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Pierre Duhem's rejection of special relativity☆

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ABSTRACT

In this paper, I analyze Pierre Duhem's rejection of Albert Einstein's special relativity. Duhem published his most influential contributions to the philosophy of science during the same years that Einstein published the theory we now call special relativity. There are numerous coincidences in the conceptions of both authors about scientific methodology to the point that it has been stated that Einstein's philosophy is supported by Duhem's. It is surprising to discover that Duhem nevertheless rejected special relativity completely. Analyzing this rejection sheds light on aspects of Duhem's philosophy of science that have not been clearly recognized, namely how he conceived of the continuity between common sense concepts, scientific concepts, and measurement.

1. Introduction

The reflections about science that the physicist Pierre Duhem (1893/1996–1916) published at the beginning of the 20th century have been widely discussed in the philosophy of science. Although this is a testament to Duhem's originality and subtlety, it must be recognized that much of the discussion surrounding his philosophy of science is due to the fact that he was not always clear or systematic. The position that Duhem took in relation to the new physical theories of his time, for example, is not always easy to explain. In particular, Duhem's rejection of Albert Einstein's special relativity is surprising. In principle, it seems that there was nothing in special relativity contrary to Duhem's methodological conclusions. At least, Einstein himself apparently did not see any conflict between his theories and Duhem's conclusions. Don Howard (1990) and Howard, and Giovanelli (2019) maintain that Einstein's philosophy of science was based on Duhem's philosophy. Also, according to Donald Gillies "from a logical point of view, Duhem's philosophy of science can be seen as offering support to the Einsteinian revolution in physics. It therefore comes as a surprise to discover that Duhem rejected Einstein's theory of relativity in the most violent terms" (Gillies, 1993, p. 105).

My objective is to clarify the philosophical reasons that led Duhem to reject Albert Einstein's special relativity. I will show that Duhem's philosophy included a particular conception of scientific concepts that has rarely been emphasized in the recent literature on Duhem. In this conception it is assumed that *there is a formal continuity between scientific concepts and common sense concepts of everyday experience*. Duhem and Einstein conceive this continuity in a different way, and it is this what led the former to reject the latter's theory.

To explain Duhem's rejection of special relativity I will begin, in section 2, by describing some historical aspects of Einstein's discovery of special relativity that I consider relevant. Then, in section 3, I will mention some relevant coincidences between Duhem's conceptions and those of Einstein, as well as with what we can observe in the early history of special relativity. This will allow, in section 4, to discuss some of the explanations that have been proposed in recent literature to explain Duhem rejection of special relativity and show their limitations. In section 5, I will explain how we can understand Duhem's rejection of special relativity. In section 6, I outline some consequences that could be inferred for understanding Duhem position regarding metaphysics. And, finally, in the conclusions section I will point out some consequences for the study of Duhem and Einstein in philosophy of science.

2. The origin of special relativity: the *aether*, the measurement of the speed of light and the concepts of space and time

Since the early 19th century, most physicists accepted that light consisted of waves produced in an imponderable medium or *aether*.

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However, until the beginning of the 20th century there were still debates about the nature of the supposed *aether*.[1] An important number of alternative conceptions of the *aether* were proposed by researchers such as Augustin Fresnel (1788–1827), Augustin Louis Cauchy (1789–1857), Franz Neumann (1798–1895), George Green (1793–1841), George Stokes (1819–1903), among others. Nevertheless, the experiments that were carried out to corroborate the predictions of these proposals generated inconsistent results, such as those carried out by Armand Hippolyte Louis Fizeau (1819–1896) or Albert Abraham Michelson (1852–1931) and Edward Morley (1838–1923).

In 1892, Hendrik Antoon Lorentz (1853–1928) set out to resolve the difficulties faced by the *aether hypothesis* through an electrodynamic theory, since, by then, it was accepted that light was an *electromagnetic wave*. This had been achieved mainly thanks to the work of James Clerk Maxwell (1831–1879) and Heintich Hertz (1857–1894). However, the unification of optics with electromagnetism did not resolve the difficulties that physicists had encountered when looking for experimental confirmations of the *aether hypothesis*. The situation was possibly worse because Maxwell's electromagnetic theory did not seem consistent with the equations that were traditionally used in physics to transfer descriptions of phenomena from one inertial frame of reference to another.

Lorentz found a solution to preserve the *aether hypothesis* by assuming that the only interaction of the *aether* with matter was through electrically charged particles present in all material bodies (which were later called *electrons*). After several years, and some reformulations, Lorentz obtained a theory with a sophisticated mathematical structure that allowed him to derive correct predictions for the experiments in optics and electromagnetism carried out until the beginning of the 20th century.[2] Henri Poincaré (1854–1912) also contributed to this work of Lorentz by providing criticism and his own formulation of the theory.

Then, in 1905, Albert Einstein published an article entitled *On the Electrodynamics of Moving Bodies*, which contains the origin of what we now call *special relativity*. The article is motivated by Einstein's concerns about Maxwell's theory; mainly about how to use Maxwell's equations when moving from one inertial frame of reference to another. In previous physics, a mathematical description of a phenomenon elaborated in one inertial frame of reference could be transferred to a different one using the so-called *Galilean transformations*. However, by the end of the 19th century it was clear that Maxwell's equations for the electromagnetic field are not invariant under these transformations, i.e., they alter the relations that the equations establish, which should not happen.

Furthermore, in the 1905 article, Einstein refers to the failed experiments to study the *aether* but drew a different conclusion than Lorentz.[3] He concluded that the *aether hypothesis* was superfluous and that he could resolve the theoretical difficulties with the experimental predictions in a different way.

> I spent almost a year fruitlessly thinking about it, expecting that I would have to modify Lorentz's ideas somehow … My solution actually had to do with the concept of time. The point is that time cannot be defined absolutely, but that there is an inseparable connection between time and signal velocity. Using this idea, I could now for the first time completely resolve the extraordinary difficulty I had had before (Einstein, 1923/2012, 637).

Einstein eliminated the *aether hypothesis* and proposed two new principles that involved redefining the concepts of space and time. These principles were the *principle of relativity* and the *light principle*. The *principle of relativity* states that the laws of physics make no distinction between inertial reference frames. For its part, the *light principle* stated that the speed of light is independent of the speed of the source of emission. Possibly, both principles were due to the fact that the experiments designed to detect *aether* by measuring variations in the speed of light had failed.

Einstein's article begins with an example of an electromagnetic phenomenon for which the theories of the time generated two conflicting explanations. According to him, "Examples of a similar kind, and *the failure of attempts to detect a motion of the earth relative to the 'light medium'*, lead to the conjecture that not only in mechanics, but in electrodynamics as well, the phenomena do not have any properties corresponding to the concept of absolute rest" (Einstein, 1905/1989, p.140, emphasis added).[4] These *failures in attempting to measure variations in the speed of light* had not only shown that there were theoretical errors but, in doing so, had also shown that the speed of light was remarkably stable. The development of electromagnetic technology also attested to this stability, as historians of science have already noted. "As electromagnetic communication networks increasingly crisscrossed the globe (both telegraphic and wireless), scientists became increasingly sure about one thing: the behavior of light on the surface of the Earth" (Canales, 2015, p. 109). In fact, the mutual support of the different methods available to measure the speed of light, towards the end of the 19th century, meant that this was recognized as a remarkably *robust measurement*. The robustness of the measure of the speed of light was so clear that the philosopher Charles Sanders Peirce (1839–1914) used it to explain his notion of what reality is.

> One man may investigate the velocity of light by studying the transits of Venus and the aberration of the stars; another by the oppositions of Mars and the eclipses of Jupiter's satellites; a third by the method of Fizeau; a fourth by that of Foucault … They may at first obtain different results, but, as each perfects his method and his processes, the results will move steadily together toward a destined centre … The opinion which is fated to be ultimately agreed to by all who investigate, is what we mean by the truth, and the object represented in this opinion is the real. That is the way I would explain reality. (Peirce, 1878, p. 299–300).

It is not surprising that, in this historical context, Einstein considered the constancy of the speed of light to be a reliable starting point.

Einstein's principles of relativity and light incorporated the robustness of light speed measurements into his research. However, the principle of relativity and the light principle seemed to imply a contradiction. According to the first, there is no absolute motion, all speed is measured with respect to something, but the second principle seems to imply that the speed of light can be the same regardless of the motion of the emission source. This is the difficulty that Einstein resolved with his analysis of the concept of time.

At the beginning of the 'kinematic part' of the 1905 paper on relativity, there is a brief but important discussion by Einstein of how our understanding of concepts (such as simultaneity, space and time) is related to our sensations. This discussion possibly was inspired by philosophical reflections. In his *Autobiographical Notes*, Einstein said that

[1] As Stanford (2006, pp. 174-175) points out, the debates about the *aether* during the 19th century were mainly *not* about its existence, but about its characteristics.

[2] A more detailed description of Lorentz's theory is found in Janssen (1995) and Acuña (2014).

[3] Gerald Holton (1969) calls into questions that the famous Michelson-Morley experiment really motivated Einstein's research that led to special relativity. However, in his 1905 paper, Einstein does mention experiments in optics that conflict with the *aether* hypotheses, although he doesn't specify which one. Norton (2004) argues that Einstein possibly had in mind *Fizeau's experiments* and the phenomenon known as *stellar aberration*. In any case, the point here is that Einstein knew that there were experimental results in conflict with the *aether* hypothesis.

[4] As stated in the previous footnote, it is controversial whether Einstein knew about the Michelson-Morley experiment, but he does say that there were "failures of attempts to detect a motion of the earth relative to the 'light medium'". So, he knew that there were experimental results in conflict with the *aether hypothesis*.

"The type of critical reasoning which was required for the discovery of this central point was decisively furthered, in my case, especially by the reading of David Hume's and Ernst Mach's philosophical writings" (Einstein, 1949/1970 p.53). According to John D. Norton (2010), what Einstein took from these philosophers was the insight that the concept we have of something depends on our experience with whatever they refer to. For example, Hume thought that the concept of time resulted from our experience with change, so this concept is not applicable to things that do not change. Einstein does not actually take this conception of time, but he does take the idea that the concept we have of time depends on our sensory experiences.

According to Norton (2010), Einstein realized that we should not assume that our concepts are appropriate to represent reality when we deal with domains that are beyond our sensible experience. In our *everyday experience*, we do not detect movements as fast as that of light, but when dealing with phenomena for which such speed is important, we are tempted to automatically assume that concepts, such as *simultaneity*, can be used in the same way. Einstein considered that we use these types of assumptions a priori and without justification. The same conclusion can be obtained with respect to the concept of *time*, since, for Einstein, "all our propositions involving time are always propositions about simultaneous events" (Einstein, 1905/1989, 141). So, he identified a priori presuppositions in the concept of simultaneity.

> Einstein, however, was willing to retain the concept as long as its arbitrary character was recognized and in a way that no longer allowed the unwitting introduction of a priori presumptions. In the case of distant simultaneity, Einstein achieved this by introducing distant simultaneity through a definition—a freely chosen stipulation —carefully designed to minimize the danger of introducing false physical presumptions (Norton, 2010, p.371).

The redefinition of concepts that Einstein stipulates assumes the principles of relativity and light. These principles are assumed to be correct and a redefinition of the simultaneity of events can be derived from them. This is done assuming that time measurements in different places can only be compared if each has coordinated clocks. The coordination is achieved, in turn, considering the exchange of light signals whose speed is assumed constant, in accordance with the light principle, regardless of the speed of the observers whose clocks are coordinated. The mathematical description of this coordination process, together with the principle of relativity, allows the deduction of equations to compare the length of objects and the measurement of time intervals in different reference frames. Using such equations it is concluded that the length of objects and the duration of events can change from one reference frame to another. That is, space and time cease to be absolute and become relative to the frames of reference. In other words, Einstein proposes a process of clock coordination, through which he can deduce equations that imply a new way of understanding space and time. *Now the concepts of space and time cease to be qualities and are understood as relation defined through measurement operations*. With these new concepts, Einstein could solve the difficulties that he had identified in the electrodynamics and optics of his time, but without the need to resort to the *aether*.

3. Coincidences between the early history of special relativity and Duhem's methodology of science

Although it is unlikely that Duhem knew about relativity when writing his best-known book, *The Aim and Structure of Physical Theory* (*Aim and Structure* from now on), it is interesting to note how much his descriptions of physics in that book are consistent with what we saw in the last section. In particular, the early history of relativity appears to follow the structure that Duhem describes for testing experiments in *Aim and Structure*.

According to Duhem, "When certain consequences of a theory are struck by experimental contradiction, we learn that this theory should be modified but we are not told by the experiment what must be changed" (Duhem, 1906/1954, p.216). We have seen that several physicists of the 19th century supported the hypothesis that there was a luminous *aether* that explained optical and electromagnetic phenomena. However, some experiments, such as those of Michelson and Morley and the one by Fizeau's, conflicted with this hypothesis. According to Duhem, there are two ways to proceed in the face of recalcitrant experimental results: the 'timid strategy' and the 'bold strategy'. These strategies can be clearly associated with those of Lorentz and Einstein. "… one may be obliged to safeguard certain fundamental hypotheses while he tries to reestablish harmony between the consequences of the theory and the facts by complicating the schematism in which these hypotheses are applied, by invoking various causes of error, and by multiplying corrections" (Ibid., p.216-217). Lorentz did this since he retained the *aether hypothesis* and tried to account for the results by other means. "The next physicist, disdainful of these complicated artificial procedures, may decide to change some one of the essential assumptions supporting the entire system" (Ibid., p.217). This is the strategy followed by Einstein, who completely avoids the *aether hypothesis* and, rather, proposes a new theory based on the *principle of relativity* and the *light principle*.

In later literature one can find a wide debate among historians and philosophers of science about whether or not Einstein's solution was actually better than Lorentz's during the first decade of the 20th century.[5] Historians and philosophers have had difficulty pointing out logical reasons why physicists of the time should have accepted Einstein's proposal, even though that is what they did within a few years.[6] Duhem said that, in such cases, there may not be such reasons of 'pure logic'.

> That does not mean that we cannot very properly prefer the work of one of the two to that of the other. Pure logic is not the only rule for our judgments; certain opinions which do not fall under the hammer of the principle of contradiction are in any case perfectly unreasonable. These motives which do not proceed from logic and yet direct our choices, these 'reasons which reason does not know' … constitute what is appropriately called good sense. (Ibid.)

The fast acceptance of special relativity by the scientific community, despite the absence of clear conclusive reasons, seems to support Duhem's thesis that something similar to 'good sense' was used in the physics of his time.[7]

Additionally, it can also be noted that the triumph of relativity is consistent with the way in which Duhem describes the historical continuity of physics. According to Duhem, physicists search for theories that approximate what he calls a *natural classification*. This requires a historical continuity in theories, such that, when one theory is replaced by another, the new one must be a better approximation to a *natural classification*.[8] When explaining what had to be preserved in theory change, Duhem points out that the theories can be divided into two parts "one is the simply representative part which proposes to classify laws; the other is the explanatory part which proposes to take hold of the

[5] Cfr. Grünbaum (1959), Holton (1969), Zahar (1973a, 1973b), Nugayev (1983), Goldberg (1984), Brush (1999), Janssen (1995, 2002, 2019), Acuña y Dieks (2014), among others.

[6] According to Stanley Goldberg "1911 is significant because there is evidence that, at least for the leaders in science, the theory [of special relativity] was thought to have been established by then" (Goldberg, 1984, p. 182).

[7] Recently, there has been extensive literature that seeks to interpret Duhem's concept of *good sense*. For example: Stump (2007), Ivanova (2010), Fairweather (2012), Bhakthavatsalam (2017) and Shaw (2020), among others. It has also been said (e.g. Martin, 1991) that Duhem's concept of *good sense* should not be confused with that of *common sense*.

[8] On Duhem's concept of natural classification and his thesis of continuity in the historical development of physical theories, see, for example, Dion (2013, 2018).

reality underlying the phenomena" (Duhem, 1906/1954, p.32). Only the representative part is to be preserved in theory change, according to Duhem, while the explanatory part is lost. When referring to the wave theory of light, *Duhem clearly identifies the assumptions about the nature of the aether as explanatory*. "The physicist who sees in every theory an explanation … believes in an ether, a body whose parts are excited by this vibration into a rapid to-and-fro motion. Of course, we do not share these illusions" (Duhem, 1906/1954, p.26).[9] In other words, the success of Einstein's special relativity is consistent with the way in which Duhem describes the historical development of physical theories, since it involved the abandonment of an explanatory element: the *aether*.[10]

The important thing here is not that Duhem had Einstein's specific case in mind when writing *Aim and Structure*; the publication dates of both of their works show that this was not the case; Rather, the fact that this case seems to fit so easily into Duhem's descriptions shows the extent to which he genuinely identified important aspects of scientific practice at the beginning of the 20th century.

Furthermore, Einstein seems to agree with Duhem that a form of *underdetermination* occurs in physics. Duhem's arguments about hypothesis testing have been interpreted in philosophy of science as the origin of modern debates about the *underdetermination of scientific theories by evidence*. Duhem added, however, that physicists have the means to choose which theory is best in such cases, but not for reasons of pure logic but by the use of *good sense*. For his part, Einstein states that:

> In this methodological uncertainty, one might suppose that there were any number of possible systems of theoretical physics all equally well justified; and this opinion is no doubt correct, theoretically. But the development of physics has shown that at any given moment, out of all conceivable constructions, a single one has always proved itself decidedly superior to all the rest. Nobody who has really gone deeply into the matter will deny that in practice the world of phenomena uniquely determines the theoretical system, in spite of the fact that there is no logical bridge between phenomena and their theoretical principles. (Einstein, 1918/2002, p.44).

Like Duhem, Einstein recognizes that there are different valid ways of formulating theories, among which pure logic does not tell us which to choose. Pure logic is not the only guide to our judgments, according to Duhem and Einstein, even so 'in practice the world of phenomena uniquely determines the theoretical system.'

4. Duhem's rejection of special relativity and some of its explanations in secondary literature

Given that the emergence of special relativity seems to follow Duhem's descriptions, and the fact that Einstein seems to agree with him on several relevant points of his conception of physics, we would expect a favorable response from Duhem to relativity. However, in his book *German Science*, Duhem shows a clear rejection of Einstein's relativity. Throughout this book, Duhem criticizes the science that was done in Germany because he considered it to lack *common sense*. In particular, Duhem expresses his disagreement with Einstein's relativity, which seems associated with the changes it introduces in the concepts of space, time and motion. According to Duhem:

> The ideas of space, time, and motion are presented to us by common knowledge as simple and irreducible ideas, which cannot be reconstructed with the aid of operations bearing on whole numbers. They are, therefore, essentially incapable of algebraic definition. But that is not obstacle! The geometrical mind refuses to consider the space, time, and motion which all people conceive clearly and about which they can talk among themselves without ever ceasing to understand one another. By operation referring to algebraic expressions—that is, in the last analysis, to whole numbers—it fabricates for itself its own space, its own time, its own motion. It subjects this space, time, and motion to postulates which are arbitrarily arranged algebraic equations. And when it has rigorously deduced a long series of theorems from these definitions and postulates, according to the rules of calculation, it says it has produced a geometry, a mechanics, a physics, although it has only developed chapters of algebra. That is how Riemann's geometry was constructed; that is how relativity physics was constructed; that is how German science progresses, proud of its algebraic rigidity, looking with scorn on the good sense of which all people have received a share. (Duhem, 1915/1996, 273).

Duhem's criticism of Einstein seems related to a conflict with *common sense*. First, though, it is important to keep in mind that authors, such as Martin (1991), have argued that Duhem uses *good sense* and *common sense* as distinct concepts in *Aim and Structure*. Nonetheless it seems clear that he does not distinguish them in *German Science*. There he says, for example: "The faculty by which we know the axioms is given the name of 'sense': it is *common sense*, or *good sense*" (Duhem, 1915/1991, p.7, italics in the original). In any case, I do not think the '*good sense*'/'*common sense*' distinction is too relevant here. Duhem's conflict seems to be with the relation between everyday concepts and scientific concepts, since he criticizes that German scientist, like Einstein, "refuses to consider the space, time, and motion which all people conceive clearly and about which they can talk among each other …" From now on I will use the concept of *common sense* as I consider Duhem does in *Aim and Structure*, that is, to indicate everyday concepts and beliefs.

Duhem's criticism seems to be centered on the modifications that Einstein introduces to the concepts of space and time. When he says that 'By operation referring to algebraic expressions—that is, in the last analysis, to whole numbers—it fabricates for itself its own space, its own time, its own motion' Duhem seems to maintain that the concepts of relativity are mathematical entities, without physical meaning. So, we would have to try to establish what reasons Duhem could have for reaching this conclusion.

There are other cases in which Duhem criticizes certain physicists for using scientific concepts in ways he considered inappropriate. The clearest case is that of the criticism he directs at the theories of Maxwell on electromagnetism. Although Duhem criticizes several aspects of Maxwell's theories in different texts, the criticism that we could associate with his reaction to relativity (since it is related to the use of concepts) is the one in which he attacks Maxwell for unnecessarily introducing a new concept: that of *displacement current*. According to Ariew and Barker (1986, p.150-151), Duhem criticized Maxwell for introducing this concept because, by doing so, he broke with a research tradition that he recognized (which came from electrical studies of Coulomb, Poisson and Ampère), without himself proposing an alternative coherent tradition (since, according to Duhem, Maxwell only proposed theories and models that were inconsistent with each other) and there being better coherent alternatives (as Duhem considered Helmholtz's electromagnetic theory). Duhem's criticism points out that a new concept should not be introduced unless there appears to be no alternative and without defining them coherently. Duhem's concern is that one risks the continuity of the historical development of theories and

[9] Almost since the beginning of the book Duhem (1906/1954, p.9) refers to the *aether* as explanatory. Also, in chapter III of the first part, he states that Fresnel trayed to explain the double refraction of light with the *aether* and that "Fresnel's theory … becomes untenable as soon as it is given as an explanation" (1906/1954, p.38). Additionally, Duhem (1906/1954, p.83-84) makes the aether part of his critic to British science.

[10] Duhem was not clear about how one distinguishes between the explanatory part and the representative part of theories. Furthermore, Marie Gueguen and Stathis Pasillos (2017) point out that the distinction may be problematic. However, we can ignore the problem here since Duhem explicitly identified the *aether* as an explanatory element. The success of special relativity, as a theory that eliminates this explanatory element, is consistent with the way in which Duhem saw continuity in the historical development of physical theories.

their logical unity by introducing new concepts unnecessarily. According to Duhem, Maxwell did not take enough care with the introduction of concepts because he was only proposing models that, although they should explain the phenomena, did not need to be logically consistent. In chapter IV of the first part of *Aim and Structure*, Duhem rejects this way of proceeding in physics and the British tradition that he associates with it.

However, it does not seem clear that the same criticisms could be applied to the case of Einstein's relativity, because alternatives to relativity (such as Lorentz's electromagnetic theory) relied on the concept of *aether* that Duhem rejected. That is, there were no better alternatives to relativity that Duhem recognized. In fact, we have seen that relativity seems to be more consistent with Duhem's requirements regarding historical continuity in the development of theories. Furthermore, there are no inconsistencies in Einstein's theory nor Duhem points at a possible one. Duhem even criticizes relativity as 'an excess of the geometric mind,' which seems more as a criticism for the excessive rigidity of the logic, clearly the opposite of inconsistency.[11]

Ariew and Barker (1986) also argue that Duhem expected there to be no breaks in ontology in the historical development of theories. "Duhem rejects the possibility of alternative ontologies in physics on the grounds that only metaphysics may pronounce on the nature of reality. Physical theories must therefore form a single continuous tradition with no abrupt discontinuities in a conceptual or ontological content" (Ariew & Barker, 1986, p. 151). This conclusion seems strange since Duhem (1906/1954, p.32) is emphatic that, in theory change, what is preserved is the *representative part* of the theories and not the *explanatory part*. The part which is supposed to be lost, the *explanatory part*, is the one that would try "to take hold of the reality underlying the phenomena" (Duhem, 1906/1954, p.32) and, therefore, is also the one that would contain ontological claims.[12] We can assume that Ariew and Barker mean that, for Duhem, physics had to preserve what we can call a 'common sense metaphysics.' In fact, most of the secondary literature on Duhem seems to consider this to be precisely the reason for Duhem's rejection of special relativity.

Stanley Jaki, for example, maintains that Duhem considered the conclusions of *everyday experience* to be real, while the theories of physics were a way of 'saving the phenomena'; The only connection that theories have with reality is the one they have with *everyday experience*. For Duhem, then, not only the logical consistency of the theories mattered "… but also its reliable connection at every step with physical reality to which common sense or bon sens gave the indispensable access" (Jaki, 1991, p. XXI). In Jaki's opinion, it is such a connection that is endangered in Einstein's theory; since relativity seems to imply that we must correct our *common sense* notions: "For Duhem clearly saw that almost from its inception relativity theory had taken on a pseudo-metaphysical if not anti-ontological message." (Jaki, 1991, p. XXII). The only metaphysics that Duhem seems willing to accept is that which is based on *common sense*, but relativity seemed to imply that we had to correct *common sense* conceptions of space and time. Jaki recognizes that "… he [Duhem] held that physics was independent of metaphysics in the sense that no specific physical theory could be constructed from basic metaphysical notions, the sole ties of physics with reality. Any deprecating of those ties was in Duhem's eyes the undermining of the very meaning of physical science as something relating to that reality which is physics" (Jaki, 1991, p. XXIII). That is, in Jaki's reading, although Duhem separates physics from metaphysics, he accepts a *common sense* metaphysics, which he conceives of space and time in a way that is not consistent with relativity.

As compelling as Jaki's reading seems to be, I find this response incomplete at best. While we could say that Duhem does seem to accept a *common sense* metaphysics, [13] what does not seem so clear is the relation of physical theories to such metaphysics. That is, from my point of view, the problem with Jaki's argument is that the same conflict between relativity and *common sense* could also be pointed out between it and other theories that Duhem accepted.

A *common sense* conclusion for centuries was to assume that the Earth is the center of the solar system. When talking about the history of physics, Duhem does seem initially to defend the ecclesiastical authorities who condemned Galileo. According to him: "The physicists of our day … have been compelled to acknowledge and proclaim that logic sides with Osiander, Bellarmine, and Urban VIII, not with Kepler and Galileo …" (Duhem, 1908/1969, p.113). However, Duhem's criticism of Galileo and Kepler is directed at the realism they supported (the idea that physics could discover true causes), rather than against the heliocentric theory. Duhem's position on the debate between geocentrism and heliocentrism in the 16th and 17th centuries was that supporters of both theories came to defend a form of realism that he considered mistaken. The defenders of geocentrism (Osiander, Bellarmine and Urban VIII) claimed that there was a distinction between the laws followed by terrestrial bodies and those followed by celestial bodies, as well as between the way astronomy and physics should be studied. At the same time, supporters of heliocentrism (Galileo and Kepler) maintained that it was possible to prove hypotheses in physics beyond a doubt. "Despite Kepler and Galileo, we believe today, with Osiander and Bellarmine, that the hypotheses of physics are mere mathematical contrivances devised for the purpose of saving the phenomena. But thanks to Kepler and Galileo, we now require that they save *all the phenomena* of the inanimate universe *together*." (Duhem, 1908/1969, p.117, italics in the original). In other words, Duhem considered that physical theories should 'save the phenomena,' that is, represent them adequately. His criticism of Galileo and Kepler was only regarding the belief that the hypotheses they proposed were necessarily true and not a way of representing phenomena.

Even granting Jaki that Duhem seeks to defend a *common sense* metaphysics, it is not clear why he could not accept Einstein's relativity as just a way to save the phenomena (just as he accepts heliocentrism). Even if we assume that *common sense* concepts of space and time should not be modified, Duhem could have maintained the same distinction that he defends in *Aim and Structure* about the concept of 'free fall'. In section 8 of chapter VI of the second part of *Aim and Structure*, Duhem argues that "The words 'free fall of a heavy body' now have two distinct meanings. For the man ignorant of physical theories, they have their *real* meaning, and they mean what common sense means in pronouncing them; for the physicist they have a *symbolic* meaning, and mean 'uniformly accelerated motion.' Theory would not have realized its aim if the second meaning were not the sign of the first …" (Duhem, 1906/1954, p.209-210, italics in the original). That is, Duhem conceived a distinction between the concepts of physics and those of *common sense*; so both are separated. The concepts of *common sense* are those that refer to what is real, while those of physics are means to save the phenomena. Therefore, Duhem could have accepted the concepts of space and time of relativity by simply drawing a distinction between them and the concepts of space and time of *common sense*. There seems to be no reason to consider that relativity must necessarily clash with *common sense* if he assumed that it was just a way of saving the phenomena. However, Duhem's rejection of relativity indicates that he considered that, for some reason, this was not an acceptable solution.

A different explanation could be inferred from the research of

[11] One might also think that Duhem had suspicions against relativity for the simple fact that Einstein makes use of Maxwell's equations. But Ariew and Barker (1986, p.151-152, n.1) point out that there is sufficient evidence that Duhem ultimately did accept Maxwell's equations and only had problems with the way they had historically been derived.

[12] The first three chapters of *Aim and Structure* describe ontological claims as explanatory.

[13] Although, some qualification regarding the idea of a 'common sense metaphysic' will be made in section 6.

Klodian Coko (2015). Coko analyzes Duhem's rejection of atomism and it could be suggested that the reasons for this rejection are also applicable to the case of relativity. Atomism was considered very problematic until the beginning of the 20th century, however, the first decade of that century produced experimental results that motivated many researchers to change their minds. "Despite their disagreements regarding the status of atomism during the 19th century, (almost) all historians agree that the atomic controversy was over by 1913 …" (Coko, 2015, p. 73). However, Duhem maintained his opposition. According to Coko, it is this late opposition to atomism that requires explanation. Coko maintains that "… in the same way Duhem's science provided support for his epistemology during the first phase of his career, history of science supplied the backing during the later phase" (Coko, 2015, p. 77). That is, Coko's conclusion is that, for Duhem, the history of science shows that theories progress towards natural classification, which, he thought, would not contain explanatory assumptions, such as atomistic hypotheses. However, this explanation (even if correct) hardly applies to the case of relativity. In fact, Coko does not attempt to extend his conclusion to that case. As we have seen, Duhem considered the *aether* an 'explanatory element,' so relativity, in fact, is consistent with his conception of the historical development of physics.

Another possibility is that, in the case of relativity, Duhem is indulging in the tendency to criticize German science that motivates his book *German Science*. When writing the lectures that make up this book, France and Germany were facing each other in the First World War, so one might think that Duhem's criticism of relativity is just an expression of French nationalism. However, several authors (such as Stoffel, 2002, p. 273) have pointed out that *German Science*, although influenced by patriotic sentiments, in general, continues themes that Duhem had already begun to develop since *Aim and Structure*. Duhem adopts the patriotic stance only to the extent that the development of the themes that he had previously defended gave occasion for it. He does not contradict his thesis, but uses them, to the extent that they allow, to criticize German science. So, it would be coherent to expect that the criticism of relativity is also consistent with his previous thesis.

Furthermore, Duhem did not hesitate to recognize German scientists whose work he considered consistent with his philosophy of science. "There are German savants whose genius, perfectly balanced, knows how to allot to each faculty its just place and to use in turn the intuitions of common sense and the deductions of the geometrical mind. For example, which of the reproaches that we have addressed to German science could be applied to a Clausius or a Helmholtz?" (Duhem, 1915/1991, p.68). Also, when mentioning Gauss, Duhem makes comments as positive as those he addresses to Helmholtz. "In such works one no longer divines the genius of this or that nation, but only the genius of humanity" (Duhem, 1915/1991, p.80). One might expect that, since Einstein avoided the *aether* in formulating relativity, Duhem would exempt his theory from the criticism he leveled against German science; however, he did not.

5. Making sense of Duhem's rejection of Einstein's special relativity

Duhem's rejection of relativity seems to be related to the use of fundamental concepts and how he thought they should relate to *common sense*. Duhem maintains that there is a distinction between *common sense* concepts and those of physics, but his rejection of relativity seems to indicate that he did not consider such a distinction to be clear-cut. It is possible that Duhem considered that there must be a relation of some kind between the concepts of physics and those of *common sense*; one that Einstein's concepts did not satisfy. A clue is Duhem's claims that relativity's concepts of space, time, and motion were mathematical fictions unrelated to physics. He maintains that the 'geometric mind of the Germans' "By operation referring to algebraic expressions—that is, in the last analysis, to whole numbers—it fabricates for itself its own space, its own time, its own motion" (Duhem, 1915/1996, p.273). That is, the problem with relativity's concepts of space, time, and motion, according to Duhem, is that they refer to algebraic expressions. For him, the concepts of relativity are abstract entities, purely mathematical, without physical meaning. This can only be a consequence of the fact that he considers that the relation that should exist between the concepts and the physical reality has been lost when Einstein modified them.

When, in *Aim and Structure*, Duhem explains the difference between the 'common sense concept of free fall' and the 'physics concept of free fall,' he argues that the two must be related. "Theory would not have realized its aim if the second meaning were not the sign of the first, if a fall regarded as free by common sense were not also regarded as uniformly accelerated …" (Duhem, 1906/1954, p.210). The concept of 'uniformly accelerated motion' from physics had to be a sign that represented the concept of 'free fall' from *common sense*. This relation of representation between concepts of *common sense* and concepts of physics is conceived by Duhem as given from measurement operations. In Chapter I of the second part of *Aim and Structure*, Duhem maintains that, when measuring, we select mathematical operations that represent properties of the phenomena that we perceive through the senses. "Theoretical physics does not grasp the reality of things; it is limited to representing observable appearances by signs and symbols" (Duhem, 1906/1954, p.115). Although Duhem maintains that the concepts of physics can be formulated in many ways, *he seems to assume that such concepts must preserve formal characteristics that we recognize in common sense* (at least, in the case of fundamental concepts). The representation of these characteristics is done through measurement operations, but without altering them. That is, for Duhem, *common sense* concepts designate aspects of the phenomena that we recognize with our senses, but when we measure some aspects of them, we define a new concept, or magnitude, that represents it. For Duhem, Einstein's modification of the concepts of space, time and motion would imply that they no longer represent *common sense*. *Common sense space and time have an absolute character, which is represented in the way classical physics uses these concepts, but no longer in the way Einstein uses them*. Therefore, the concepts of space and time of relativity no longer represent anything for Duhem, they are mathematical expressions without empirical content.

As we saw in section 2, Einstein discusses *common sense* concepts of space and time and how these depend on our sensations. Einstein's conclusion is that this dependence limits the application of *common sense* concepts to certain areas. Einstein realized that sensations allow us to conceive the concepts of space and time in ways that are appropriate only to the realm of *everyday experience*; but that way of understanding the concepts may not be appropriate in other areas (such as when we deal with phenomena as fast as light). Duhem, unlike other authors of the time such as Mach or Einstein himself, does not carefully analyze the processes by which we formulate and accept the conclusions of *common sense*. The only clear reason Duhem seems to give for the reliability he attributes to *common sense* is the broad agreement it commands. When criticizing relativity, as we saw, he points out that "The geometric mind refuses to consider the space, time, and motion which all people conceive clearly and about which they can talk among themselves without ever ceasing to understand one another" (Duhem, 1915/1996, p.273). Even granting that this agreement shared by 'all people' is sufficient reason to accept the validity and certainty of *common sense* concepts in the realm of everyday life, there is no reason to think that this agreement is sufficient to accept them in other realms. *The epistemic innovation of special relativity consists precisely in showing that a common sense generalization that was seen as justified, in fact, was not: the absolute character of space and time.*

The absolute character of space and time is the result of *common sense* generalizations, which are certain for Duhem, and that is why he expected that the concepts and theories of physics, although defined by measurement operations, would represent that aspect of space and time. Even if we used concepts of space and time in physics that were different from those of *common sense* and only represented them; Duhem would expect such a representation to include the characteristics attributed to them by *common sense* and not to contradict them. What measurement does, according to Duhem, is allow us to formulate precise mathematical concepts, but it does not change the characteristics of *common sense* concepts. Modifying the concepts of physics, as Einstein does, causes us to lose the representation of those properties of the phenomena that *common sense* recognizes in them.

What only recent philosophy of science has emphasized when studying scientific measurement is that, in the historical development, not only do material resources (such as instruments) change, but the very concepts of what we measure also change. That is, measuring something and defining it, in physics, are operations that co-evolve. "The questions *What counts as a measurement of (physical quantity) X?* and *What is (that physical quantity) X?* cannot be answered independently of each other" (van Fraassen, 2008, p. 116, italics in the original). *To modify the concepts allows us to coordinate them in new ways with measurement operations.*[14] However, *Duhem has a conception of scientific measurement that assumes that common sense generalizations are fixed*[15] and must be represented when defining physical quantities. *It is this conception of a rigid preservation of formal characteristics of phenomena recognized by common sense (which is absent in explanation of Duhem's thinking, such as that of Jaki) what explains Duhem's rejection of special relativity*.

We can understand Duhem's position as a precaution against the fear that physics may become a merely mathematical discourse without connection with the phenomena of our experience. We must remember that it is not always easy to recognize which concepts of theoretical physics refer to real entities and which are fictitious. Even leaving aside the more general debates about scientific realism, it must be recognized that the mathematical equations of theoretical physicists often admit solutions that do not make physical sense; but it is not always easy to distinguish them from those that do.[16] Duhem seems to have sought to distinguish between physically meaningful mathematical results and non-physically meaningful results by anchoring scientific concepts with formal features that we can recognize in *common sense*. However, Einstein's relativity was introducing a new way of understanding the concepts of physics and their relation with phenomena; one that does not give cognitive or epistemic priority to its relation with *common sense*. *As in any process of abstraction, disconnecting concepts from the particular characteristics with which we perceive what they designate, on the one hand, allows us to coordinate them in new ways with measurement operations, but, on the other hand, they are moved away from our sense experience*. The redefinition of concepts of space and time, for example, allowed Einstein to solve important theoretical problems and initiate new lines of research, but in return, 20th century physics became more counterintuitive than it had ever been.

6. Duhem and metaphysics

Finally, a remaining question is: what does Duhem's rejection of relativity teach us about the internal consistency of his philosophy? Given his rejection of metaphysics, does Duhem's own dismissal of relativity align with his program, or does it highlight an inconsistency?[17] A full answer would require a discussion of the ample literature on Duhem's stand on theory choice and metaphysics which goes beyond the scope of this text but, at least, I can outline some important points for an answer.

The literature on Duhem's stand on theory choice usually separates the terms of *common sense* from that of *good sense.* As mentioned in section 4, Duhem does not distinguish *good sense* and *common sense* in *German Science,* but he apparently does so in *Aim and Structure*. In any case, only *good sense* is considered relevant for theory choice, even though Duhem is not entirely clear on how he understands it. At least, it seems clear that (in *Aim and Structure*) Duhem's *good sense* refers to some kind of judgment that is made against a hypothesis whenever there are no reasons of 'pure logic' to reject it. We have seen that Duhem rejected relativity theory because of a conflict between it and *common sense* concepts, regardless of not having any other logical reasons against relativity. This suggests that, for Duhem, one of the forms that *good sense* could take is that of a judgment as to whether or not the physical concepts of a theory are appropriately related to *common sense.*[18] It is not a judgment as to whether the content of physical concept is identical whit that of *common sense*, but rather whether there is the *right* kind of relation between the two. The relation would be right if the concept proposed by a new theory does not contradict features attributed to the phenomena by *common sense* generalizations. But then, does this imply an inconsistency with the idea of rejecting the *explanatory part* of physical theories, since it seems that a *common sense metaphysics* is to be preserved and not contradicted?

A possible response to the last question hast to do with the very idea of a '*common sense* metaphysics.' As we saw in Duhem's discussion of the concept of 'free fall', he thought that c*ommon sense concepts* have a 'real meaning'. So, it seems natural to think that he defends some kind of *common sense* metaphysics. However, there is a sense in which Duhem thought that *common sense*, like physics, is independent of metaphysics. In an early text, title "Physics and Metaphysics," Duhem states that the physicist's method is the *experimental method* and that:

> This method employs a certain number of concepts, for example, the concepts of physical phenomenon and physical law, body, extension,

[14] The complex historical processes by which this happens can be appreciated in works like that of G. Guillaumin (2017). Also, Alisa Bokulich (2020) gives an interesting account of the changes in measurement standards inspired by Duhem (I thank one of the reviewers for pointing this text out to me.).

[15] Textual evidence that Duhem conceived of *common sense* generalization as fix can be found in *Aim and Structure*. He stated there that "What is characteristic of a law is that it is fixed and absolute. A proposition is a law only because once true, always true, and if true for this person, then also for that one. Would it not be contradictory to say that a law is provisional, that it may be accepted by one person and rejected by another?.. Yes, certainly, if we mean by *'laws' those that common sense reveals, those we can call true in the proper sense of the word; such laws cannot be true today and false tomorrow*, and cannot be true for you and false for me …" (Duhem, 1906/1954, p.172, emphasis added).

[16] The equations of relativity, for instance, mathematically allow solutions for hypothetical particles faster than light known as 'tachyons,' nonetheless most physicist nowadays consider that tachyons do not really exist. Another example is to remember that, for a time, black holes were thought to be mere mathematical consequences of general relativity but not physically real. Nowadays, black holes are considered real objects.

[17] Although this is a deeply interesting question, and I thank one of the reviewers for calling attention to it, I think it is strongly connected with broader debates. A full answer would require a more in deep discussion of those debates. Therefore, I can only outline here the direction in which I think they can be address.

[18] The more common reading in secondary literature is that *good sense* consists in a cluster of intellectual and moral virtues. I don't dispute this here; I am only pointing out a possible reading that Duhem's rejection of relativity suggests. That rejection also suggests that the harsh division we often see in secondary literature between *good sense* and *common sense* might not be true to Duhem's intentions. Duhem never explicitly distinguishes between *common sense* and *good sense*, the idea that he implicitly does can be traced back to works such as R. N. D. Martin (1991, pp. 81-88). Martin outlines some different ways in which Duhem seems to use the terms *good sense* and *common sense,* but it is not that clear that he was trying to stablish a harsh distinction between the two terms. Nonetheless, David J. Stump (2007, pp. 152-153) makes the distinction proposed by Martin crucial in his discussion of Duhem. Then Milena Ivanova (2010) takes on the analysis of Stump's conclusions without much discussion on the relation between the terms *common sense* and *good sense*. More recent literature usually doesn't even mention explicitly the term *common sense* when discussing theory choice in Duhem, only that of *good sense*. Without denying the value of resent literature, it seems that the Duhem's *good sense* is much more deeply related to his conception of *common sense* than is sometimes assumed.

> time, and motion … To use these concepts, it is not necessary to have constructed a metaphysics. These principles and concepts appear to our intellect sufficiently certain and sufficiently distinct in themselves that we should be able … to put them into play trough the experimental method … It is in this sense that one may state the following proposition: *The experimental method rests on principles evident in themselves and independent of any metaphysics.* (1893/196, p.34, italics in the original)

The concepts that Duhem acknowledge as certain are those of *common sense.* So, according to him, *common sense* concepts and principles are fundamental to the experimental method and independent from metaphysics.[19] This seems consistent with the idea that he rejected relativity due to a conflict with *common sense generalizations* and with his idea that physical theories are independent from metaphysics. However, the clear difficulty here is: how can *common sense* be independent from metaphysics given what Duhem says about it?

It is possible that Duhem means that *common sense* is independent from metaphysics in the sense that it is independent of any known metaphysical *system* or *doctrine*. He probably thought that there is a correct metaphysics behind *common sense*, but that we don't have access to it. So, agreeing with *common sense* does not necessarily imply endorsement of one or another metaphysical system. In *Aim and Structure,* Duhem points out that different persons might agree in a *common sense* law, such as 'all men are mortal', even if they believe in different metaphysical systems.

> Take a peasant who has never analyzed the notions of man or of death and a metaphysician who has spent his life analyzing them; take two philosophers who have analyzed and adopted different, irreconcilable notions of man and of death; for all, the law 'All men are mortal' will be equally clear and true. Duhem (1906/1954, p.167)

Common sense is certain, for Duhem, because it is true for all. But he also thought that *common sense* is, for the most part, too complex and general. "Ordinary testimony, which reports a fact established by the procedures of common sense and not by scientific methods, can be certain only at the expense of not being detailed or minute, and by taking the fact as gross or in its most salient aspect" (Duhem, 1906/1954, p.163). By itself, *common sense* is not clear or specific enough to determine a metaphysics, even though it is our best access to reality. He states that this is the reason why we cannot use *common sense* to deduct physical hypotheses. "These certainties and truths of common sense are in the last analysis the source of all truth and all scientific certainty. But we have also said that the observations of common sense are certain to the extent and degree to which they are deficient in detail and precision" (Duhem, 1906/1954, p.264). Lacking detail and precision, *common sense* is compatible with different metaphysical systems. To reject a theory due to its relation with *common sense* doesn't imply endorsement of a particular metaphysics because, for Duhem, *common sense* is not linked to any particular already made metaphysics.

Much of Duhem discussion on metaphysics in *Aim and Structure* seems directed against the pretention of subjecting physical theories to a priori or preconceived metaphysical doctrines but not so much against any trace of metaphysic. For him, the only limitation for a physicist should be to keep the consequences of the theory consistent with experience (which could include *common sense*). Duhem seems more concerned about defending that freedom from traditional doctrines than in attacking every trace of metaphysics (as positivists are often portrayed). According to Mark Wilson, the very idea of separating *physical concepts* from *common sense concepts* may have been part of a strategy of the time against the pretention of limiting physicist's freedom.

> By achieving semantic independence … scientific usage can emancipate itself entirely from the cavils of traditionalists who complain about the misuse of familiar terms … These historical motivations are sometimes now forgotten, for the simple reason that no credible philosophical opposition to these freedoms still persists … (nineteenth-century philosophers/scientists often seized upon the doctrine as a simple way of answering their traditionalist critics). (Wilson, 2017, p.151).

Regardless of having obvious metaphysic implications, *common sense* might be seen as *neutral* with respect to any already made metaphysical *systems*. But being based on (everyday) experience, *common sense* may still have something to say about which theories are acceptable. So, in the end, one could still maintain the consistency of Duhem's philosophy if we understand his notion of 'independence from metaphysics' as just 'independence from any already made metaphysical system' (even though Duhem prose often invite a reading of his claims as a stronger opposition to metaphysics). Perhaps Duhem should have used the word '*neutral*' rather than '*independent*' when it comes to the relation between *common sense* and metaphysics.

In my view, a more serious and deeper problem with Duhem philosophy is the resistance to seeing *common sense* as subject to correction in the course of scientific progress.

7. Conclusions

The objective of this work is to clarify the philosophical reasons that led Duhem to reject Albert Einstein's special relativity. What I sought to show is that Duhem's philosophy included a particular conception of fundamental scientific concepts and measurement that is rarely mentioned in the secondary literature, but that influenced his evaluation of relativity. This conception assumes that there is a formal continuity between scientific concepts and *common sense* concepts of *everyday experience*. Duhem and Einstein conceive this continuity in a different way, and it is this different way of understanding it that led the former to reject the latter's theory.

As we have seen, the early history of special relativity, as well as several of Einstein's methodological reflections, is consistent with Duhem's descriptions of physics. But the relation between fundamental physical concepts and measurement operations may evolve historically in a more complex way than Duhem seems to have anticipated. That is, *Duhem did not consider that the continuity that he prescribes between physics and common sense, which consists of preserving the generalizations implicit in common sense concepts, could be abandoned*. With special relativity, Einstein showed that the robustness of measurement could allow the formulation of principles (such as those of relativity and light) that, in turn, allow concepts to be redefined appropriately by correcting *common sense* generalizations. Unlike Duhem, Einstein implicitly attributes more certainty to robust scientific measurements than to such generalizations.

Recent historians, such as Nugayev (1983), Janssen (2002) or Acuña and Dieks (2014), attribute the early success of relativity over Lorentz's theory to some conflicts between the later and nascent quantum physics. However, it is not clear that it would be impossible to modify Lorentz's theory to avoid such conflicts; Nonetheless, physicists preferred to adopt Einstein's proposal even with its radically counterintuitive implications for space and time. At least, from then on, the concepts of physics began to be defined based on measurement operations, without giving cognitive or epistemic priority to their relation with *common sense* generalizations. In fact, many concepts central to some of the most important later theories, such as general relativity or quantum mechanics, were notoriously difficult to understand as mere precisions or representations of something we could recognize in *common sense*. The use of counterintuitive concepts in physics in the first half of the 20th century was a problem recognized by important authors of that period.

Percy Williams Bridgman (1882–1961), for example, reflecting in the mid-20th century on the changes that physics had undergone during

[19] Rogelio Miranda Vilchis points out: "Undoubtedly, Duhem thought that common sense is independent of metaphysics…" (2018, p.93).

that century, recognized a new way in which scientific concepts had been separated from those of *common sense*. "Relativity theory has thus shown … that some of the apparently simple terms of common sense are actually complex when we attempt to apply them in situations beyond the bounds of ordinary experience … we are discovering that in fact the world is not constructed according to the preconceptions of common sense" (Bridgman, 1955, p. 267). He also noted that "It seems to me that, as a minimum, we henceforth cannot regard a man as well educated who does not intuitively recognize that common sense is not to be taken for granted …" (Bridgman, 1955, p. 277). Bridgman himself attempted to promote *operationalism*, a position holding that all scientific concepts should be defined based solely on measurement operations, but that proved unconvincing.[20]

I consider that there are two relevant consequences of what is shown here. First, *Duhem's philosophy of science, despite its subtlety and importance, seems limited by an excessively rigid conception of the historical development of scientific measurement*. Second, *one contribution of the study of the early history of special relativity to epistemology is to show how the development of reliable measurement processes exposes the lack of justification of inadvertent common-sense generalizations*.

Data availability

No data was used for the research described in the article.

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