

On the Underdetermination of Theory by Experience and Related Issues

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The subject matter of this paper is the thesis on the underdetermination of theory by experience, in the local account due to Duhem and in the global version due to Quine. This thesis has significant implications concerning some epistemic uncertainty about the accuracy of the tested predictions of theories. We find this thesis plausible, though more feasible, limited to physical theories, as in Duhem's approach. We examine the thesis of the impossibility of crucial experiments that Duhem finds implied by his thesis on empirical indeterminacy, as well as the thesis of the possibility of empirically equivalent theories that are logically incompatible, which Quine also finds linked to his thesis on empirical indeterminacy. From a conceptualist approach that acknowledges the abstract character of physical concepts and the idealized nature of physical laws, and assuming Hanson's thesis on the theory laden of scientific observation, we conclude that the anterior Duhem's thesis is sound, although the preceding Quine's thesis does not seem viable.

Keywords: holism, empirical indeterminacy, epistemic uncertainty, crucial experiments, equivalent theories, conceptual content

Introduction

Is it methodologically possible to test a hypothesis via experiments and observations to confirm it as an accurate general statement? That is the question that underlies the central issue of this paper. From holistic approaches, independently, Duhem (1914/1954) and Quine (1951/1953) advance similar theses on the procedure of testing hypotheses, which entail an epistemic uncertainty about the support that the results of experiments and observations can provide for tested hypotheses. The thesis of Duhem and Quine, known as the underdetermination of theory by experience, not only responds negatively to that question, as Popper did, but also sustains a sort of impossibility in determining the accuracy or inaccuracy, or the truth value, of theoretical hypotheses by means of scientific experience, both experiments and observations.

Duhem's thesis rejects that a single hypothesis can be tested in isolation, but rather that a group of theories are involved in the derivation of the predictions of the hypothesis, and it is the theoretical group that is tested by experiments. In case the experimental results are in favor of a given prediction, the hypothesis has been confirmed in the sense that it is reasonable to hold it provisionally, although it is not proved. In case the experimental results do not match the prediction, it is not necessary to reject the hypothesis in question because any element of the group of theories may be erroneous, which implies the revision of the theories involved and an eventual modification of some elements of them.

Like Duhem, Quine refuses that the hypotheses can be tested in isolation. For him to test a given hypothesis, it becomes necessary to deduce from a set of theoretical statements its empirical consequence. If the observations match such consequences, one obtains evidence in favor of it; though, as the hypothesis is a general statement, we cannot affirm that it is true. If the observational results disagree with the empirical consequences deduced to test the hypothesis, there is a mistake in some theoretical statement involved, which requires revision and correction; it is even possible that any element of our scientific knowledge may be rejected and replaced to eliminate the error.

In very rough terms, the previous expresses the thesis on empirical underdetermination by Duhem and Quine. Duhem obtained a strong consequence from that thesis: the impossibility of crucial experiments, that is, a single experiment to decide between two rival hypotheses or theories. Quine adds a strong consequence from such a thesis: the possibility of logically incompatible and empirically equivalent theories, that is, alternative theories that have the same empirical consequences, though they are not logically compatible.

First, we surveyed the thesis on the underdetermination of theory by experience in Duhem and Quine versions. We find this thesis plausible, although more feasible, limited to physical theories as Duhem did. Then, we focus on Duhem's thesis on crucial experiments and on Quine's thesis on empirically equivalent theories, making some comments on them. Generally, philosophers of science addressing philosophical problems, such as the one about the relation between theory and experience, do not take into account that physical theories are indeed permeated by abstractions and idealizations in their concepts, laws, and models.¹ We briefly expound a few theses on conceptual content embedded in physical theories, emphasizing the abstract character of concepts and the idealized nature of laws, thus illuminating these two issues in such a way that they adopt different aspects. Lastly, from a conceptualist approach to physical theories and assuming Hanson's thesis on the theory laden of scientific observation,² we conclude with some critical remarks about the theses on crucial experiments and empirically equivalent theories: We find that Duhem's thesis is sound while Quine's thesis does not seem viable.

Duhem's Thesis on the Underdetermination of Theory by Experience

Pierre Duhem originally proposed the thesis called "The underdetermination of theory by experience" from a holistic view of the methodological procedure of testing hypotheses or theories. He criticized the thesis on the crucial experiments also, which could allow deciding between rival hypotheses. Duhem's central theses can be summarized as follows:

- (1) The confirmation procedure of a hypothesis is holistic in character, involving a group of theoretical statements or even theories, not only the single hypothesis subject to testing.
- (2) The scientific experience does not determine univocally a predicted hypothesis that has been tested, but only partially because the adverse experimental results entail an uncertainty about what statement or subgroup of statements must be removed or changed.
- (3) Because adverse experimental results do not indicate where the mistake is in the group of theories involved, the physicist is compelled to decide not based on experimental facts.

¹ Regarding the topics of abstraction and idealization in science, see, for example, McMullin (1985), Nowak (1992), Liu (2004), Portides (2005), Martin (2005), Weisberg (2007), Moulines (2007), Ladyman (2008), De Donato (2011), and Rolleri (2013).

² Quine recognizes that thesis when, in the context of his holistic view, referring to some basis observational statements, he claims: "[...] some statements are closely linked to observation, by the process of language learning. These statements are indeed separately susceptible to tests of observation; and at the same time they do not stand free of theory, for they share much of the vocabulary of the more remotely theoretical statements" (1975, p. 314).

(4) The crucial experiments lack support to decide which of two rival theories is accurate, because the experimental results could at most rule out one of the theories involved, which does not mean that we are allowed to hold the other theory.

Duhem expresses the two former Theses (1) and (2) as closely linked. About his local holism, he wrote:

A physicist decides to demonstrate the inaccuracy of a proposition; to deduce from this proposition the prediction of a phenomenon and institute the experiment which is to show whether this phenomenon is or not produced, to interpret the results of this experiment and establish that the predicted phenomenon is not produced, he does not confine himself to making use of the proposition in question; he makes use also of the whole group of theories accepted by him as belong of dispute. (1914/1954, p. 185)

And immediately, about underdetermination, he adds:

The prediction of the phenomenon, whose nonproduction is to cut off debate, does not derive from the proposition challenged if taken by itself, but from the proposition at issue joined to that whole group of theories; if the predicted phenomenon is not produced, not only is the proposition questioned at fault, but so is the whole theoretical scaffolding used by the physicist. The only thing the experiment teaches us is that among the propositions used to predict the phenomenon and to establish whether it would be produced, there is at least one error; but where this error lies is just what it does not tell us. (1914/1954, p. 185)

In relation to the former Thesis (3), Duhem points out:

In sum, the physicist can never subject an isolated hypothesis to experimental test, but only a whole group of hypotheses; when the experiment is in disagreement with his predictions, what he learns is that at least one of the hypotheses constituting this group is unacceptable and ought to be modified; but the experiment does not design which one should be changed. (1914/1954, p. 187)

The thesis on the underdetermination of theory by experience has the epistemological consequence that experimentation cannot conclusively establish a hypothesis or a theory as valid. An experimental result favorable to a hypothesis h may confirm it, but only in a provisional way. Duhem admits that a theory, such as Newton's mechanics, could be confirmed if the experimental results provide evidence in favor of it. However, this does not mean that the theory has been proved as a true theory.

A corollary of Duhem's Theses (1) and (2) is that experimental results against a hypothesis h open the possibility that any of the members of the group of theoretical statements involved in predicting h could be wrong, with the methodological consequence that the whole group must be revised and put in question. According to the former Theses (1-3), Duhem claims, contrary to Popperian falsificationism, that experimental results contrary to a hypothesis do not necessarily refute *it*. There is always room to save it from refutation through a modification of auxiliary hypotheses or even of some theoretical statements. At the time of Duhem, Newtonian mechanics was a confirmed theory, and similarly, present-day quantum mechanics is a confirmed theory. This does not mean from Duhem's view that those theories are true, but rather that they are valid in the sense that it is methodologically reasonable to claim that they hold in their respective domains, which makes it feasible to consider Duhem's theses in a non-realistic sense.

Duhem provides as an example of the underdetermination of theory by evidence the historical case of the velocity of light in different media. For him, the results of Foucault's experiment, which seem favorable to the hypothesis that the speed of transmission of light is faster in air than in water, do not refute the theory that light is a beam of particles and prove the wave theory of light. Some changes could be made in any element of the group of theories supposed to perform that experiment to save the particle's view of light (see 1914/1954, p. 187).

Some historical cases show that sometimes physicists decline hypotheses based on adverse experimental results, as in the case of the hypothesis on the straight-line trajectory of light, which is contrary to experimental results on the diffraction of light (see Duhem, 1914/1954, p. 187). This example suggests, as Kyle Stanford points out, that Duhem's thesis on empirical indeterminacy has a *transitory* character, that is to say, that he holds the indeterminacy of tested hypotheses provisionally concerning the present experimental results and not *permanently* to all possible experience, as Quine claims (see Stanford, 2023, Section 1).

Duhem's local holist view on the confirmatory process of hypotheses seems fit with the historical case of the discovery of the planet Neptune, where the background supposition about the existence of only seven planets was questioned to save the observations about the trajectory of Uranus. As is known, there were discrepancies between observations of Uranus' trajectory and the predictions of classical mechanics. Adams and Leverrier, independently, advanced the hypothesis that such discrepancies are due to the influence of an eighth planet, a hypothesis that was later confirmed by observing Neptune.³

On Crucial Experiments

The former Theses (1)-(2) entail Thesis (4) against crucial experiments. Duhem's underdeterministic thesis means that, because of the holistic character of the test hypothesis procedure, when the prediction of a theory does not match the experimental results, this does not teach us which statement of the group of theoretical statements used to derive such a prediction is wrong. Thesis (4) affirms that it is impossible to decide based on a single experiment which of two rival hypotheses is accurate because there could be more alternative hypotheses than those considered to perform the experiment. In this sense, Duhem claims that:

Unlike the reduction to absurdity employed by geometers, experimental contradiction does not have the power to transform a physical hypothesis into an indisputable truth; to confer this power on it, it would be necessary to enumerate completely the various hypotheses which may cover a determinate group of phenomena, but the physicist is never sure he has exhausted all the imaginary assumptions. (1914/1954, p. 190)

The idea that crucial experiments are not demonstrative is entailed in the thesis on the underdetermination of theory by experience because even experiments performed to test a single hypothesis cannot establish its truth when the experimental evidence is favorable to it. The basic idea is that the experimental method in physics does not have the power to prove any hypothesis; at most, it is possible by that method to confirm hypotheses in the sense that it could be reasonable to claim that they hold for the phenomena studied.

Considering the historical case on the nature of light, corpuscles or waves, two physicists may perform two separate and independent experiments; one uses Newton's optics, whereas the other utilizes Huygens' optics. The first will find that the hypothesis that light travels faster in water than in air fails. The second will give some support to the hypothesis that the velocity of light is faster in air than in water, as provided by the experimental results. Thus, the Newtonian physicist must analyze the failed experiment and determine which of the theoretical statements used to derive the prediction is a mistake. His Huygens' colleague, in contrast, has obtained a favorable result for his hypothesis on the nature of light as waves. According to Duhem, due to the holist underdetermination thesis, the experiment performed by the Newtonian physicist would not refute the hypothesis and, thereby, the conception of light as a beam of particles. For the same thesis, the Huygensian physicist would not demonstrate

³ Posterior Leverrier's failure to explain the irregular perihelion of Mercury by postulating a planet called Vulcan shows that a strategy to save a phenomenon does not always work (see Stanford, 2023, Sec. 2.1).

that light has a wave nature. The quantum dualism particle/wave of light seems to give reason to Duhem that experiments cannot decide on the nature of light.

Although we are not supposing a single experiment related to Duhem's thesis on the impossibility of crucial experiments, two independent experiments to test different predictions from two diverse optical theories will not show which of the two rival hypotheses is wrong even if the experimental results are against one of them, and according with Thesis (2), the whole group of auxiliary hypotheses and theoretical statements have to be revised to save the hypothesis in question. At most, crucial experiments could show that one of the rival hypotheses seems to be wrong. Still, they do not prove that the other hypothesis is right because the experimental experience underdetermines it.

Concerning Thesis (3), Duhem invokes the scientific good sense to decide between alternative strategies to save some hypotheses. That is his response to the indecision issue that arises from the underdetermination of theory by experiment, which admits that different physicists may take diverse decisions in the face of discrepancies between theory and experiment (see 1914/1954, pp. 208-211).

We wish to close this section by pointing out a claim due to Duhem, which we find sound with the conceptualist stance that we adopt here, about two kinds of apparatus related to experiments: one abstract, conceptual apparatus, the other concrete, physical apparatus. In this respect, he said:

We have seen that in the mind of the physicist there are constantly present the two sorts of apparatus: one is the concrete apparatus in glass and metal, manipulated by him, the other is the schematic and abstract apparatus which theory substitutes for the concrete apparatus and on which the physicist does his reasoning. For these two ideas are indissolubly connected in his intelligence, and each necessarily calls on the other; the physicist can no sooner conceive the concrete apparatus without associating with it the idea of the schematic apparatus [...] (1914/1954, p. 183)

Quine's Thesis on the Underdetermination of Theory by Experience

Independently, Willard Quine (1951/1953) advances a strong thesis on the underdetermination of theory by experience. He exposes global holism to the procedure of testing hypotheses and the consequences of a conflict between theory and experience. For him, the unity of empirical meaning is the whole of our knowledge in such a way that when one is testing a hypothesis, such a whole could be involved. It is not a group of statements that are concerned when a hypothesis is tested, but the whole. So, in contrast to the holistic local thesis of Duhem, limited to physical theories, Quine's holistic thesis has a global character with a broad scope that embraces our web of beliefs, that is, the set of our interrelated beliefs about the world: ordinary empirical beliefs, scientific beliefs, and even our beliefs about logic and mathematics.

Quine's theses agree, in general lines, with the previous Theses (1) and (2). First, he distinguished the thesis on empirical underdetermination from the holistic view concerning the testing procedure of hypotheses. According to the former thesis:

Scientists invent hypotheses that talk of things beyond the reach of observation. The hypotheses are related to observation only by a kind of one-way implication; namely, the events we observe are what a belief in the hypotheses would have led us to expect. These observable consequences of the hypotheses do not, conversely, imply the hypotheses. Surely there are alternative hypothetical substructures that would surface in the same observable ways. Such is the doctrine that natural science is empirically under-determined; under-determined not just by past observation but by all observable events. (1975, p. 313)⁴

⁴ It is worth noting that while Duhem refers to quantitative data of experiments, Quine discusses observational statements in terms of a concept of observation related to our sensory stimuli, statements that are, however, corrigible (see 1975, p. 316).

To which Quine links closely to the latter thesis:

This doctrine of empirical under-determination is not to be confused with holism [...] It says that scientific statements are not separately vulnerable to adverse observations, because it is only jointly as a theory that they imply their observable consequences. Any one of the statements can be adhered to in the face of adverse observations, by revising others of the statements. (1975, p. 313)

Moreover, for Quine, the holistic thesis provides some support for the underdetermination thesis:

This holism thesis lends credence to the under-determination theses. If in the face of adverse observations we are free always to choose among various adequate modifications of our theory, then presumably all possible observations are insufficient to determine theory uniquely. (1975, p. 313)

According to Quine, because of the underdetermination of theory by experience in the face of a disagreement between the result of an experience and our whole body of knowledge, any element of the latter could be revised, changed, or even ruled out and replaced with a new element. However, he offers a different response than Duhem to the problem that arises from Thesis (3), when there is a disagreement between theory and experience. He maintains that to save a given hypothesis from being refuted, it is possible to modify any element of the whole of our knowledge, preserving its consistency. No component of that whole is exempt from change or even elimination.⁵ As an example, Quine alludes to the change of classical logic to quantum logic to confront Heisenberg's principles of indetermination (see 1951/1953).

From a pragmatic stance, Quine response to the issue involved in the underdetermination thesis about how to decide a modification of the whole of our knowledge when there is a discrepancy between theory and experience consists in that one must seek the minimal mutilation and at the same time the maximal of epistemic virtues as simplicity and prediction power (see Quine, 1990, p. 12).

On Equivalent Theories

In "On Empirically Equivalent Systems of the World", Quine (1975) advances a new thesis about scientific knowledge that he finds associated with the thesis on the underdetermination of theory by experience. Quine sustains that there are, or could be, theories which are logically incompatible and empirically equivalent; this thesis assumes that the theories concerned share, in a large extent, the domain of application so that they could exhibit the same observable consequences.

Thus, for Quine, the notion of empirical equivalence means that: "[...] for any one theory formulation there is another that is empirically equivalent to it, but logically incompatible with it, and cannot be rendered logically equivalent to it by any reconstrual of predicates" (1975, p. 322). This thesis involves: (1) that two formulations of the same theory may have the same empirical support: that the empirical consequence that is confirmed by one of them is confirmed by the other also as well as that the adverse results against one of them is adverse to the other too, and (2) that the logical incompatibility of two formulations of a theory implies that there is, at least, one statement of one of them that is contrary, or even contradictory, to one statement of the other formulation. It seems complicated that a pair of formulations of physical theory fulfills both previous conditions. The Condition (1) on empirical equivalence entails that there is no observational statement that is true in one of them and false in the other. Although it may include some observational statements derived from both formulations, which lack

⁵ According to the conceptual pragmatism of C. I. Lewis (1929), former teacher of Quine at Harvard, concepts must be rejected or replaced by new concepts when they lose their pragmatic value.

truth values due to adverse actual observations. According to Condition (2) on the logical incompatibility, it seems that the two formulations would be incompatible at the theoretical level, not at the empirical level.

Is the difference between two formulations of a theory just a mathematical difference? Indeed, we find in the field of physics theories that differ in their mathematical formulations. Hamiltonian and Lagrangian formulations of classical mechanics differ; however, they share the same mathematical predictions, which are derived from Newton's laws rather than being logically deduced. Moreover, originally, quantum mechanics had two different formulations: Heisenberg's and Schrödinger's formulations. Nevertheless, it has been mathematically proven that Heisenberg's particle mechanics and Schrödinger's wave mechanics are equivalent. In both former cases, the different mathematical formulations do not involve any contradiction between them.

It is worth noting that even a high degree of confirmation of a given law, nobody is allowed to affirm that it is true: A high, or moreover maximal, confirmation of a theoretical statement, a *methodological* concept, does not imply that it is a true statement, a *semantic* concept. If that is right, the discussion about different theories that are empirically equivalent, if any, cannot be about their truth values, but rather about our acceptance or something similar. A consequence of the former is that one cannot say two theories purportedly empirically equivalent are logically incompatible, because this last logical concept implies that both theories cannot be true; that is, it implies that if one of these theories is true, the other is false. However, if we cannot affirm that either of those two theories is true, we cannot say that they are logically incompatible. An alternative, possibly consistent with Quine's idea of theories being empirically equivalent, is that there is a semantic inconsistency between their predicates, but not a terminological one, rather a conceptual one.

Quine provides an artificial example of two atomic theories that differ only in that the terms "electron" and "molecule" are interchanged. This example is unsatisfactory, Quine points out, because one could convert them to logically equivalent theories by a simple permutation of those terms, in which case they are the same theory, with different formulations (see 1975, p. 319). However, later Quine reveals a remark about the previous example: "Yet the two formulations are logically incompatible, for the one attributes properties to molecules that the other formulation *denies* of molecules and attributes to electrons (I am indebted here to Humphries) (1981, p. 29). We think that the presumed incompatibility between these two formulations is not logical but rather a conceptual inconsistency at a theoretical level, which arises from the different concepts of molecule and electron that occur in nomic statements of atomic physics theory. Due to that conceptual inconsistency, the two formulations involved become incongruous with each other at a theoretical level. We can say that a difference that could be between two theories with the same empirical domain consists of a conceptual diversity: When Quine talks of a difference of predicates, he is not referring to a terminological difference but to a difference of the concepts that the predicates connote.

Quine reformulated some of his ideas under discussion, introducing a criterion to individualize theories as follows: Two formulations express the same theory if they are empirically equivalent and there is a reconstruction of predicates that converts one formulation into a logical equivalent of the other. This last thesis is plausible; however, it refers to equivalent formulations, both empirical and logical, of the same theory, rather than to theories that have the same empirical consequences but are logically incompatible. If we realize that there are not physical theories without laws and that there are not physical laws without concepts (quantitative concepts that denote physical magnitudes), and if we assume two theories with the same domain but conceptually different,

then the predictions of those theories will differ on their conceptual content,⁶ which impedes that they could be empirically undistinguished. A possible reconstrual of the relevant concepts (predicates in a linguistic version) that transforms conceptually equivalent theories seems implausible.

There is another difference between the two mathematical formulations of the same theory that share their predictions. The alternative theories involved in the historical case alluded to by Duhem on the velocity of light in different media differ, at least, in their conceptions of the nature of light: corpuscles or waves. It was an ontological discrepancy! The experiment assumes that the two theories share sufficient concepts to describe all pertinent aspects *neutrally*. A similar difference existed between the two original formulations of quantum mechanics, developed by Heisenberg and Schrödinger. Besides their different mathematical formulations, there was a discrepancy in the ontologies postulated by these two theories: particles or waves. What we can say, again, is that they differ in the ontologies postulated. However, as is now known, the results of some experiments testing specific hypotheses derived from one of those two theories do not match both; instead, they match either the wave interpretation or the particle interpretation. That means that Heisenberg and Schrödinger's quantum theories, which are mathematical equivalents, do not have the same empirical consequences. In the first case, wave theory and particle theory of light make different predictions, in addition to the differing ontologies they postulate. In the second case, the two formulations of quantum theory, which assume different ontologies, do not share all their predictions. Thus, it appears that the ontology postulated by different formulations of a theory plays a crucial role in the issue of theory identification.

Although the former does not intend to mean that the ontology postulated is part of a theory. However, the issue of what components of physical theories arise. In the present context, we can say that a physical theory contains, at least, laws and the concepts in which they are formulated, which seem compatible with Quine's view of theories as systems of laws. We can, of course, add the models of the theory. Nevertheless, physical theories rest on some metaphysical assumptions, for example, classical mechanics' causal determinism or quantum mechanics' acausal indeterminist conception. Both theories, with their metaphysical suppositions, provide a world view, which includes theses about what exists and what happens in the physical world: a world formed by causal processes governed by deterministic laws or a world containing random processes governed by probabilistic laws.

It seems that quantum mechanics does not fit with Quine's thesis on the existence of empirically equivalent theories. Both classical formulations of such a theory, although mathematically equivalent, differ in the ontologies they postulate and differ also in their empirical consequences. One could argue that they are the same theory, just with different but equivalent mathematical formulations. However, in some applications of quantum theory, the results match the conception of light as waves, whereas in other applications, the results match the conception of light as particles.

This double nature of light, the dualism wave/particle, has not been eliminated in the present quantum theory. If two physical theories differ in the ontologies they postulate, it is unlikely that they will have the same empirical consequences. An adjustment *à la* Quine of our system of the world does not seem feasible for that quantum dualism, meaning the type of adjustment that Laudan expressed Quine's underdetermination thesis: "Any theory can be reconciled with any recalcitrant evidence by making suitable adjustments in our other assumptions about

⁶ See *supra*, Section "Final Remarks".

nature” (1990, p. 328).⁷ Of course, Quine’s thesis is not about theories that make different predictions; instead, his thesis is about different theories that yield the same empirical consequences. How could empirically equivalent theories be different?

Quine (1983) speaks of the ontology and the ideology of theories. He does not maintain a criterion of existence but rather a criterion of ontological commitment to a theory. His approach to the matter is semantic; answering the objection that what there is, is a question of fact and not of language, Quine wrote: “True enough. Saying or implying what there is, however, is a matter of language; and this is the place of the bound variables” (1983, p. 499). Quine’s related slogan is “To be is to be the value of a bound variable”. Concerning this idea about ontological commitment of theories he says that a theory T is commitment with the existence of the entities needed for their statements could be true; in his words: “A theory is committed to those and only those entities to which bound variables of the theory must be capable of referring in order that the affirmations made in theory be true” (1948/1953, p. 33). That criterion demands that the theory concerned be formulated in the language of a first-order logical system. If T is formulated in such a logical system, then their existential assertions adopt the form: $(\exists x) (Fx \& Gx \& Hx)$, where F , G , and H are first-order predicates, and the range of the individual variables is the domain of T . These are Quine’s basic ideas on that topic.

Concerning the ideology of a theory, he said: “I long ago distinguished between ontology and what I called ideology, this latter being one’s stock of simple terms or predicates” (1983, p. 501). Perhaps, if we transfer that idea of ideology to physical theories, we could say that the ideology of a theory consists of the set of ideas or concepts, and the relations among them, that are needed to formulate the nomic statements of T : class (or kind) concepts and quantitative (metric) concepts. In general, physical theories do not admit formulations in first order logic; for example, Kuhn points out that Newton second law is not a statement of a law but rather a law-sketch or law-schema where the symbol F , that stands for the general concept of force, is a functor, that is, a function of functions or a second order function (1970, p. 188). Thus, Quine’s criterion requires logical systems of high order for physical theories, which involve the quantification of first and second-order predicates, and not only on individual variables. Nevertheless, the major problem with Quine’s criterion for physical theories consists in that we are not allowed to affirm that the laws in physics are true statements. Quine’s criterion is correct for formal theories, but we need another criterion for factual theories. However, Quine’s insight is right. Intuitively, we can say that the ontological commitment of a physical theory consists in the sets of entities and magnitudes that their laws presuppose to exist, that is, their existential presuppositions. The entities postulated by physical theory are denoted by their class concepts, whereas the magnitudes are denoted by their quantitative concepts. Both kinds of concepts, and their relations, would conform to what, in a Quinean vein, we could call the ideology for physical theories.

If one considers that Quine’s thesis about different theories that are empirically equivalent refers only to the ideology of the theories involved, then the criterion to claim that two theories differ is simply that there is a difference in their conceptual schemes, leaving aside the question about their respective ontologies. However, this could not be sufficient because a theory intends to refer to the physical world, and its empirical consequences are, of course, about the phenomena that happen in the postulated world.

⁷ Laudan’s main critique of the Quinean underdetermination thesis is on the rationality of theory choice between rival theories, given the empirical indeterminacy, which, according to him, Quine does not account for.

Final Remarks

Quine's thesis on theories empirically equivalent and logically incompatible seems in opposition to Duhem's Thesis (4) concerning the impossibility of crucial experiments. The basic idea of this type of experiment involves two alternative theories on the same subject matter, which may have different empirical predictions, allowing an experiment to decide between them. Empirically equivalent theories give no place for crucial experiments; they are empirically indistinguishable, sharing all their empirical consequences and evidence.

Until now, we have seen that there are theories with different predictions that can be mathematically equivalent, although they have different world views. Also, we have theories that are logically incompatible but can hardly be empirically equivalent. The latter issue rests on the supposition that physical theories could predict what happens in their postulated worlds and that some of their claims could be factually true. In particular, it assumes that the empirical consequences of physical theories have truth-values; otherwise, they could not be logically incompatible. This thesis adopts a classical, bivalent logic. In contrast, the thesis that crucial experiments are unable to decide between alternative hypotheses or theories does not assume the logical principle of excluded middle. At most, an experiment can rule out a hypothesis but cannot prove the opposite hypothesis, even if they are mutually exclusive; there is always the possibility of additional alternative hypotheses, according to Duhem, because theories are underdetermined by experience.

Quine's thesis about empirical or observational indeterminacy neither implies the refutation of a theoretical hypothesis when the observations obtained are adverse, contrary to it. This last matter is congruent with Quine's holistic conception of the procedure for testing hypotheses, but it seems contrary to his thesis on empirically equivalent theories, because it involves the possibility of determining the truth values of the predicted hypotheses that share the same empirical evidence. That conflicts with Quine's thesis on the logical incompatibility of theories that imply the same empirical consequences.

Indeed, both Duhem and Quine sustain the thesis on the underdetermination of theory by experience (sometimes called "the Duhem-Quine thesis"); the difference between their views, as we have seen, lies in the scope of their respective theses. Duhem related his thesis to a criticism of the crucial experiments whereas Quine linked his thesis to the issue that, though logically incompatible, there are or could be empirically equivalent theories. The shared central thesis involves that the results of an experiment or observation that verified the predictions of a theoretical hypothesis h only determine partially h and does not prove h as valid or true. For that, other hypotheses, alternative to such hypothesis h , could fit equally well with the results of such experiment or observation as h . The strength of the empirical indeterminacy thesis is manifest in cases where the results of experiments or observations are contrary to the hypothesis under consideration, because it means that there is something wrong in the group of theoretical statements or the whole of our knowledge, implying an *epistemic uncertainty* about which element of the theoretical framework involved is erroneous. Due to the holistic view of the procedure of testing hypotheses sustained by Duhem and Quine, they do not think, as a naive Popperian philosopher could think, that a prediction that fails is false and, by *modus tollens*, the hypothesis involved is empirically refuted.

Let us examine the issues at hand from a conceptualist, or conceptual relativist, perspective.⁸ To achieve this, we first present some ideas about the *conceptual content* of physical theories and related topics. The content

⁸ See Roller (2023).

of a concept is composed of the set of concepts it connotes. The relationship between a concept and the concepts that it connotes is of entailment, not of implication, which is a relation between statements.⁹ In general, the conceptual content of a statement consists of the set of concepts contained in the statements that it logically implies (including, of course, itself); the logical consequences of a set of statements cannot include more concepts than those statements. The *conceptual content* of a set of physical laws of a theory consists of the set of concepts—class concepts and quantitative concepts—included in the laws, as well as their logical consequences.

The set of classes of entities and magnitudes intended to be denoted by general physical concepts—class concepts and quantitative concepts, respectively—as contained in the laws of a theory, forms the ontology postulated by it. Understanding the systems of concepts and laws of a theory, together with the postulated ontology, amounts to understanding the theory at an abstract level, which is *epistemologically prior* to any application, whether empirical, practical, or technological.

The systems of scientific concepts and laws form the basis of our understanding and comprehension of the physical world, including how we conceptualize it, what exists, and what happens in it, relatively to physical theories. The conceptualization of the world that is the domain of a theory from its perspective is anterior both to any pragmatic application and to any empirical confirmation of it. Both pragmatic and empirical tasks of a theory presuppose an understanding, a conceptualization, of the world that is the domain of the theory involved.

From a conceptualist view, which is consistent with Quine's general epistemological outlook, underlying our system of beliefs, there is a system of concepts that provides content to our beliefs about the physical world. The content of our scientific beliefs about the physical world is formed by our scientific conceptual framework of its subject matter. That means that the content of such kind of beliefs rests on the conceptual content of the statements of the relevant physical theory. In other words, those sorts of beliefs have a conceptual content relative to the conceptual system of our theory. What matters to epistemology is not what we believe but rather their conceptual content, which comes from physical theories. Thus, conceptual content is epistemologically anterior to beliefs, and it is what matters for scientific knowledge. What is peculiar about those beliefs is a psychological, subjective feature: the fact that we trust in their content, and so we think that what we believe is true. However, very often we are not in an appropriate epistemic position to believe them as true.

A scientific device to conceptualize a process is the construction of a model. In physics, models of certain types of processes offer abstract and idealized conceptualizations of the processes concerned. The previous is due to the abstract nature of physical concepts together with the idealized character of physical laws. Models are valuable tools for understanding the processes that occur in the physical world *relative* to a theory. If our understanding, our conceptualization of what there is and what happens in the physical world, is relative to and dependent on a given theory via its models, the theses of Duhem and Quine adopts different forms.

Let us assume Hanson's thesis on the theory laden of scientific observation which entails that no observation is exempt from theoretical suppositions (Hanson, 1958, Chap. 1). If we realize that scientific experience, both experiment or observation requires a conceptualization of its subject matter from the perspective of a theory, provided by an abstract and idealized model, then a crucial experiment cannot be neutral, *impartial*, with respect to the two theories involved. It cannot be decisive, as Duhem sustains, since the experimental results would be theory laden to one or the other of the two rival theories. For the same reasons we may say that two different theories, logically incompatible, about the same subject matter, if any, could not be empirically equivalents,

⁹ In contrast to Brown's thesis which affirms that concepts are related by implication. See Brown (2007).

against Quine claim, because any scientific observation requires an abstract and idealized conceptualization of its subject matter that is theory laden to one or another of the two theories concerned, which imply the no equivalence, the *divergence* of the observations to test their respective hypotheses.

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