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Phenomenotechnique: Bachelard's Critical Inheritance of Conventionalism

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Abstract

The concept of phenomenotechnique has been regarded as Bachelard's most original contribution to the philosophy of science. Innovative as this neologism may seem, it benefited from a generation of debates on the nature and status of scientific facts, among conventionalist thinkers and their opponents. Granting that Bachelard stood among the opponents to conventionalism, this article nonetheless reveals deep similarities between his work and that of two conventionalist thinkers who insisted on what we call today the theory-ladenness of scientific experiment: Pierre Duhem and Édouard Le Roy. This article, therefore, compares Bachelard's notion of phenomenotechnique with Duhem's developments on the double character of scientific instruments, and with Le Roy's claim that scientific facts are fabricated to meet the requirements of theory. It shows how Bachelard retained Duhem and Le Roy's views on the interplay between theory and experiment but rejected their sceptical conclusions on the limitations of experimental control. It claims that this critical inheritance of conventionalism was made possible by a reflection on technology, which led Bachelard to re-evaluate the artificiality of scientific facts: instead of regarding this artificiality as a limitation of science, as Le Roy did, he presented it as a condition for objective knowledge.

The concept of phenomenotechnique has been regarded as one of Bachelard's most original contributions to the philosophy of science (Gaukroger, 1976; Rheinberger, 2005; Tiles, 2005; Bontems, 2010). Innovative as this neologism may seem, it had benefited from a whole generation of debates on the nature and status of scientific facts. The very beginning of the 20th Century indeed saw intense discussions on this subject between several authors that we usually refer to as conventionalists—Henri Poincaré, Pierre Duhem, Gaston Milhaud, Édouard Le Roy and Joseph Wilbois—and their diverse opponents, among which were Léon Brunschvicg, Louis Couturat and Abel Rey. The project of reading Bachelard's texts on phenomenotechnique from the perspective of these earlier debates has been carried out by Christina Chimisso (2001, 2008), who identified Bachelard as an opponent to conventionalism and heir of Brunschvicg. Undeniable as it is, this statement may yet be a hindrance to the appreciation of more positive aspects of Bachelard's relation to conventionalist thinkers. Among the authors who were rightly or wrongly associated with conventionalism, Pierre Duhem and Edouard Le Roy had indeed acknowledged the interplay between theory and experiment in a way that seems similar to Bachelard's phenomenotechnique. Can we read that “it may well be the instruments that produce the phenomenon in the first place” and “instruments are nothing but theories materialised” (Bachelard, 1984 [1934], p. 13) without thinking of Pierre Duhem's claim (1962 [1906], p. 153) that “the theoretical interpretation of phenomena alone makes possible the use of instruments”? Bachelard's conception of the experiment as production of phenomena could also find a precedent in Édouard Le Roy's play on words: *les faits sont faits—facts are fabricated* (Le Roy, 1899b, p. 515). We could, therefore, switch our perspective and regard phenomenotechnique as Bachelard's inheritance from conventionalism, even though this inheritance may be partly critical.

Before any re-evaluation of that legacy, we will start by presenting Bachelard's concept of phenomenotechnique and the way in which it was part of a critique of conventionalism. With that provision, we will then compare Duhem's and Bachelard's views on physical experiment. That comparison will show that their works share deep similarities, due to their common

insistence on what we call today the theory-ladenness of the physical experiment. We will state, however, that the two philosophers characterize differently the way theory relates to experiment: whereas Duhem conceives of it as a relation of symbolisation—“the relation of sign to thing signified” (Duhem, 1962 [1906], p. 20)—and borrows the notions of *interpretation* and *representation* from the tradition of hermeneutics, Bachelard finds his main conceptual resources in the vocabulary of technology and industrial production. That difference has consequences in the way both philosophers account for the objectivity of knowledge, leading the former to the notion of “natural classification” (Duhem, 1962 [1906], p. 24) and the latter to the elaboration of “technological realism” (Bachelard, 1984 [1934], p. 5). This will lead us to a second comparison, between Bachelard and Le Roy, for Le Roy is the first reader of Duhem who interpreted his work on physical theory in the sense of an artificial construction of scientific facts. That will allow us to follow the evolution of the notion of *artificiality* from the Bergsonian perspective of Le Roy to the Bachelardian concept of phenomenotechnique: it will appear that Bachelard’s main innovation in that regard consisted in reversing the epistemological value of artificiality from an objection to a condition of the objectivity of science.

1. Bachelard’s Critique of Conventionalism

1.1. Phenomenotechnique and Noumenology

Even if phenomenotechnique has focused the attention of commentators, it may still be useful to open our retrospective and comparative inquiry by a brief presentation of this concept. “Phenomenotechnique” cannot be separated from another Bachelardian neologism: “noumenology”. Both neologisms appear in “Noumène and Microphysics” (Bachelard, 1970 [1931]) and aim at elucidating the relation between theory and experiment in the development of scientific knowledge.

Noumenology stands for a specific conception of the role of mathematics in experimental science that Bachelard elaborated progressively in his studies on physics (Bachelard, 1973 [1928], 2014 [1929], 1970 [1931]) and extended later to chemistry (Bachelard, 1973b [1932], 1968 [1940]). His study on the history of the physics problem of thermic propagation led him to formulate methodological precepts as to the use of mathematics in physics that he found in the exemplary work of the mid-19th Century physicist Gabriel Lamé (Bachelard, 1973 [1928]): rather than regarding mathematics as a secondary tool for an experimental inquiry, he presented it as an indispensable means of investigation of the physical world, opening paths to knowledge that would not be suggested by experience alone. The mathematical art of finding and solving equations follows central scientific norms, namely the exhaustive investigation of all rational possibilities compatible with a given set of explicit constraints. Bachelard gave great importance to such systematic investigation, for he believed the mind has a natural tendency to consider too narrow a set of possibilities and to be unaware of such a limitation (1968 [1940]). The concept of noumenology thus designates the use that can be made of mathematical investigation in experimental science, and the conviction that one should always follow all mathematical suggestions, even if they do not seem at first to have an empirical correlate.

In Bachelard’s view, the considerable autonomy that noumenology grants to mathematics is only legitimate inasmuch as mathematical hypotheses are exposed to a thorough experimental testing. The notion of phenomenotechnique designates Bachelard’s conception of scientific experiment, and may be regarded as an original thesis on the nature of experimental verification (Gaukroger, 1976, pp. 216–223). That conception of verification is a paradoxical one, since phenomenotechnique does not only assume that instruments produce phenomena, instead of simply detecting them, but further claims that one verifies a hypothesis through the technological creation of an object that matches that hypothesis (Bachelard, 1984 [1934], pp.

12–13, 2004 [1949], p. 118). More precisely, Bachelard (2004 [1949], pp. 1–4) conceives the relation between noumenology and phenomenotechnique as a dialectic, *an evolutive relation of co-determination*, which goes as follows: one intends to verify a hypothesis by producing a corresponding phenomenon; however, this attempt faces difficulties, which, in the case of persistent failure, can lead to modifying the prior hypothesis. Hence, the production of phenomena and the theory that leads it perpetually enrich and correct each other.

We do not imply that phenomenotechnique merely answers to the traditional question of the conditions for objective knowledge. Rheinberger (2005, p. 315) has shown that the implications of “what it means to be a scientific object in the sense of a technophenomenon” are much wider in scope. Indeed, phenomenotechnique “conceptualizes the relation between scientific thinking and technology in modern science” (Rheinberger, 2005, p. 313), revealing that each scientific object “derives its existence from a circuit that is at the same time material and discursive” (316)—which implies, first, that scientific objects essentially differ from the immediate objects of intuition, to which would correspond *a rupture between common and scientific knowledge* (318-20); second, that the scientific mind and its objects are bound in an open evolutive process which is inseparably both conceptual and material (316-9); lastly, that “the sciences necessarily became fragmented into different epistemological regions”, as “conceptual dynamics finally became inseparable from the phenomena in which and through which they expressed themselves” (316). To use a vocabulary posterior to Bachelard (Daston, 2000), we could also say the noumenon and the techno-phenomenon are two sides of a scientific object: its theoretical and experimental mode of existence. The noumenon is a mathematical entity which gathers all possible configurations for a given set of phenomena; the techno-phenomenon is the materialisation of one of these configurations (Bachelard, 1970 [1931], p. 18).

However, granting that Bachelard’s phenomenotechnique is much more than a way of accounting for the objectivity of scientific knowledge, we cannot deny that it also plays that specific epistemological role, and is worth being studied from that perspective, especially when we intend to compare Bachelard with conventionalist thinkers. Indeed, Bachelard (2004 [1949], p. 118) regarded the ability of phenomenotechnique to verify scientific hypotheses as an objection to conventionalism: “Scientific hypothesis, in the details of thoughts and techniques, is verified, is *realised*. . . How far are we from that epistemology which takes the hypothesis for a temporary scaffolding, for a set of convenient assumptions!” The insistence on the role of phenomenotechnique in Bachelard’s definition of objective knowledge may prevent a misleading interpretation, according to which Bachelard substituted “the concept of objectivity by that of intersubjectivity” and emphasized the “strictly social character of science” (Castelao-Lawless, 1995, p. 57). Even though Bachelard (2004 [1949], pp. 12–64) did emphasize the importance of intersubjectivity in achieving objective knowledge, he never defined objectivity as intersubjective agreement. Such definition of objectivity, according to Bachelard (1984 [1934], p. 11), characterizes conventionalism: “If we were entirely given over to society, we would seek knowledge in the realm of the general, the useful, the conventional: The world would be our convention.” He objects to this conventionalist claiming that the conjunction of noumenology and phenomenotechnique makes the scientific world more than a convention, “that which we verify” (*Ibid.*). Intersubjective control in the scientific community is only a means to ensure that the requirements of noumenology and phenomenotechnique are met, and Bachelard would have objected to those who equate objectivity with intersubjective agreement that the pre-scientific mind offers countless examples of intersubjective agreement on wrong ideas. As we will see, one of the objections that Bachelard raises against conventionalism is precisely that it fails to account for the difference between scientific and prescientific knowledge.

1.2. Bachelard's Critiques of Conventionalism

Since “Noumène and Microphysics”, Bachelard's notions of noumenology and phenomenotechnique are conjointly presented as a refutation of conventionalism, according to which scientific theories are nothing but conventional hypotheses, and mathematics nothing but a convenient language (Bachelard, 1970 [1931], p. 14; 1984 [1934], p. 55; 1968 [1940], p. 51 & pp. 120–121; 2004 [1949], p. 5; 1953, pp. 151–169). Before examining Bachelard's arguments against conventionalism, some preliminary remarks seem necessary in order to specify what the term refers to. *Conventionalism* is a notion which emerged in the reception of popularized essays of Poincaré, and was retrospectively applied to a set of writers who had never used that notion and, for a part, resented being associated with one another—see for instance Poincaré's (1909, p. 171) complaint, his critique of Le Roy (Poincaré, 1913 [1902]), and Duhem's objections to Poincaré (Duhem, 1962 [1906]). As a result, the notion of conventionalism is to be used cautiously, even by commentators like Brenner (2003, 2004) who intended to prove that there is a genuine philosophical unity among the authors who were gathered under that term. However, Bachelard himself did use the notion of conventionalism, among many other broad and ill-defined philosophical positions, such as *realism*, *empiricism*, *positivism*, or *idealism*. Moreover, he mostly referred to conventionalism in order to criticise it. One could, therefore, legitimately object that Bachelard claimed an easy triumph over a caricatured adversary of his own making. We will indeed argue that there is much more in Poincaré, Duhem and Le Roy than the caricatured version of conventionalism which Bachelard rejected—and we will further try to prove that Bachelard himself had a more nuanced reading of these authors than his bold critique of conventionalism reveals. Nonetheless, these critiques of conventionalism remain important to the understanding of Bachelard's own philosophy, for a series of contrastive arguments presents phenomenotechnique and noumenology as a way out of conventionalism.

At first sight, Bachelard's attacks on conventionalism may seem incoherent: in some passages, he condemns conventionalism as a kind of naïve positivism (1970 [1931], pp. 13–18), whereas other texts present an accusation of idealism (2004 [1949], p. 5). To investigate this dual character of Bachelard's critique, we may introduce a distinction between *positivist conventionalism* and *idealist conventionalism*.

Positivist conventionalism, in Bachelard's view, stands for the belief that there would be independent facts, and theoretical hypotheses on the top of them that come and go. That way of associating conventionalism and positivism may not surprise us, if we remember Maiocchi's (1990, p. 387) remark, that what we usually regard as proper to the late 19th Century's conventionalism—“Diffidence toward hypotheses, a phenomenalist view of science, and an instrumentalistic, manipulative interpretation of theories”—was already widespread among French positivist scientists of the 19th Century. In that positivist context, the devaluation of theories was part of a will to reduce science to pure experience. In opposition, Bachelard (1970 [1931], p. 14) underlined the constitutive role of theory in scientific experiment, and even proposed to reverse the positivist opposition between arbitrary theories and necessary facts: “what is hypothetical today, is *our* phenomenon; for our immediate grasp on the real only plays the role of a confused, provisory, conventional data, and this phenomenological grasp requires inventory and classification. In contrast, it is reflexion that will make sense of the initial phenomenon by suggesting an organic series of research, a rational trail of experiments.” In that direction, Bachelard (1984 [1934], p. 55) criticised Poincaré's efforts to demonstrate the mathematical equivalence of competing theories, inasmuch as they were meant to support the thesis that theories are just different languages to express the same phenomena: one may well prove that different theories are equivalent, it does not follow that mathematics is only a means of expression, for the link between theory and phenomena is, in Bachelard's view, much narrower. Taking the example of tensor calculus in relativistic physics, Bachelard (1984 [1934],

p. 55) argued that it defines the phenomena and paths of discovery, to the point that “tensor calculus knows physics better than the physicist does”, according to Langevin’s famous phrase. Would tensor calculus be proved equivalent to another mathematical tool, it would nonetheless remain that “[w]ithout mathematics science could not even conceptualize the phenomena of relativistic physics” (*ibid.*). Against positivism, and the part of conventionalism which opposed the conventional character of theories to the firm ground of facts, Bachelard thus insisted that the definition of facts themselves depended through and through on theory. Paradoxically, that feature of Bachelard’s critique of conventionalism will make all the more interesting his comparison with authors like Le Roy, who extended that conventional character to facts themselves and therefore departed from positivism.

What about idealist conventionalism? In *Le Rationalisme appliqué* (2004 [1949], p. 5), Bachelard drew a famous diagram, representing two paths of “weakened thoughts” spreading up and down from a centre. At this centre stood Bachelard’s philosophy, presented as a balanced view on the importance of both theory and experiment; the way up symbolized a growing overestimation of the role of theory, leading to idealism, and the way down an opposite overestimation of the experiment, leading to realism. In this diagram, conventionalism stood at the last stage before absolute idealism: forgetting of the constraints experiment imposes on the theory; conventionalism would regard theory as an arbitrary creation of the human mind. Granting the mind such freedom, it could make a step further into idealism in order to explain how these personal conceptions may still constitute knowledge, and finally identify the mind and the world. The idealist tendency of conventionalism would thus sin in overestimating our intellectual freedom, and Bachelard would correct that view by insisting on the role of experimental control, which leads to constant modifications of theory and prevents it from being arbitrary.

In either case, according to Bachelard, conventionalism would misconceive the link between mathematics and experiment, either by overestimating the independence of facts from theory—in the case of positivist conventionalism—or the other way around—in the case of idealist conventionalism.

If Bachelard condemned conventionalism as an inadequate philosophy of science, he still suggested that it could provide an accurate description of the beginnings of scientific activity, where the relation between theory and experiment remains loose and unsatisfying. He granted to Poincaré, for instance, “that the mathematical formulation of the laws of attraction serves simply to specify certain instances of the general idea and to link together various of its consequences; [that] the law of surfaces is much the same, it, too, being an expression of something whose intuitive meaning is straightforward and clear” (Bachelard, 1984 [1934], p. 55). The authentic noumenology, irreducible to the mathematical expression of pre-existing phenomena, would only appear in more advanced physics. To idealist positivism, he conceded, symmetrically, that the notations and classifications of chemistry were at first mere conventions, chosen for their convenience and with some arbitrariness, before the progress of chemistry both modified and motivated them to increase their realistic value (Bachelard, 1973b [1932], 1953, pp. 151–169). Bachelard, therefore, presented the evolution of chemistry as progress from conventionalism to phenomenotechnique: “The conventionalism of the first representations which were proposed in the 19th Century has been superseded by a technical materialism which realises its schemata.” (2004 [1949], p. 11)

As he associated conventionalism with prescientific knowledge, Bachelard firmly condemned any description of the scientific mind in terms of simplicity and convenience, and sharply criticised what he identified as Poincaré’s “commodism”. He departed here from the benevolence of Léon Brunschvicg (1922, p. 446), who warned that the philosophical work of Poincaré should not be reduced to its vulgar interpretation, and granted that “the intellectual physiognomy of a Henri Poincaré is infinitely more complex and nuanced than most commentators presented it.” In Bachelard’s view, Poincaré’s commodism would insist on the

contingency of scientific theory, but would try to reduce this contingency by offering a principle of choice among several theoretical possibilities: the search for convenience and simplicity. To Bachelard, such advocacy of simplicity in an advanced science like contemporary physics cannot be but an obstacle to the progress of knowledge. In particular, Bachelard (1984, p. 38) condemns Poincaré's "philosophical mistake" as to the use of non-Euclidian geometries in physics: "After Poincaré had shown that various geometries were logically equivalent, he asserted that Euclid's would always remain the most convenient, and that if this geometry should ever come into conflict with physical experience, people would always prefer modifying the physical theory to changing the elementary geometry." He regards that decision as a kind of scientific conservatism, which intends "to immobilize the perspective of intellectual clarity" because it does not dare to quit its "rational habits" (Bachelard, 1984, p. 38); in contrast, he argues that the simplicity of Euclidean geometry was merely relative to a stage of our knowledge, and that it is one of the main interests of contemporary physics to compel the mind to use complex and counter-intuitive geometries. Indeed, as Bachelard (1968, p. 30) wrote, phenomenotechnique "must force the nature to go as far as our mind goes", he also held the reverse to be true: "the mind must adapt itself to the conditions of knowing. It must create in itself a structure which corresponds to the structure of knowing" (Bachelard, 1968 [1940], p. 123). The conjunction of these requirements defines Bachelard's dialectic between mind and reality.

As a whole—whether we regard it as an accurate description of science at its beginnings, or as a philosophical misconception of contemporary science—conventionalism would lose track of one of the two Bachelardian requirements: "no empty rationality, no scattered empiricism" (2004 [1949], p. 3). The articulation between positivist and idealist conventionalism would follow what Bachelard (2002 [1938], p. 30) identified as the "psychological law of the bipolarity of error", according to which we cannot, at first, avoid an excess without falling into an opposite one: we would swing between positivism and idealism, as we want to maintain either facts or theory.

Given these objections to conventionalism, a key question in the study of phenomenotechnique is to elucidate how it could pretend to overcome both positivism and idealism: how could Bachelard claim—in his objection to idealism—that theory should be grounded in the firm ground of facts, and at the same time—in opposition to positivism—that there are no facts independent from theory? And how could science actually achieve that goal? Paradoxically enough, given Bachelard's critique of conventionalism, we believe that Duhem and Le Roy provided him philosophical resources to achieve that balance.

2. Bachelard and Duhem on Scientific Experiment

Duhem and Bachelard are traditionally opposed as the defenders of a continuist and discontinuist vision of the history of science—Duhem stressing the continuities between medieval and modern science, while Bachelard emphasizes the ruptures between pre-scientific and scientific knowledge, and between modern and contemporary science. Bachelard (1953, pp. 209–217) implicitly targeted Duhem among the *continuists* who chose to stay in the elementary zone of science (210) and to ferret out "influences" (212) in order to hide the fact that scientific progress "necessarily 'bursts' traditional epistemology" (210). There is no point in minimizing the depth of that disagreement, which also points to a political opposition, between the conservative Duhem and the progressive Bachelard. However, there is more to a comparative study of Bachelard and Duhem's works than the opposition between continuity and discontinuity. The question of the relation between theory and experiment constitutes another fruitful but neglected angle for the comparison of these two authors. That perspective puts Duhem's continuism in the background and focuses on his complicated relations with conventionalism.

2.1. Departing Duhem from Conventionalism

The legitimacy of including Duhem among conventionalist thinkers is a debated point: Maiocchi (1990) gathered evidence that “the historiographical scheme, that makes Duhem . . . the advocate of a vision of science proceeding on the basis of choice and decided by a criterion of simplicity . . . is completely wrong”, that *The Aim and Structure of Physical Theory* was actually written against conventionalism and the conventionalist interpretation of Duhem’s early writings. We may nevertheless wonder whether Bachelard himself regarded Duhem as a conventionalist thinker. The few explicit mentions of Duhem in his work provides us with contrasting elements. First, as Bachelard briefly commented on the Duhem’s texts on crucial experiment, he (1951, p. 47) condemned his “educated scepticism” (*scepticisme instruit*) and proffered a critique which resembles the one he made against Poincaré’s demonstrations of equivalence: any theory may well be made compatible with any fact, and proven equivalent to another theory; the actual history of science nevertheless follows definite paths, according to “epistemic values” which indicate what may or may not count as an experimental objection. That critique clearly identifies Duhem as a conventionalist. However, Bachelard (1973a [1927], p. 176) also used the Duhemian expression of “natural classification” to acknowledge the objective value of advanced heat transfer theory, and contrasted it with the conventionalist, anti-realist use of the notion of classification. Later, he praised Duhem’s abundant use of the notion of *representation*, for that concept could apprehend the relation between theory and experiment characteristic of “truly scientific phenomena” and constituted “the most natural intermediate to determine the relations of the noumenon and the phenomenon” (Bachelard, 1968 [1940], pp. 63–64). From the rare mentions of Duhem in Bachelard’s work, we may, therefore, presume that he thought that Duhem belonged to a conventionalist background, but departed from it in his efforts to acknowledge the objective value of physical theory and the solidarity between theory and experiment.

These elements put Maiocchi’s reading of Duhem in an interesting perspective. We may indeed object to Maiocchi and maintain that Duhem’s work did contain diverging tendencies, as Duhem intended to refute one or the other of his philosophical enemies (Roux, 2016). Therefore, it may not fit entirely with the anti-conventionalist presentation Maiocchi made of it—which may explain why many associated Duhem with conventionalism. However, it is striking how Maiocchi’s description of Duhem could apply to Bachelard: Maiocchi (1990, p. 398) presents Duhem as an opponent to both conventionalism and positivism and a rationalist defender of the primacy of theory: “contrary to the flattening out imposed by the empiricist method of his predecessors, he had to avenge the rights of theory, showing how the ineliminable theoretical components present in every observation gave meaning to the scientist’s experimental work” (Maiocchi, 1990, p. 387). Such an attitude could, indeed, define Bachelard’s rationalism: even though Bachelard (2004 [1949], p. 1) stated “the reciprocity of dialectics which go endlessly, and both ways, from mind to things”, he made no concessions to empiricism and maintained that “the epistemological ‘vector’ . . . surely points from the rational to the real and not, as all philosophers from Aristotle to Bacon professed, from the real to the general” (Bachelard, 1984 [1934], p. 4).

Our choice to consider Duhem from a Bachelardian perspective, in order to detect what Bachelard inherited from him, will therefore be reminding of Maiocchi’s reading. Neither Bachelard nor Maiocchi gave much importance to Duhem’s negative conclusion, that is, the impossibility of a crucial experiment and the limitation of experimental control it seemed to imply. Both insisted, however, that *The Aim and Structure of Physical Theory* contained valuable elements to apprehend the way theory relates to experiment.

2.2. Duhem's Physical Experiment: The Material and the Symbolic

The project to compare Bachelard and Duhem directs our attention to a neglected aspect of Duhem's analyses on a physical experiment (1962 [1906], pp. 153–158): the concept of *symbolic instrument*. Duhem elaborated that notion as he commented on the experimental work of Henri-Victor Regnault, paying particular attention to the procedures which allowed him to increase precision in the study of gas properties. Duhem intended to elucidate a paradoxical feature of Regnault's experiments, namely, the fact that Regnault did not hesitate to modify his measurement results, and even regarded such correction as a condition for accuracy. According to Duhem (1962 [1906], p. 156), that attitude would make no sense if a physical experiment were "simply the observation of a group of facts" and, therefore, proves that it is "also the translation of these facts into a symbolic language." This double aspect of scientific experiments would be reflected in the double character of scientific instruments: each instrument would possess what we may call two modes of existence, a material and an ideal one. An instrument is a concrete entity—in the case of Regnault's manometer, "a series of glass tubes, solidly connected to one another, supported on the walls of the tower of the Lycée Henri IV, and filled with a very heavy metallic liquid called mercury"—but the same instrument would also exist as an ideal, theoretical entity, inseparable in Regnault's mind from the material one—"a column of that creature of reason called a perfect fluid in mechanics, and having at each point a certain density and temperature defined by a certain equation of compressibility and expansion" (Duhem, 1962 [1906], pp. 156–157). Regnault's experiment would precisely consist of the comparison and adjustment of those concrete and ideal instruments, in order to legitimate and improve the relation of symbolisation that he has established between them. The value of physical theory would indeed depend on a matching process that we could sum up as follows: the theoretical instrument allows calculation, whereas the concrete instrument allows measurement. If the measured results are judged to depart excessively from the calculated ones, the pretention of the former to offer an accurate representation of the latter would be put into question. Such disparity could be diminished, however, if we could modify the theoretical instrument to increase its resemblance to the concrete one—hence the major contribution of experimental corrections to the progress of physics. Such corrections complexify our theoretical representations, taking into account a new set of parameters that turned out to have an impact on the experiment results, such as the compressibility of fluids or the variations of temperature and pressure in Regnault's experiment. Duhem (1962 [1906], p. 158) finally compared the physicist with "the artist who, after finishing the line sketch of a drawing, adds shading in order to express better on a plane surface the profile of the model": the progress of knowledge would essentially consist in such complexification and rectification of our theoretical representations of reality.

2.3. From Symbolism to Phenomenotechnique

If we consider Bachelard's phenomenotechnique from the Duhemian perspective just mentioned, we may regard it as an insistence on the fact that the symbolic relationship between the ideal and material instrument *goes both ways*. Reconsidering that symbolic connection from the side of the concrete instrument, we notice that Regnault devised his concrete instrumental setting as a *materialisation* of a theoretical configuration he had in mind. Hence is it not enough, for Bachelard, to claim, with Duhem, that an experiment is an observation of facts and their translation into a symbolic language: we could go further and consider experiment as a *production* of phenomena that "bear the stamp of theory throughout" (Bachelard, 1984 [1934], p. 13). The Bachelardian notions of *noumenon* and *techno-phenomenon* can thus be regarded as a reinterpretation of Duhem's symbolic and concrete instruments: the noumenon is a theoretical entity, and phenomenotechnique "tend[s] towards the effective realisation of the

noumenon” (Bachelard, 1984 [1934], p. 13) by the production of a phenomenon that would constitute its material correlate. The discrepancy between concrete and ideal instruments could therefore be reduced by modifying the concrete instrument to make it match the theoretical one, just as the other way around. Considering for instance the uneven thickness of the glass tubes, the irregularity of the wind, or other factors that we do not regard as pertinent for our current symbolisation, but that actually modify our experimental results, we could either choose to take them into account as causes of error, as Duhem (1962 [1906], p. 156) enjoined us to do, or try to physically prevent their influence by a technical intervention. Hence, admitting that a physical experiment is the methodical confrontation of a theoretical entity and a concrete entity, conceived as an instantiation of the former, there would be a complete convertibility between our technological efforts to produce a definite physical effect and our theoretical efforts to represent an empirical configuration accurately.

What may have prevented Duhem from going as far as Bachelard in that direction—and claim that theory *produces* phenomena as its material correlate—is perhaps the phenomenalist position that lay behind his insistence on the symbolic character of theory. The notions of symbol and representation are indeed at the core of both part I and part II of Duhem’s *Aim and Structure of Physical Theory*, but, it seems, with two different philosophical aims: in the second part of the work, the notion of symbolic instrument is associated with what we call nowadays the theory-ladenness of physical experiment; however, the main purpose of the notion of symbolism in the first part of the book is to underline that the symbols of physical theory “have no connection of intrinsic nature with the properties they represent” (Duhem, 1962 [1906], p. 20). This is Duhem’s famous claim on the distinction between physical theory and metaphysical explanation, according to which physical theory may offer “rational analysis of phenomena”, but should not pretend to reach “the reality hidden under the appearances” (Duhem, 1962 [1906], p. 20). If we try to articulate both uses of the notion of symbol in Duhem’s work, we may say with Gaukroger (1976, pp. 215–216) that Duhem reduced the gap between theory and experiment, but conversely widened the gap between phenomena and reality. The comparison of Bachelard and Duhem may here shed a new light on a debated point in Duhemian studies. Many commentators (Bhakhavatsalam, 2015; Darling, 2003; Dion, 2013; Ivanova, 2010; Lugg, 1990; McMullin, 1990; Stoffel, 2002) have indeed questioned the consistency between Duhem’s phenomenism and the notion of “natural classification” he elaborated to apprehend the increasing objective value of physical theory: that notion seemed to bend towards a more traditional kind of realism, in its concession that “the more complex it becomes, the more we apprehend that the logical order in which theory orders experimental laws is the reflexion of an ontological order” (Duhem, 1962 [1906], p. 26). Rather than a contradiction, it now appears that there is a solidarity between the concept of natural classification and Duhem’s analysis of physical theory as a representation, for the measure of the accuracy of a representation is its accordance with the order of things it represents. Hence, even if Duhem drew an opposition between *representation* and *explication*, the notion of representation does not overthrow the notion of truth as *aletheia* as much as it supposes it. In contrast, Bachelard’s notion of phenomenotechnique would have got rid of phenomenism and realism altogether, for it does not define the objectivity of knowledge as the accurate representation of a pre-existing order of things. Bachelard indeed follows the progress of human experience from the subjectivity of common sense to scientific knowledge, and identifies the access to objective knowledge with the possibility of a phenomenotechnique: our conceptions give evidence of their validity as they prove able to lead a successful technical production, and are just as valuable as the technical production they allow. We could thus say that the passage from *perceiving* to *producing* equates the passage from subjective to objective experience. Instead of indexing the notion of objectivity on a pre-existing order of things, Bachelard (1951, pp. 216–223) even claimed that science is the progressive instauration of an order which is both intelligible and physical, as the progress of theory leads innovative technical productions.

The comparison of Bachelard and Duhem revealed that, even if Duhem underlined the interplay between theory and experiment, he somehow maintained a traditional conception of truth one he only displaced: instead of an *adequatio rei et intellectus*, he considered an agreement between *theorized experiment* and *reality*. In contrast, following Duhem's indication that theory and experiment shape each other and adjust to each other, Bachelard regarded that relation as a starting point for a redefinition of objective knowledge. In that respect, we may be tempted to regard Édouard Le Roy as a middle step between Bachelard and Duhem: his original reading of Duhem challenged the conception of truth as *adequatio rei et intellectus*, and conceived scientific activity as a construction of scientific facts.

3. Bachelard and Le Roy: Reconciling Artificiality and Objectivity

3.1. Le Roy's Bergsonian Conventionalism

Contrary to Duhem, Le Roy's inclusion among conventionalist thinkers is not a debated point. He even contributed to the perception of conventionalism as a unified movement, for he presented the work of Poincaré, Duhem, Milhaud and Wilbois as examples of a new approach to science which insisted on the conventional character of science (Le Roy, 1899a). However, Le Roy's conventionalist philosophy of science is but one aspect of his work, and perhaps not the most important one. The resources that Le Roy borrows from Poincaré, Duhem, Milhaud and Wilbois aim at extending to science the analyses that Bergson already applied to common sense (Le Roy, 1899b, p. 515). We may consider, therefore, that Bergsonism provides a better key to Le Roy's work than conventionalism, or, at least, that Le Roy's work lays at the intersection of both orientations: as Pradelle (2012) shows how Le Roy's conventionalism distorted his Bergsonism, we may argue, symmetrically, that Le Roy's Bergsonism distorted his conventionalism. Moreover, that philosophy of science is but one piece of Le Roy's system, which goes from the analysis of sensation to Christian miracles, passing by pure mathematics and evolutionary biology. We will, therefore, have to measure the impact of these other aspects of his work on his philosophy of science.

We have few indications of Bachelard's relation to Le Roy. He praised his mathematical work on the equations of heat propagation (Bachelard, 1973 [1928], p. 169), but made no mention of his philosophy of science, except in one particular text (Bachelard, 1972 [1960]). When Bachelard succeeded Le Roy as a member of the Académie des sciences morales et politiques, he was in charge of a traditional homage to the life and work of his predecessor: he then praised him as a promoter of human progress, whose precise knowledge of science allowed him to "estimate the power of reason" and "the creative activity of mind" (Bachelard, 1972 [1960], p. 167). Even though the circumstances of that speech prevent us from giving it much significance, we may consider that Bachelard genuinely shared with Le Roy and Bergson an enthusiasm for the creative power of the human mind (Bachelard, 1984 [1934], pp. 176–177). From that perspective, the study of the way Bachelard reassumed Le Roy's insistence on the creativity and artificiality of scientific facts, may contribute to the investigation of the impact of Bergsonism in French Philosophy of the 20th Century (Bianco, 2015; Bianco & Worms, 2002; Wunenburger & Worms, 2015).

3.2. Different Hierarchies for Perspectivism

Le Roy's first major writing, "Science et Philosophie"—published in three episodes from 1899 to 1900 in the newly created *Revue de Métaphysique et de Morale*—compares three attitudes of the human mind: common sense, science, and philosophy. It defines each attitude by its own norms and procedures, as well as by its objective correlate: the objects of common sense differ from the objects of science, as they both differ from the objects of philosophy. The

first similarity between Le Roy and Bachelard is, therefore, their perspectivism. When Le Roy (1899a, p. 376) writes that “there are no positive facts, but rather a positive mind to consider the facts”, he indeed seems to open the path to Bachelard’s investigations on the evolutive correlation between the mind and its objective correlates. The complete view on Bachelard’s perspectivism is the “epistemological profile” drawn in his *Philosophy of No* (1968 [1940], pp. 34–43), which exposes what Bachelard intends by *mass* according to the different attitudes he adopts at different times of the day: the notion evolves as he considers a mass of sorrow, the mass of an envelope, the Newtonian mass, or its relativist and Diracian refinements—different kinds of masses which correspond to successive stages of his knowledge.

Further, both Bachelard and Le Roy adopt what we may call a hierarchical perspectivism: if they both acknowledge, to a certain point, the autonomy and legitimacy of each attitude of the human mind, they make clear that one of these attitudes has a definite superiority, at least with regard to the achievement of knowledge. A significant difference appears, however, because they rank these attitudes differently: Le Roy gives precedence to metaphysics over science, whereas Bachelard condemned all attempts to elaborate a metaphysical discourse that would be external and superior to scientific activity. As a result, if it turns out that Bachelard’s views on science share similarities with that of Le Roy, we will have to explain how Bachelard nonetheless refused to regard science as a subordinate activity. Provided Le Roy only pretended to consider science for its own sake but actually wanted to prove that it must leave room for metaphysics, how did Bachelard separate the *pars destruens* from the *pars construens* of Le Roy’s study of science?

3.3. Science Fabricates the Truth It Looks For

Le Roy’s study of scientific facts is rooted in a Bergsonian argument from *Matter and Memory*: “That which is commonly called a fact is not reality as it appears to immediate intuition, but an adaptation of the real to the interests of practice and to the exigencies of social life” (Bergson, 1911 [1896]; quoted in Le Roy, 1899a, p. 379). Le Roy (1899b, p. 515) wants to apply a similar analysis to scientific activity. He starts by refuting the positivist conception of scientific facts, what leads him to motivate the etymological link between *fact* and *facere*:

“Preoccupied with trying to establish a correspondence between things and thought, we usually conceive a fact as a piece of nature cut out with a cookie cutter. Facts, as we picture it, are like gemstones, hidden in dark and ignored corners, that we would have to search for a long time until we could grasp them, but which would suddenly appear ready-made before our eyes as soon as we would discover them. Hence the banal idea one only needs to state the facts. The very name of *fact* should suffice to overthrow the common belief: what has been made [*factum*] cannot be an immediate datum . . . Let us besides question a physicist in his laboratory: we will see if he does not have the strong and constant feeling of constituting the facts, informing nature, creating in the amorphous and continuous matter of the given the particular beings he observes.”

If both common sense and science constitute their objects, Le Roy claims, however, that these two attitudes do not meet the same criteria: the construction of scientific facts is no longer subordinated to “the interests of practice and to the exigencies of social life” but to the ideal of *perfect discourse*, that is, the elaboration of a deductive theory that would start from clear and simple premises and include all facts as its consequences (Le Roy, 1899b, pp. 517 & 551–559).

Among the examples that support this view is Gaston Milhaud’s analysis of phosphorus (Milhaud, 1896; quoted by Le Roy, 1899b): this chemical element has a scientific definition which specifies its properties, such as a 44°C melting point. Scientists would only consider what falls under that definition, and make abstractions from the various and variable properties presented by the real bodies we chose to refer to as phosphorus. Le Roy insists that the

determination of those qualities was not necessary—it was *conventional*—however, he concedes that this choice of qualities is not *arbitrary*, but motivated by the whole corpus of modern chemistry. Such arguments may seem close to Bachelard’s works on chemistry (1973b [1932], 1968 [1940], 1953), which gave great significance to synthetic elements, artificially produced with the indications of the periodic table. Bachelard did not regard those synthetic elements as a limit case, but rather as exemplary of all entities of chemistry; he even reversed the meaning of what was originally a critique of some illegitimate procedures of chemistry (see Dagognet, 2002), to claim the fundamental artificiality of chemical entities: “the great chemist August Laurent already said: ‘Chemistry has become today the science of bodies that do not exist’. One must give the existence to bodies that do not exist. As to those which already exist, the chemist must, in a way, recreate them, to give them the required status of purity, to put them on an equal level of artificiality [*facticité*] with the other bodies created by man” (Bachelard, 1953, p. 22). The feeling of similarity between Le Roy and Bachelard’s philosophy of science grows as we consider Le Roy’s references to Bachelard in his later work (1929, 1935a, 1935b). Le Roy’s “Ce que la microphysique apporte ou suggère à la philosophie” is indeed very close to Bachelard’s “Noumène et Microphysique”, and Le Roy’s (1935b, p. 327) developments on spectrum analysis seem directly inspired by Bachelard (1970 [1931], pp. 15–17): would we consider spectrum analysis as a simple way to detect the activity and properties of particles, we would not understand the procedures which discriminate between the relevant and irrelevant rays, and rely through and through on theoretical assumptions. Both philosophers thus agree that scientific observation “shows as it demonstrates; it establishes a hierarchy of appearances; it transcends the immediate; it reconstructs first its own models and then reality” (Bachelard, 1984 [1934], pp. 12–13). They both present this co-determination of reason and reality as an evolutive relation: Le Roy (1899b, p. 561) states, in terms very similar to Bachelard’s dialectic, that “the construction of science implies some combined deformations, some converging modifications of reality and mind; scientific truth results from a slow adaptation of the former to the latter.” Le Roy is also close to Bachelard in his claim that no definition of scientific truth can be found outside of that evolutive relation of theories and facts: Le Roy (1899b, pp. 359–360) claims that we should get rid of the tendency to consider truth as “a precious metal in a gemstone” and realize that science must “fabricate the truth it looks for.” His main argument against the conception of truth as an *adequatio rei et intellectus* is that scientific activity cannot be assimilated to a representation or a translation since we cannot compare our productions with the original to estimate their resemblance. Hence “The only possible criteria are internal to science itself”, such as “coherence, stability, harmonious progress in a specific endeavour of the mind, growing success in our conquest of the world”(Le Roy, 1899b, pp. 560–561).

As long, therefore, as we consider Le Roy’s philosophy of science for its own sake, we may get the feeling of a far-reaching similarity with Bachelard: they both give primacy to theory in the constitution of experiment; they both condemn the naivety of the positivist conception of facts, as it remains unaware of the mental operations that are always already constituting facts; they also condemn all reference to a pre-existing order of things in the evaluation of scientific activity, regarded as a process through which both theory and experiment constitute each other. However, if both Bachelard and Le Roy depict fundamental philosophy of science as a “rationalist attitude”, they differ in that Bachelard plainly adopts this philosophy of science, whereas Le Roy criticises it from the external point of view of metaphysics. It would, nonetheless, be simplistic to consider that there is a mere change of perspective from Le Roy to Bachelard without measuring the impact of Le Roy’s metaphysics on his philosophy of science.

3.4. The Impact of Le Roy’s Metaphysics

Le Roy’s Bergsonian metaphysics indeed pervades his philosophy of science, even

though the fundamental assumptions of that metaphysics may be opposed to what Le Roy identified as the rationalist attitude of scientists. When he depicts the inner philosophy of science, Le Roy refuses the notion of “given”, insisting on the construction of scientific facts, and refuses to define truth as conformity with reality in order to study how science defines its own norms. As a metaphysician, however, he rehabilitates an extra-scientific reality as a norm for knowledge. He supposes that the immediate data of consciousness offer a richer view of reality than science and common sense, which both operate a structuration and impoverishment of these immediate data. Le Roy (1899a, p. 379) compares the latter to “a great aurora borealis, something like a set of colours with an absolute heterogeneity and a perfect liaison, where an unceasing evolution of subtle and infinitely diversified nuances would take place.” Hence, he criticised the naïve views of positivism, which regard as given what is actually the product of a series of mental operations; but he did not get rid of the notion of given altogether and identified it with the immediate data of consciousness. The artificiality of scientific facts acquires, from that perspective, a negative meaning: science operates an artificial selection among those data, which may be legitimate according to its relative ends, but must be overcome to achieve true knowledge of reality. This leads Le Roy (1899b, p. 518) to separate science and objectivity: “there is in every fact a mysterious residual of objectivity, but it is the same one and continuous Given which lays at the bottom of every fact . . . What interests science is not what is objective in facts, but what is artificial.” This is also reflected in Le Roy’s attitude towards the representation of truth as a rare metal in a veinstone: whereas he condemned that metaphor as inadequate to represent scientific truth, he rehabilitates the image to describe the passage from science to metaphysics (1900, p. 54): “We took the composite ores that are called science and common sense; we submitted them to a purifying treatment; now that they are disaggregated, we can separate the metal from the useless scoria: that precious metal is reality captured and possessed by the mind.”

From that perspective, the artificiality of scientific facts constitutes an objection to the objective value of science: what is artificial is subjective, inauthentic, and perhaps illusory. We should recognise, however, that the situation is further complexified by the fact that Le Roy is somewhat ambivalent as to what we may call the metaphysical value of artificiality. On one level, he claims that consciousness should refrain from structuring perception in order to enrich its view on reality, and denounces the artificiality of scientific facts; however, on a deeper level, Le Roy’s metaphysics also intends to go beyond the separation between matter and consciousness, and claims their fundamental identity under the form of a single creative process. In that last respect, the artificiality of scientific facts acquires a new positive meaning, as an evidence of the creative power of the intellect. Le Roy (1900, p. 59) even borrows Aristotelian concepts to present the operations of the mind on immediate data as progress from potentiality to activity.

3.5. Bachelard Among the Critiques of Le Roy

Bergsonian metaphysics was profoundly influential on Bachelard’s first philosophical work, his *Essai sur la connaissance approchée* (1928). However, his further work on science strongly rejected it, to anchor his philosophy in the process of scientific knowledge. How could Bachelard (1984, pp. 175–176) keep insisting on the creative power of mind when departing from Bergson and Le Roy’s metaphysics? In that regard, it is interesting to compare Bachelard’s position with the objections which were addressed to Le Roy’s philosophy of science in the newly created Société française de philosophie (1901) and in the *Revue de Métaphysique et de Morale* (Couturat, 1900; Poincaré, 1913), in the wider context of a tumultuous reception of Bergsonism (Brunschvicg, 1901; Jacob, 1898) and conventionalism (Rasmussen, 1996).

A recurring pattern in these critics is that Le Roy’s representation of science overestimated the creative freedom of mind, which would have prevented him accounting for

the objective value of science. Poincaré's objections to Le Roy are exemplary in that respect: Poincaré (1913, pp. 325–333) admitted that a series of conventions is constitutive of scientific facts, which depend on our admitted theory; but he insisted that this liberty in the definition of scientific facts is limited by brute or crude facts (*les faits bruts*), constraining data with which every theory must comply in order to possess some objective value. These brute facts were presented as the invariant elements which allow competing theories to be proved equivalent and grounds their objectivity. All things considered, “all the scientist creates in a fact is the language in which he enunciates it” (Poincaré, 1913 [1902], p. 332), not the fact itself.

We may consider that Bachelard took an opposite direction to that of Poincaré: he did not enjoin his readers to consider that the brute facts were lying behind the constructions of science, but to assume the constructive character of scientific activity plainly. However, as he reassessed the fundamental artificiality of scientific facts, he put a new emphasis on the objective value of technology. Indeed, among Poincaré's objections to Le Roy, Bachelard gave a great importance to the following argument: “However able the worker may be, his freedom is always limited by the properties of the raw material on which he works” (Poincaré, 1913 [1902], p. 331). In his *Essai sur la connaissance approchée*, Bachelard (1928, p. 155) endorsed Poincaré's argument on the constraints of technical production, and associated industrial development with experimental verification: “Technology . . . fully realises its object and that object, to come to existence, had to satisfy so many heterogeneous conditions that it overcomes all sceptical objections. It is factual evidence (*une preuve par le fait*) in the whole sense of the term.” This reflection on technology is all the more instructive as it appears in a book where Bachelard—probably influenced by Bergson and Le Roy—tends to denounce the artificiality of scientific objects, in the sense that the constructions of science would lose the trace of the real. From these premises, his chapter on technology contrasts science and technology, and paradoxically claims that the objectivity of technology is higher than that of the former. This reflection on technology and on the conditions for a successful production of an artefact has an impact on the notion of artificiality: it reconciles it with objectivity. The paradox of Bachelard's first philosophical work is to combine Le Roy's notion of artificiality in his critique of science—defined in opposition to reality, as what is ill founded, deceptive or illusory—with the new understanding of artificiality he developed in his study of technology. Ever since that first philosophical work, Bachelard regarded technological production as the most challenging way of testing theoretical assumptions. In his later work, he would no longer oppose the figure of the engineer and that of the physicist, but rather identify them, considering that science itself tests its hypothesis by means of technological production.

4. Conclusion

The trajectory from Duhem to Le Roy and Bachelard may be summed up in an assertion that Maiocchi (1990, p. 390) attributed to Duhem himself: the criticism of positivism needs not give way to sceptical conclusions. Duhem's reading of Claude Bernard can be regarded as the mourning of a certain ideal of experimental control. Although Bernard had already stressed the importance of preconceived ideas in the elaboration of an experiment, he insisted that “so long as the experiments last, the theory should remain waiting, under strict orders to stay outside the door of the laboratory; it should keep silent and leave the scientist without disturbing him while he faces facts directly” (Duhem, 1962 [1906], p. 181)—otherwise, the very notion of experimental control would fall apart. Against that traditional view, Duhem stated that theory could no longer stay “outside the door of the laboratory”, at least in a mature science like physics. He drew some consequences from that fact, which may seem mostly negative from the old point of view, but also paved the way to a renewed conception of experiment and theoretical progress. As a reader of Duhem, Le Roy pursued the investigation of the evolutive relation between scientific theory and its objects and made room for an elucidation of the norms and

procedures of science that would not subordinate it to the traditional notions of truth or reality. However, Le Roy's writings articulated a study of science for its own sake, which rejects all accusations of scepticism, and a critique of scientific attitude in favour of a higher kind of spirituality. Hence, the creation of scientific facts appeared both as an acknowledged dimension of scientific activity, and as evidence against the objectivity of scientific knowledge. The association of Duhem and Le Roy with a "crisis of science", perceived as a fightback of metaphysics and religion against the positivist and rationalist tendencies of the 19th Century (Rasmussen, 1996), was therefore not unfounded if a little simplistic. In contrast, Bachelard's optimistic rationalism can be regarded as a philosophy of scientific progress, which inherited from the positive aspects of Duhem and Le Roy's analysis and condemned their critical character. His reflection on technology allowed him to take seriously Le Roy's claim that facts are fabricated, and turn that objection into an argument in favour of scientific knowledge: would a theory actually lead the technological production of a definite object, it would prove by that alone to be more than an arbitrary convention. Following the theme of the artificiality of scientific facts and its evolutions, we could extend our investigation by a study of social constructivism, which occasionally referred to Bachelard's phenomenotechnique (Latour & Woolgar, 1986), and wonder whether these developments simply renewed the opposition between conventional knowledge and objectivity, or tried to redefine both notions through the study of their actual combination.

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