Mathematical demonstration and experimental activity: a Wittgensteinian philosophy of physics

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Abstract : This article aims at reducing the gap between mathematics and physics, from a Wittgensteinian point of view. The gap between the two disciplines is usually characterized by two discriminating features. (1) The propositions of physics assert something which might be false; they have a hypothetical character. On the contrary, since mathematical propositions are rules that condition the form of assertions, they remain immune from falsification. (2) The propositions of physics refer to *facts* that may confirm or refute them. On the contrary, since mathematical propositions have no meaning independently of the demonstration procedures, one cannot say that they refer to "facts" that pre-exist demonstrations. If we take a closer look, however, these two differences fade away. On the one hand, the propositions of physics are usually more resistant to experimental tests than has been said in the wake of logical positivism. On the other hand, the "factual" empirical material is defined and co-constituted by instruments whose arrangement may be determined by the theory to be tested (just as mathematical propositions are defined and constituted by demonstration procedures). I conclude by discussing the possibility of a Wittgensteinian philosophy of contemporary physics.

The purpose of this paper is to sketch a philosophy of physics in the spirit of Wittgenstein (though not a strictly Wittgensteinian philosophy of physics). A preliminary step is provided by some remarks on the relations between the Wittgensteinian conception of mathematics and the contemporary philosophy of physics.

My first remark bears on the difference between mathematical propositions and factual propositions. At first glance, imposing a radical distinction between these two kinds of propositions is an inescapable feature of Wittgenstein's philosophy of mathematics. In his book *Le pays des possibles*, Jacques Bouveresse points out that if we do not keep this distinction between factual propositions and mathematical propositions in mind, we simply cannot understand Wittgenstein's insistence on the conceptual gulf between conjectures and demonstrations. In mathematics, it is demonstration, and demonstration alone, that gives meaning to the demonstrated proposition; by contrast, according to Wittgenstein, a conjecture is only "(...) a signpost for mathematical research, and an incentive for mathematical construction"[1]. Since, in mathematics, a proposition has no meaning independent of the demonstration which leads to it, then in no case can one say that a conjecture and a demonstration point to the same pre-existing "fact"; in no case can we say that a conjecture is a proposition stating in advance a *fact* which the demonstration will establish. Only an incorrect analogy with the strategy of the natural sciences, which are deemed to have natural 'facts' as their object, tends to make us believe this.

The gap between the propositions of the natural sciences and the propositions of mathematics becomes even broader when it comes to their respective status. The propositions of the sciences of nature assert something which might be false; they are *hypothetical*. Mathematical propositions, on the other hand, are rules which condition the *form* of all that we can assert about what falls within their domain of validity. The sensitivity to refutation of the propositions of the sciences of nature appears to oppose the statutory immunity of the propositions of mathematics. However, the distance between the two kinds of propositions can easily be reduced. This can be done while remaining faithful to Wittgenstein's critique of mathematical Platonism and formal realism, if one agrees to bring the physical propositions closer to the mathematical propositions, rather than the other way round. The outcome of this move turns out to be a compromise between Wittgenstein's explicit divide between mathematical and physical propositions, and Quine's undifferentiated, holistic conception of the set of scientific propositions.

Let us begin, then, with a critical examination of the hypothetical nature of the propositions of the natural sciences.

[1] L. Wittgenstein, *Philosophische Grammatik,* Basil Blackwell, 1969, p. 371; Trad. Fr. M-A. Lescourret, Gallimard 1980; cité par J. Bouveresse, *Le pays des possibles,* Minuit, 1988, p. 196

It is true that in his text closest to verificationism, namely in paragraph 225 of the *Philosophical Remarks,* Wittgenstein likens ordinary and scientific propositions to *hypotheses* coupled more or less closely with reality. But then, in paragraph 227 he states that "a hypothesis is connected to reality by a link which is *looser* than that of *verification*", and this has the consequence that "... a hypothesis is renounced only for something that has an even higher value" [2]. In other words, for Wittgenstein, as for Lakatos later on, the propositions of the natural sciences are more robust than was believed in the atmosphere of logical positivism, and more robust, at any rate, than what the word "hypothesis" suggests. The central reason for this robustness is the holistic solidarity of these propositions. "It is not a *single* proposition that I juxtapose to reality as a measurement standard, but the *whole system* of propositions", Wittgenstein writes in paragraph 82 of his *Philosophical Remarks*[3]. Similarly, paragraph 141 of *On Certainty* states that "if we start to believe something, it is not an isolated proposition but an entire *system* of propositions"[4]. In this system there are elements that are more or less mobile and fragile, and others rendered more or less fixed and solid in virtue of their axial position in the motion of the whole; but no refutation can be made without potentially threatening the whole system, since no individual element is *absolutely* intangible.

If one slightly stretches the previous remarks, it seems that it is only by way of an evaluation of their different degree of integration into the system that Wittgenstein maintains a distinction between the propositions of mathematics and the propositions of physics. However, as mentioned previously, Wittgenstein considers that the propositions of mathematics consist of norms rather than descriptions; and this seems to make them radically different from the empirical propositions of physics. Yet, things are not so simple. As Wittgenstein asks, are certain physical laws (such as the laws of Hertz'

[2] L. Wittgenstein, *Remarques philosophiques,* Gallimard, 1975, p. 271
[3] ibid p. 107
[4] L. Wittgenstein, *De la certitude,* Gallimard, 1976, p. 57

mechanics) not norms rather than descriptions?[5] Does Hertz not assert at the outset of his treatise on mechanics that any apparent deviation from his laws should be considered as due to hidden masses, which transforms such laws into norms for the search procedure of still unknown masses? Only the *extent* to which the belief system has to be questioned in the case of an alteration of certain mathematical propositions, exceeds what must be done in the case of an alteration of the laws of Hertz's mechanics. Firstly, every scientific proposition, including the propositions of mathematics, can be challenged during a scientific revolution. This is the case, e.g., of the propositions of (Euclidian) geometry, that were challenged by the advent of General Relativity and its Riemannian fabric. Secondly, and conversely, most scientific propositions, including the propositions of theoretical physics, can hold the position of norms for research.

In spite of this, no position inspired from Wittgenstein can be likened to that of Quine, who drew the ultimate consequence of similar holistic reflections by radically challenging any distinction between necessity and contingency, between analytic and synthetic, between norm and description[6]. Indeed, Wittgenstein was aware that the absence of a reason for hypostatizing the necessity and normativity of certain scientific propositions (especially those of mathematics) does not imply that the difference between them and the empirical propositions has no role to play in the *practice* of science. These two kinds of propositions in practice fulfill different *functions,* although they are not different in principle. On the one hand, in the absence of in-principle difference, the propositions of mathematics and the propositions of physics can fulfill alternatively the normative and the empirical *functions*. They are functionnally interchangeable. On the other hand, their (normative or empirical) *functions* are strictly exclusive of one another.

[5] L. Wittgenstein, *Wittgenstein's lectures, 1932-35,* A. Ambrose (ed.), B. Blackwell, p. 16; cité par J. Bouveresse, *La force de la règle,* Minuit, 1987 p. 168

[6] L. Wittgenstein, *Wittgenstein's lectures, 1932-35,* op. cit. p. 69; J. Bouveresse, *La force de la règle,* op. cit. p. 147.

The second way we have to reduce the gap between physical propositions and mathematical propositions is to question the very concept of "fact". The idea of a pre-existence of the factual content of empirical knowledge, and the foundational position attributed by logical positivists to observational statements, have long come under criticism. But this criticism remains incomplete as long as it confines itself to stressing the "theory-ladenness" of facts; for nothing prevents us from understanding this expression as saying that what we call "facts" in the natural sciences results from the theoretical overinterpretation of some raw "empirical material" which remains the solid ground of research in the natural sciences. A reflection on quantum mechanics and especially on Bohr's holistic concept of phenomenon suggests that we should go further. Quantum mechanics encourages us to consider that the so-called raw empirical material itself is both defined and co-constituted by instruments whose arrangement is determined by the theory to be tested.

Andrew Pickering follows this process of de-reification of "fact" to its logical conclusion. He rarely refers to Wittgenstein. But when he does so, it is to acknowledge that his philosophy of mathematics and physics is inspired by Wittgenstein. The slogan Pickering borrows from Wittgenstein is the following : "Every sign by itself seems dead. What gives it life ? In *use* it is alive"[7]. Pickering then asserts, in the same spirit, that "conceptual systems hang together with specific disciplined patterns of human agency"[8].

This idea has taken on the evocative name of "Mangle of practice". Indeed, according to Pickering, it is from a complex mechanism including cognitive, normative, social, material, technological, interpretative, formal, elements that our "world picture" arises. Pickering's option is to reverse the traditional relationship between the representationalist idiom of the theory of knowledge and the "performative idiom" of the experimenters. Far from holding the performative idiom for a

[7] L. Wittgenstein, *Philosophical Investigations,* 1953, § 432
[8] A. Pickering, *The mangle of practice,* op. cit. p. 115

mere auxiliary of the representationalist idiom, taken as the only holder of truth, Pickering considers that the representationalist idiom is derived from the performative idiom by imposing ontological crystallizations onto it. His lineage is pragmatist, as many references to James and Dewey make it clear [Pickering 1995, 179]. The principle of Pickering's approach then consists in refusing to adopt from the outset the point of view of the *final* result of the experimental and conceptual practices of the researchers, where one can make a distinction between what belongs to real objects and what arises from the subject's intervention [Latour 1997]. Instead, Pickering says, one should follow the course of these practices, which consist indistinctly in actions-of-subjects-in-the-reality-they-partake-of.

Once this return to the performative source of the sciences of nature has been accomplished, the question that arises is no longer that of the *correspondence* between human knowledge and a pre-constituted external nature, but that of the co-stabilization within practice:

(a) of objects that can be treated *as if* they were independent of this practice,

(b) of theoretical structures which, beyond their value as a predictive instrument, can be interpreted as descriptions of these processes or objects.

In other words, one no longer wonders how it is possible that a theory be the faithful representation of an independent reality, but how the activity of the researchers makes it possible to elaborate the relation of representation. One no longer worries about whether a correspondence between reality and its representation exists ([Kant 1800, 54][9]), but just wonders by what performative and adaptive path a situation that allows one to speak *as if* there were such a correspondence has been established. The central axis of research practice is the experimental instrumentation, or more broadly the set of tools and "machines" used in the laboratory. These instruments first

[9] "(...) Since the object is outside me and knowledge is in me, all that I can appreciate is if my knowledge of the object agrees with my knowledge of the object. The ancients called 'diallel' such a circle in the definition".

embody an investigation project because they are oriented towards the production of the conditions that one wishes to explore. And secondly, they represent the place where the obstacles which oppose the smooth running of the initial plans manifest themselves. The instruments closely combine these two characteristics, because they allow these obstacles to be revealed only through the reading grid imposed by the project that led to their conception. Since the obstacles are informed by a project of action incorporated in the apparatus, Pickering considers it unwise to call them "constraints". According to him, the term "constraint" connotes the static and pre-given character of the obstacle [Pickering 1995, 66]. On the contrary, the term "resistance" suggests the reciprocity of a reaction responding to action. The water of the ocean thus raises a resistance to a ship's progress. The resistance of the water, with its directional structure and its intensity, emerges at the same time as the planned act (namely the directional progression of the boat) to which it opposes. [Pickering 1995, 67].

The consequence of this change in vocabulary and concepts is a decrease of the temptation to ascribe ontological significance to the obstacles encountered by research. "Constraints" may be held to be something that already exists, and that scientific theories have to discover and represent. On the contrary, "resistances" are structured by practice; they are neither due exclusively to the medium explored nor exclusively to the exploration project, but to the joint contribution of the two terms. Here, what is given the antecedence it takes to be ontologized (the explored "environment"), does not possess by itself the structures that can be represented. Conversely, the structures that arise in reaction to an ordered activity, and which are representable, do not have enough independence to be granted an "ontological" dignity.

Ian Hacking, who also supports this passage from "constraints" to "resistances", offers a provocative formulation of it: scientific researchers do not *explain* pre-given phenomena, he writes; they "create" phenomena by their activity [Hacking 1983, 355]. However, once this very strong thesis is asserted, I. Hacking finds himself led to qualifications and concessions.

Firstly, Hacking considers there are some exceptions to his general thesis of the "creation" of the reproducible phenomena scientific theories must account for. One such exception is astronomical phenomena.

Secondly, with regard to the phenomena or "effects" obtained in the laboratory (such as the "Hall effect"[10] or the "Josephson effect"[11]), Hacking admits that they are not created from scratch but *isolated and purified* from a complex natural process.

However, these two concessions could have been downplayed.

Firstly, the belief in pre-given astronomical regularities seems self-evident only because the conditions of their constitution are common-place; too common-place for anyone to pay attention to them. In order for astronomical regularities to emerge, we must first have given ourselves the means of re-identifying celestial bodies, through the succession of days and nights, or before and after their occultation by clouds. It is also necessary, as soon as these celestial bodies have been reidentified, to follow them along their trajectory by means of appropriate coordinate systems. Without these procedures of re-identification and tracking, there would be no regularity and therefore no astronomical "phenomena" to be "saved" by any "world system" whatsoever.

Secondly, the idea of a mere decomposition of the natural complexity into "effects" isolated in the laboratory is far less audacious than Bohr's conception of quantum phenomena. According to Bohr, a phenomenon is not something to be treated as if it occurred spontaneously in nature, and it is not even something that could be separated from the natural becoming by an active process of analysis. Experimental instrumentation does not play only the role of a means to *isolate* pre-given phenomena; it participates indissolubly in

[10] An electrical current crossing a material submitted to a magnetic field generates a tension in a direction orthogonal to the current.

[11] An electrical current arises between two superconductors separated by an insulator.

their *definition* by its architecture, and in their *production* by its uncontrollable and irreversible operation. However, the phenomenon is not individually determined by a decision of the experimenter. Its capacity to manifest "resistance" to inappropriate theorization remains intact. Only the range of possibilities to which it belongs depends on the research project that is embodied by the apparatus.

Why, then, are neo-pragmatist philosophers of sciences suspected of maintaining that facts are "fabricated" by the experimental subject? This suspicion reveals above all the frame of thought of those who formulate it. In the dualistic context of the theory of knowledge, it is indeed natural to consider that the reason why the phenomenon "revealed" by experiments cannot be attributed to the object alone, is that the subject has fabricated somehow this phenomenon. But in the context of an emergentist conception, the division of tasks between a stabilized object and a cognitive and social subject able to describe it, is a secondary outcome of the investigation rather than its starting point.

In any case, regions of stability manifest themselves in the course of the dialectical history of the physical sciences, and they cry out for explanation. From a neo-pragmatist perspective, these regions of stability do not express genuine "discoveries" but rather stationary cycles of locally optimal adjustment between theories and experimental instrumentation. The transformations of theoretical structures and laboratory apparatus follow one another, until they reach a state where they become, at least for some time, "mutually self-justifying" [Hacking 1992]. This circle proves to be "virtuous" rather than "vicious" because it is both open and open-ended. It is open to any unexpected event arising from the unspecified part of the experimental device, and open to redefinitions of the experimental devices, thus becoming open-ended.

This neo-pragmatist concept of a virtuous circle has the advantage of going beyond the usual and hopeless opposition between the correspondence theory of truth and a thesis that ascribes the truth of theories to their *internal* coherence. Hacking's virtuous circle extends the coherence theory of truth, which was purely intellectual at first, to practices and phenomena. We can give meaning to Hacking's idea of coherence between statements and practices, by putting it in contrast with the concept of "performative contradiction" due to K.-O. Apel. It is performatively contradictory to argue against the validity of arguments in general, for this very act of enunciation is inconsistent with the content of the statement it makes. Similarly, it is performatively contradictory to use an interferometric device to produce new optical phenomena (such as holography) if one adheres to Newton's corpuscular theory of light, since the configuration of the apparatus does not correspond to any effect that can be predicted by means of this theory. In both cases, "doings" are opposed to "sayings", and it seems possible to infer, conversely, that only certain "doings" agree with certain sayings. This kind of agreement is what we will call *generalized coherence,* or theoretico-performative coherence.

The generalized coherence theory of truth has important consequences. In the framework of this theory, all that can be said of a theory is that it is true of *this* category of phenomena, manifested by means of *this* idealized class of activities using *this* kind of instruments. Conversely, when a new resistance arises, thus destabilizing a circle of coherence, it must not be conceived as a piece of information making the associated theory "false" in the sense of a lack of correspondence to the real *external* source of information. Instead, this resistance merely indicates that the present circle of practices, material devices, and concepts has inadvertently come out of the field of operativeness of the theoretical and performative rules that governed the previous circle; and that it then gives rise to a new ongoing dialectic of resistances and adaptations.

This idea of a theoretico-performative circle of coherence is exploited in various ways, depending on the authors. Hacking attaches decisive importance to the gradual detachment of the "virtuous circle" of resistances and adaptations from the socio-historical circumstances that accompanied it during its stabilization phase. Hence the affinity of Hacking's position with entity realism: if a theoretico-performative circle that is stable, unique and autonomous with respect to the history of its production is operating, nothing prevents us from treating as *real* the entities that the theory considers as manipulable. In contrast, Pickering appears reluctant to let his "pragmatic realism" turn into a form of entity realism. Pickering admits the possibility of a "freezing" of procedures, of a "mechanical" iteration of gestures, and of a stabilization of the "dance" of practices into a stable "choreography" [Pickering 1995, 102]. But he constantly insists on the emergent nature (and hence on the historical antecedents) of these cyclical processes. And he emphasizes that, according to him, the trace of the history that led to each cycle can not be erased (thus siding with historicist relativists).

An objection that I make to the main protagonists of this debate is that the situation inaugurated by quantum physics does not easily agree with any of the two main options they propose.

On the one hand, standard quantum mechanics appears free from the historical, cultural, and conceptual contingencies that have produced it. We should not forget that this formalism was conceived by Dirac and Von Neumann on the basis of two initial theories (matrix mechanics and wave mechanics) which derive from two mutually exclusive models, one discontinuous and the other continuous. As an abstract residue of these two antagonistic lines, or as their lowest common denominator, the quantum formalism was doomed to retain as little as possible of both.

But on the other hand, this strong dehistoricization of quantum theory is far from having lifted all the difficulties of a realist conception of its entities. There are considerable obstacles to such conceptions. It is in particular excluded to replace the concept of "observable" with that of property (which would justify the attribution of a predicate to something) ; it is also excluded to replace the concept of number of quanta of excitation of an oscillator of the "quantum vacuum" with that of spatio-temporally localized and reidentifiable objects (which would justify referring to something isomorphic to a material body). Many difficulties make unlikely the projection of the stability of the immanent theoretico-performative cycle of quantum physics, into transcendent entities. Here, one realizes that the usual alternative, between maintaining the connection of theories with the history of their emergence, and a realism based on the an-historicity of these theories, no longer works. The reason why this is so, is that the quantum formalism reflects not only the actual dialectic of resistances and adaptations of which it is the fruit, but also a very general, and until now exhaustive, class of possible resistances and possible adaptations.

Thus, however dehistoricized quantum physics may be, it carries within the very structure of its formalism the trace of an impossibility of detaching phenomena and entities from the experimental circumstances of their manifestation. The fact that successful manipulations are carried out under the presupposition of the existence of such entities does not in any way attenuate this finding. For this presupposition can only be maintained locally, between the limits required by the activity guided by it. It does not have the universality required to be projected ontologically. Quantum mechanics is then at odds with both a relativistic historicism *and* a realism of entities. It invites a new approach to physical theories, that associates neo-transcendental aspects with pragmatist elements. Now, as I previously pointed out, I consider that this kind of combination of *a priori* and *a posteriori,* of functional *a priori* and performative *a posteriori* is typical of Wittgenstein's philosophy of science.

The throbbing question of the "unreasonable effectiveness of mathematics in the natural sciences" [Wigner 1979] is also addressed by the neo-pragmatist philosophers of science. Pickering makes a distinction between at least three levels of the dialectic of resistance and adaptation. Three levels that should not be mixed up despite their ability to retro-act on each other. One of these levels concerns laboratory practices, the second concerns mathematical theories, and the third, which involves the search for the "alignment" of the first two, concerns physical theories. The central remark here, is that mathematical theories emerge, like physical theories, from a dialectic of resistances and adaptations. The only difference being that in mathematics the resistances do not come from a "material generativity" at work in experimental instruments, but from a "disciplinary generativity" imposed by rules of symbolic concatenation. As for the "alignment" between mathematics and physics, it consists in selecting the symbolic structures and the disciplinary resistances which admit among their *possibilities* the operative structures and the actual resistances of certain experimental research activities. Far from the "Platonic" conception of mathematics, one then avoids the mystery of a correspondence between the entities of the world of forms and the tangible entities of the physical world.

Let us emphasize here again the peculiarity of quantum physics. If we had dealt with classical physics alone, one could indeed have objected that interpreting mathematical entities as projections of a stabilized cycle of symbolic operations, and natural entities as projections of a stabilized cycle of experimental practices and theoretical expectations, only introduces unnecessary complications. Since the neo-pragmatist epistemologists themselves admit the reciprocity of the relation between cycles of practice and postulated entities, is there any reason not to adhere unreservedly to the way in which physicists remove the scaffolding of practices to deal exclusively with entities? And is there any reason left in this case for not taking their meta-representation of a correspondence between natural and theoretical entities seriously?

Things change completely with quantum mechanics; that is to say with a theory whose symbols are not immediately interpretable as representing properties belonging to natural entities but as instruments of probabilistic prediction of phenomena obtained under specified experimental conditions. For, in this case, the idea of conferring on the theory the purely "grammatical" status of a predictive norm no longer has to be justified by an archaeological work about the circumstances of the elaboration of this theory; here, this grammatical status imposes itself from the outset. Conversely, the usual tendency to consider a theory as the representation of a system of relations between natural entities now requires a long, difficult, and cumbersome justification; a justification which sometimes calls for non-classical logics, sometimes for instantaneous influences at a distance between processes inaccessible to experience.

At this point, many of the lessons learned from the Wittgensteinian philosophy of mathematics can be transposed almost immediately to the case of the natural sciences. Let me take an example. Jacques Bouveresse pointed out that, according to Wittgenstein, "The connection that exists between arithmetical propositions and reality can only be shown in their application. There is therefore no question of describing this connection in terms of a comparison with facts accessible from a point of view completely external to the practice of the language game"[12]. An equivalent of this assertion for the natural sciences would be that "the connection that exists between physical theories and reality can only be shown through the instrumental structures they invite to set up, and through the outcome of the working of such instruments. There is therefore no question of describing this connection in terms of a comparison with facts accessible from a point of view completely external to the practice of a technological game".

Maintaining a dichotomy between "facts" and theoretical norms despite its epistemological dissolution, can nevertheless be justified in physics by a reason similar to that which led Wittgenstein to maintain an effective dichotomy between the contingency of empirical propositions and the necessity of mathematical propositions. For, refusing to hypostasize "facts", refusing to grant them an autonomous existence from a point of view completely external to a practice of technological and symbolic games, does not imply that distinguishing them from the principles that guide such practice has no heuristic function to fulfill.

In the same way, the usual distinction between propositions of physics that are essentially descriptive, and mathematical

[12] J. Bouveresse, *La force de la règle,* op. cit. p. 142

propositions serving as a norm and guide for operations, is attenuated considerably if we recognize that, strictly speaking, the propositions of theoretical physics do not describe any pre-existent process; that they operate as normative guides for the experimental practices from which phenomena arise.

Undoubtedly, the idea of likening propositions to a guide of activity, be they propositions of the empirical sciences or propositions of mathematics, was not foreign to Wittgenstein.

One can be convinced of this by reading a sentence in paragraph 113 of the *Philosophical Grammar:* "In what sense can I say that the proposition is an image? When I think about it, I want to say: it must be an image to show me what I have to *do;* So that I may guide myself according to it". Thus, the descriptive and figurative conception of propositions conveyed by the *Tractatus* is here changed into a conception with pragmatist undertones, applied to ordinary language, to experimental sciences and to mathematics as well. At most, one must maintain a clear distinction between mathematical propositions and physical propositions on another plane, by emphasizing that mathematical propositions guide the disciplined symbolic practice of computation and demonstration, while physical propositions guide the disciplined operational practice of experimental preparations, and technological design. Thus, the central role of mathematics in the physical sciences may well be to offer a symbolic translation of the coordinated set of gestures performed in the laboratory.

It is now time to read other texts of Wittgenstein so as to know what he himself thought of the relations between his conception of mathematics, and the problems of the physics of his time. The indications on this point are rather scarce and scattered, but very rich. The first indication I have noted is in paragraph 225 of the *Philosophical Remarks:* "The views of contemporary physicists (such as Eddington) are quite consistent with mine when they say that in their equations the signs no longer have any meaning (or reference), and that physics cannot lead to such meanings but must remain at the level of signs"[13]. In this sentence, Wittgenstein seems to accept that his warning against the temptation to consider that mathematical propositions refer to "facts" of a particular kind, and mathematical symbols to objects of a Platonic universe, can also be relevant to physics and its traditional ontological claims. Very quickly, however, Wittgenstein adds an important *proviso:* "To tell the truth (contemporary physicists) do not see that these signs have a meaning insofar as (...) the observed phenomenon immediately corresponds or does not correspond to them". Then, even though Wittgenstein approves of the idea that the signs which occur in the symbolism of physical theories have no transcendent referent, he distinguishes these signs from the signs of mathematics by asserting that they at least have a meaning which is conferred to them by their relation to *phenomena*. According to Wittgenstein, the Bohrian considerations of many physicists of the early 1930s on the purely symbolic and non-referential character of the formalism of quantum theory are tantamount to the following immanentist statement: that "the phenomenon is not the symptom of something else, it *is* the reality"[14].

The problem is that the consequences of the reflection of the creators of quantum mechanics are only half-acknowledged by Wittgenstein; for, as I pointed out earlier, even what one would like to call "the pure matter of the phenomenon" is not independent of the theoretical project of investigation embodied by the instrument which defines and co-constitutes the phenomenon. As soon as this has been recognized, one can go much further than Wittgenstein in the parallel between mathematics and physics. In this case, what Wittgenstein said about the link between the mathematical proposition and the deductive system which leads to it, can also be said of the link between the physical assertion and the instrumental and formal system on which the phenomena depend. Just as, in mathematics, a proposition has no meaning independent of the demonstration which leads to it, in physics, a factual statement

[13] L. Wittgenstein, *Remarques philosophiques,* op. cit. p. 270
[14] ibid.

has no meaning independent of its formal, instrumental, and performative context.

Wittgenstein may then have been shy in his analysis of some revolutionary teachings of quantum mechanics. However, he clearly saw that the specificity of quantum theory was not so much due to the purely symbolic character attributed to it by physicists in the 1930s, as to the fact that this symbolic character is much more obvious in this case than in classical physics. A short paragraph at the end of point 6 of the appendix to his *Philosophical Grammar* illustrates this point: "Imagine that we invented to play chess not on a chessboard but with figures and letters (...). But now, someone discovers that this game perfectly matches a game that can played on a chessboard (...). This discovery would have greatly facilitated the game (...). But it is clear that this new illustration of the rules of the game would only be a new symbolism easier to dominate (...). Compare this now to what is said about physics, which today no longer works with mechanical models, but only 'with symbols'"[15]. Thus, according to Wittgenstein, a physical theory that uses mechanical models, as was often the case in the nineteenth century, is just as symbolic as quantum physics; only the type of symbol changes from one case to another. In neither case should one think that a physical proposition has a transcendent referent, even though the physics of the nineteenth century made it particularly tempting to think so, by way of a one-one correspondence between the elements of its mechanical models and the putative referents.

Another remark I would like to make bears on texts where Wittgenstein implicitly clarifies some conceptual problems of contemporary physics, by way of appropriate metaphors. A striking example is the problem of "indistinguishable particles", which Wittgenstein explores in a few brilliant sentences of the appendix to the *Philosophical Grammar,* without ever naming it explicitly. "The meaning (of a name)", he writes, "changes according to the criterion which will tell us whether this object is the one I had called N before". Here,

[15] L. Wittgenstein, *Grammaire philosophique,* op. cit. p. 228

Wittgenstein does not assert flatly (as an empiricist or a verificationist would do) that the meaning of name is exhausted by the list of the criteria used to identify its referent, or that the meaning of an expression is exhausted by the list of its verification criteria. He just says that, independently of these criteria, such names and expressions would be meaningless, and that, therefore, their meaning indirectly relies on these criteria. In the precise case he evokes, the meaning of the name relies on the re-identification criteria that apply to the named object. The typically quantum case where re-identification criteria are lacking, is developed immediately after (here again, without explicitly mentioning quantum physics): “If we give names to objects in space, our use of these names rests on the criterion of identity, a criterion which presupposes the continuity of the movement of bodies and their impenetrability. If with A and B I could do the same things as with their shadows on the wall, of the two bodies making one, then two again, it would be absurd after that to ask which is A and which is B”. In other words, without re-identification criteria, the very possibility of naming is lacking. This position is quite interesting in the current debate which opposes: (a) philosophers of physics according to whom it is not incorrect to treat the case of indistinguishable particles by first naming them separately and then subtracting permutation terms, and (b) other philosophers who emphasize, on the contrary, that the very conditions of the act of denomination cannot be fulfilled in quantum physics, and that it is therefore incorrect to attempt to instantiate the classes “Electron, proton, quark u, etc.” by individuals (*this* particular electron, *this* particular quark, etc.)[16]. By the quoted sentences, Wittgenstein shows that he leans towards the latter. And he confirms this option when he writes “We must not mix up the question ‘which object satisfies the predicate F’ with the question ‘what *kind* of object etc.’. (...) So, asking ‘which red spot do you see?’ may be meaningless, but asking ‘what *kind* of red spot you see (a

[16] M. Bitbol, *Mécanique quantique, une introduction philosophique,* Champs-Flammarion, 1997, §4-3-2, 4-4-2; M. Bitbol, *L'aveuglante proximité du réel,* Champs-Flammarion, 1998, chapitre 5

round, or a square etc.)' makes sense"[17]. Often, in microscopic physics, it makes no sense to ask which particular particle is involved in a reaction, due to the lack of identification procedure. But it always makes sense to ask what *kind* (bosonic or fermionic, protonic or electronic, etc.) was involved in a process. Indeed, this question admits a possibility of unequivocal answer through the measured values of a list of "superselective observables".

To recapitulate, what Wittgenstein warned us about is the temptation to deal with the philosophy of contemporary physics at a low cost by continuing to use familiar modes of expression, sometimes (as most physicists do) by accepting minor adaptations of terminology and by fragmenting its domain of validity, sometimes (as hidden variable theorists do) by imposing a dissociation between the language games and the operational criteria of their use. "(...) Old logic, Wittgenstein wrote, involves far more conventions and physics than one would have thought. If the substantive is the name of a body, if the verb is the designation of a movement, if the adjective is used to describe the property of a body, we can see that this logic is full of presuppositions (...)"[18]. These presuppositions may well have to be suspended, as it is the case in the domain of validity of the quantum theory.

To conclude, I would like to emphasize that a philosophy of contemporary physics in a Wittgensteinian spirit still remains to be completely worked out; but its features are easy enough to sketch. It would combine a sustained interest in the practices that condition the theoretical propositions, diagrams, and attempted representations, with a radical ontological critique.

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[17] L. Wittgenstein, *Grammaire philosophique,* op. cit. p. 210
[18] ibid.

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