

[27] I. Kant, *Critique of pure reason,* (new edition, by V. Politis), Everyman's library, 1993, B25, p. 43

But what I call "Destouches' transcendental structuralism" is even more explicit in his detailed reconstruction of quantum theories. According to Destouches, structuralism is forced upon us by the all-pervasive contextuality which underpins quantum mechanics. More precisely, a theory in which pairs of conjugate variables do not commute, due to the incompatibility of the corresponding measurements, can only be a theory of pure structures. But why is it so? Destouches' explanation is contained in a crucial paragraph of the first volume of the *Fundamental principles of theoretical physics:* "A physics in which some pairs of simultaneous measurements are impossible cannot be a physics of intrinsic properties. It is bound to be a physics of pure relations. (...) The theory will only provide us with predictions for future measurements, from the outcome of previous measurements. In this theory, the elements of prediction and all the other elements are articulated by a certain number of relations. (...) Now, a set E of elements and a set R of relations taken together (E,R) can be called a *structure*. (...) For any category of elements that is contained in our physical theory, we are led to this kind of structures. The latter structures play the most fundamental role; *hence the name 'structural physics' we give to our theory*"[28].

Destouches here makes two distinct statements:

(1) Since contextuality entails lack of knowledge of intrinsic properties, we can only hope to grasp *relations and structures*.

(2) These structures concern not directly the phenomena, but the so-called « elements of prediction » of the theory.

The first statement is quite similar to Kant's[29]: the reason why the objects of our knowledge only consist in relations is that they are pure *phenomena*. For these phenomena are in turn the byproduct of epistemic *relations* between the thing in itself and our senses. But Destouches also adds a distinctive quantum component to that argument. Whereas in classical physics, nothing prevented one from behaving *as if* the phenomena reflected intrinsic

[28] J.L. Destouches, *Principes fondamentaux de physique théorique,* op. cit. Volume 1, p. 164
[29] I. Kant, *Critique of pure reason,* op. cit. B. 340

properties (this is the well-known kantian *Als Ob),* in quantum physics, even the *as if* is precluded. Indeed, the phenomena are not stable enough across series of measurements of complementary variables to be treated as *direct* reflections of invariant properties. If *as if* properties are needed, their relation to phenomena must be made utterly indirect, as it is the case in contextualist and non-local hidden variable theories.

As for the second statement of Destouches, it departs even more from Kant. According to Kant, in physics, we can only know relations between *phenomena*. But according to Destouches, in quantum physics, we know even less: relations between elements of prediction, namely between those mathematical tools used to calculate *probabilities* of given phenomena. Here, the structure concerns mediately the probabilistic rules, and only immediately the phenomena.

To sum up, Destouches transcendental structuralism is at the same time more radical and weaker than Kant's. It is more radical because, due to complementarity and contextuality, it is so to speak inescapable. And it is weaker, because the structures organize a set of entities (say probabilistic algorithms) which are more remote from whatever one may call "reality" than the phenomena they help to predict.

Let us now further inquire into some consequences of Destouches' reflective stance. The first consequence bears on the classification of the different parts of physics. Let us accept, in conformity with the basic assumption of transcendentalism, that physics does not claim to predicate anything of pre-existing objects; that it only accounts for *relations* between objectified phenomena which in turn are the byproducts of relations between nature and experimenters approaching it with certain technical and conceptual presuppositions. If this is the case, the subdivisions of physics cannot be determined by the variety of its objects, but rather by the variety of its modes of investigation. A consequence of this new criterion is provided by the subdivisions of Destouches' *Fundamental principles of theoretical physics*. The second and third volumes of this treatise are respectively entitled: *Physics of* *the individual* and *Physics of the collective*. A superficial reading of these titles, influenced by the usual prejudice according to which parts of physics are defined by their objects, may induce one to think that the first part of the treatise is about isolated particles whereas the second part is about sets of interacting particles. But this is not so. The physics of the individual deals with the relation which can be established between systems and an *individual* experimenter by means of instruments. And the physics of the collective bears on the coordination of the information obtained by several experimenters distributed in various spatial locations and in various inertial frames. In other terms, the so-called *physics of the individual* essentially reduces to standard quantum mechanics, whereas the *physics of the collective* adds to it the relativistic group of transformation.

Another consequence of Destouches' reflective stance is his study of the very nature of physical theories. If no feature of phenomena had forced us to relinquish the idea (or the *as if* belief) that they just reveal intrinsic properties of pre-existing objects, theories could be ascribed the project of describing these properties and their evolution. But provided we have been led to accept, with Bohr, that each experimental result expresses an isolated and unanalysable interaction between systems and apparatuses, the theory cannot keep on with its former project, lest it relies on a discourse (which Destouches calls "metaphysical") about essentially hidden predicates[30]. As mentioned in Destouches' definition of structural physics, this theory must then content itself with providing predictions for future experimental results under the condition of one or several past experimental results. Here, prediction is not and cannot be a byproduct of some underlying description; it is primary. Quantum mechanics is a primarily and fundamentally predictive theory.

This minimal goal of theories, namely prediction of phenomena, was already considered as the only legitimate aim, by some philosophers of science in the time of classical physics. It is enough

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[30] J.L. Destouches, "Retour sur le passé", in: A. George (ed.), *Louis de Broglie, physicien et penseur,* Albin Michel, 1953

to remind Ernst Mach's or Pierre Duhem's position[31], according to whom the physical theory does not have to provide explanations but only an economical classification and an anticipation of phenomena. But this option can prevail itself of much more compelling arguments in quantum physics than in classical physics.

The first argument is that the very concept of a phenomenon has undergone severe alterations from classical to quantum physics. Whereas Duhem still speaks of properties to which measurements associate an ordinal symbol, Bohr, and Destouches after him, consider that the measurement is co-constitutive of a phenomenon. This being granted, one must realize that predicting phenomena which depend for their very definition on a certain constitutive experimental context can, and must, be made independently of any description of pre-existing physical processes.

The second argument is a theorem due to Paulette Destouches-Février[32] about indeterminism. This theorem shows that any theory which deals with contextual phenomena, and which is such that the relevant contexts are sometimes incompatible, is "essentially indeterminist". By saying that this kind of theory is "essentially indeterminist", Paulette Février means that it cannot be interpreted as describing statistically some underlying variables having "a physical meaning". Of course, this does not preclude the possibility of hidden variable theories, but this imposes that the hidden processes can have no "physical meaning" in the sense Jean-Louis Destouches and Paulette Février ascribe to this expression. This imposes in other words that the hidden processes, if any, have no possibility, even remote, of becoming one day accessible to experiments.

These two circumstances led Destouches to develop a "general theory of (probabilistic) predictions", of which quantum mechanics is a special instance, and from which classical theories can be derived as even more special instances. Let me summarize the most important components of Destouches' "general theory of predictions", first stated (in 1941) in the first volume of his book

[31] P. Duhem, *La théorie physique,* Vrin, 1989
[32] P. Destouches-Février, *La structure des théories physiques,* P.U.F., 1951

Corpuscles and systems of corpuscles. Firstly, Destouches demonstrates that it is always possible to analyse any procedure of prediction in three steps. These steps are the following:

(1) associate with the preparation of some experiment a unique initial "element of prediction" which, unlike probabilities, does not depend on the measurement to be performed after the preparation,

(2) calculate a symbol of prediction at any time from the symbol of prediction at time t=0, and,

(3) assess the probabilities of a given set of contextual outcomes of measurements at any time from the element of prediction at this time.

Secondly Destouches analyses the third step, namely the assessment of probabilities by using an element of prediction, in three more parts. These three further parts are the following:

(1') determine the *basic elements of prediction* of the variable to be measured, namely the elements of prediction which would yield probability 1 for a given value of the variable,

(2') after having completed the set of elements of prediction in such a way that it acquires the structure of a vector space, make the relevant element of prediction correspond to a linear superposition of the basic elements of prediction, and,

(3') show that the probability that a given value of the variable be measured, is a function of the coefficient which multiplies the corresponding basic symbol of prediction in the linear superposition.

The most interesting part of Destouches' endeavour concerns the latter point, namely the determination of the function which associates a certain probabilistic valuation to each coefficient of the linear superposition. In the initial version of the general theory of predictions, namely in *Corpuscles and systems of corpuscles,* Destouches contented himself with some restricting theorems showing that there is a well-defined class of acceptable functions for probabilistic valuations. But in 1946, Paulette Février[33] used a generalized form of the Pythagoras theorem borrowed from von

[33] P. Février, "Signification profonde du principe de décomposition spectrale", Compte-Rendus de l'Académie des Sciences, 222, 867-868, 1946

Neumann, to show that whenever a single symbol of prediction is used in order to predict the probabilities of phenomena in two or more mutually incompatible experimental contexts, the acceptable probabilistic function becomes unique. Now, this unique function is such that the probability of obtaining the value of a certain variable is equal to the square modulus of the corresponding coefficient in the linear superposition. This is exactly *Born's rule,* or alternatively the formula which gives the intensity of each chromatic component in a wave.

With this remarkable result in mind, Paulette Février and her husband Jean-Louis Destouches were entitled to claim that they had finally clarified the "deeper meaning" of the strange "probability waves" that occur in quantum mechanics. This meaning is not that probability waves somehow describe real waves *out there,* as de Broglie contended in 1923; it is rather that wave-like distributions of discrete phenomena are the most specific mark of the *relativity* of these phenomena with respect to mutually incompatible contexts. And since (i) the quantization of variables could be derived from the wave-like formalism of quantum mechanics, and (ii) indeterminism had already been derived directly from contextuality, Paulette Février and Jean-Louis Destouches concluded that every single distinctive feature of quantum mechanics was nothing more than a consequence of the contextuality of phenomena combined with the incompatibility of certain couples of contexts. At that point, Jean-Louis Destouches and Paulette Février had the feeling that they had made a major meta-theoretical discovery. They thus published together a paper entitled "On the physical interpretation of wave mechanics"[34]. They concluded their paper with the following enthusiastic sentences: "Every characteristic of the quantum theories devive from the former principles. Now, apart from the second principle (of subjectivity), these principles underly all the physical theories. If one retains, instead of this second principle, a principle of objectivity (existence of state magnitudes), one obtains classical

[34] J.L. Destouches & P. Février, "Sur l'interpretation physique de la mécanique ondulatoire", Compte-Rendus de l'Académie des Sciences, 222, 1087-1089, 1946

theories. But if one retains the principle of subjectivity, one obtains the quantum theories. (...) Thus, the mystery of *quanta* disappears: the *quanta* originate in the inexistence of a fully objective external world, independent of the way one makes experiments on it. There has been a shift of objectivity. The results of measurements are properties of the complex apparatus-system, without any possibility of telling the contribution of the system in the result. This is enough to explain quantization and all the other characteristics of quantum theories".

I realize that these formulations of Destouches and Destouches-Février are quite misleading. They make a fuzzy reference to "subjectivity", when nothing else than *contextuality* is concerned. And they adopt a metaphysical stance to assert the "inexistence" of a fully objective external world, whereas they should content themselves with pragmatic remarks about the impossibility of *treating* phenomena *as if* they were direct reflections of properties. However, provided one avoids these improper wordings, provided one complements their analysis with more recent results, such as Gleason's theorem, I think the conclusion of J.L. Destouches and P. Février can still be upheld nowadays[35]. This conclusion is tantamount to showing that the basic framework of quantum theories is the most economic structural precondition of a unified system of probabilistic predictions bearing on contextual phenomena. In other terms, the structure of a theory is accounted for, in a large proportion, by a transcendental argument. This is the highest ambition of transcendental structuralism.

Now, Jean-Louis Destouches did not restrict his contextualist critique of the ontological furniture of physics to the *properties* of physical systems. He extended this critique to the systems themselves. According to him, the concept of a physical system is relative to an operational procedure of parcelling out, or in other words of "splitting up of the undifferentiated reality"[36]. This being granted, physicists are allowed to keep on with an almost unaltered

[35] M. Bitbol, *Mécanique quantique, une introduction philosophique,* Paris : Flammarion, 1996; M. Bitbol, "Some steps towards a transcendental deduction of quantum mechanics", *Philosophia Naturalis,* 35, 253-280, 1998

[36] J.L. Destouches, *Principes fondamentaux de physique théorique,* op. cit. vol. 2, p. 177

mode of speech provided they do not forget that it has a very limited scope. According to Destouches, "We can perfectly use an almost realist language to speak about physical systems and their parts, although we know that this language has no longer an absolute value, 'in itself', but is relative to (a certain experimental method)"[37]. Actually, things are slightly more complicated than what is implied by this sentence. In view of Kant's critical philosophy, physics, either classical or quantum, is *never* concerned by things in themselves. Then, the problem is not to know whether quantum physics deals with things in themselves or not (since the answer to *that* question is negative from the outset), but once again whether the order of microscopic phenomena is such that one may speak *as if* they manifested the behaviour of systems having intrinsic properties and an intrinsic existence. Destouches' answer to the latter question also is clearly negative. He does not only insist that the order of phenomena which are relative to incompatible contexts is not such that one can speak and behave *as if* they manifested intrinsic properties. According to him, this order of phenomena also challenges the possibility of speaking and behaving *as if* a well-defined number of systems pre-exists to any experiment. Indeed, the concept of physical systems requires not only that a procedure of splitting up has been led to completion, but also that the byproducts of the said splitting up can be individualized and reidentified across time[38]. Individualization and reidentification across time being not always possible, one often deals with indiscernible microsystems. The problem, says Destouches, is then that indiscernible objects can no longer be arranged in a definite order or counted[39]. Sets of microobjects must be ascribed very peculiar characteristics, which do not even allow one to treat them according to classical set theory. As Destouches points out, "(...) one may ascribe a cardinal number to a set of physical elements of the same species, but one cannot establish any ordering between elements; in this case, the concept of ordinal

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[37] ibid. p. 177
[38] ibid. p. 270 sq.
[39] ibid. p. 281; also chapter I of *Corpuscules et systèmes de corpuscules,* op. cit.

number is completely devoid of physical meaning"[40]. But if the concept of ordinal number is generally devoid of physical meaning, if procedures of continuous monitoring and counting are generally precluded, then one must realize that the ascription of a cardinal number to a set of physical elements cannot be dissociated from the very act of "splitting up" which defines them. In the same way as dynamical properties of microsystems have been replaced by relational observables, the property "number of elements" ascribed to sets of microsystems have therefore to be replaced by an appropriate relational observable. The property "number of elements" is just as relative to the process of splitting up as any other property.

One may notice incidentally at this point that the modified set theory (or quasi-set theory) developed by G. Toraldo di Francia and D. Krause[41] to deal with the problem of indiscernible microsystems, can be considered as a modern development of these early reflections of Jean-Louis Destouches. Indeed, its central feature precisely consists in modifying the extensionality axiom in such a way that a set can have a cardinal without having an ordinal number.

Conclusion

To sum up, Jean-Louis Destouches was fully aware, as Ernst Cassirer was at about the same time, that the quantum revolution could not be restricted to a change from deterministic to indeterministic laws. He thought, in the same way as the most radical advocates of the Copenhagen interpretation of quantum mechanics, that this revolution was bound either to jeopardize the very ontological furniture of classical physics, or to confine the latter ontology in a metaphysical world devoid of any empirical content. Accordingly, he applied his transcendental structuralism not only to properties but also to entities. Any descriptive discourse

[40] ibid. p. 180

[41] M-L. Dalla Chiara & G. Toraldo di Francia, "Individuals, kinds and names in physics", in: G. Corsi et al. (eds.), Bridging the gap: philosophy, mathematics and physics, Kluwer, 1993; D. Krause, "On a quasi-set theory", Notre Dame Journal of Formal Logic, 33, 402-411, 1992

about the hypothetical bearers of properties was discarded, and replaced by a network of relations between symbols allowing prediction of phenomena. True, later investigation into the foundations of quantum mechanics showed that this view could take advantage of no decisive *proof*. But it opened an alternative philosophical research program, which is just as promising as the ongoing “realist” program (including its structuralist version), and which moreover has some advantages over the latter. Among these advantages I would like to single out two of them:

(i) Transcendental structuralism is very much in tune with the current connectionist and non-representationalist trend in the theories of cognition; and we know that synergy between cognitive science and philosophy of science is presently a very powerful incentive for both disciplins;

(ii) Transcendental structuralism also provides a natural philosophical frame for several recent derivations of quantum mechanics from information-theoretical assumptions, such as Zeilinger’s or Bub’s.