Symmetries and Measurements

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Abstract

According to the orthodox view, one can appeal to the symmetries of a theory in order to show that it is impossible to measure the properties that are not invariant under such symmetries. For example, it is widely believed that the fact that boosts are symmetries of Newtonian mechanics entails that it is impossible to measure states of absolute motion in a Newtonian world (these states vary under boosts). This paper offers an overview of the various ways by which philosophers have spelled out the connection between the symmetries of a theory and the alleged impossibility of measuring some properties (the variant ones). The paper will use the case of absolute motion as a case study, and will discuss a recent unorthodox view according to which this kind of motion can actually be measured in Newtonian mechanics. The paper ends by considering some avenues by which the discussion can be further developed.

Keywords: Symmetry, measurement, absolute velocity, Newtonian mechanics, variant quantities

Contents

1 Introduction

In the last two decades or so, the philosophical literature on symmetries has grown rather rapidly. Among other topics, philosophers have explored the connection between symmetries and representation (see Hall and Murgueitio Ramírez [2024] for a recent overview), symmetries and the formulation (and interpretation) of physical theories (e.g., see Møller-Nielsen [2017], Read and Møller-Nielsen [2020] and Luc [2023a]), and, as we will explore in this paper, symmetries and measurement. Why is this last topic of philosophical interest? Because, as we will discuss, it is widely believed that the symmetries of a physical theory give us information about which of the properties in that theory are, in principle, measurable and which ones are not. In particular, it is widely believed that those properties that are *not* invariant under the action of a symmetry transformation cannot be measured (we will explain these concepts below). And whether a property is in principle measurable is, and has been for a long time, a subject of philosophical interest because of its implications to the question of what successful scientific theories say about what kinds of entities exist. For instance, some philosophers working on symmetries have appealed to the alleged non-measurability of variant properties in order to argue that they are not real (e.g., see Baker [2010], Dewar [2015] or Dasgupta [2016]). In short, the exact connection between symmetries and measurement is a topic of considerable philosophical interest, and the main goal of the present paper is to offer an overview of the various ways in which philosophers have spelled out such a connection for the particular case of absolute motion and the symmetries of Newtonian mechanics. The paper will also present a recent non-orthodox position according to which states of absolute motion can be measured, and will end by suggesting avenues by which the discussion could be further developed.

2 Situating the debate

2.1 The Basic World

Imagine a Newtonian world (a world in which Newton's laws of motion and universal gravitation are true) endowed with absolute space and absolute time. And imagine that such a world has a very long railroad that has always been, and will always be, at absolute rest. On the railroad, there is a train with a very simple speedometer that points to "REST" when the train is parked and to "MOVING" when it is not. Since the railroad is at absolute rest by stipulation, the speedometer seems to correctly indicate states of absolute motion of the train; when the train has some non-zero absolute velocity, it shows "MOVING" and when it is at absolute rest, it shows "REST." Following Middleton and Murgueitio Ramírez [2020], let's call this world "The Basic World." According to the orthodox position in both physics and philosophy, it is impossible, due to symmetry considerations, for there to be a device that measures states of absolute motion in a truly Newtonian world. Despite appearances, then, the standard view is that the train's speedometer does not measure states of absolute motion for the train (although it does measure the relative motion of the train with respect to the railroad). This article will offer an overview of the main arguments defending the orthodox position and a recent non-orthodox position according to which states of absolute motion can actually be measured.

2.2 An introduction to symmetries

Roughly, the symmetries of a physical theory are invertible transformations that preserve the equations for the laws of the theory. For example, consider the theory of Newtonian gravitation. According to this theory, one can represent the law describing the motion of a massive body (say the Earth) in the presence of a second massive body (say the Sun) in this manner:

$$-G\frac{m_2}{|\mathbf{r_1}-\mathbf{r_2}|^3}(\mathbf{r_1}-\mathbf{r_2}) = \frac{d^2\mathbf{r_1}}{dt^2}, \tag{1}$$

where $\mathbf{r_1}$ is a vector that represents the position of one body (say the Earth), $\mathbf{r_2}$ and m_2 represent the position and the mass of the other body (e.g., the Sun), t stands for the time, and G is the constant of universal gravitation. Now, it is easy to show mathematically that this equation does not change under shifts in the position variable, meaning that the equation is *invariant* if one replaces $\mathbf{r_1}$ with $\mathbf{r_1} - \mathbf{d}$ *and* $\mathbf{r_2}$ with the new variable $\mathbf{r_2} - \mathbf{d}$, where $\mathbf{d}$ is some constant vector that represents some physical displacement (e.g., $\mathbf{d}$ might represent a translation of the objects of five meters to the west).[1] Given that the equation does not change by constant shifts in the position vector, we say that these shifts are symmetries of the equation and thus symmetries of Newtonian gravitation (which employs equation 1 to represent the law of gravitation).

Equation 1 is also invariant under constant changes in the vector representing the velocity (these changes are known as "boosts"). In particular, the equation does not change if one uses variables $\mathbf{r_1} + \mathbf{v}t$ and $\mathbf{r_2} + \mathbf{v}t$ instead of $\mathbf{r_1}$ and $\mathbf{r_2}$, respectively (here $\mathbf{v}$ is a vector that represents a velocity, for example 5 mph to the north). Hence, we say that boosts are symmetries of the equation and thus symmetries of Newtonian gravitation. In contrast, one can easily show that if one replaces $\mathbf{r_1}$ and $\mathbf{r_2}$ with $\mathbf{r_1} + 0.5\mathbf{a}t^2$ and $\mathbf{r_2} + 0.5\mathbf{a}t^2$ (where $\mathbf{a}$ is a vector that represents an acceleration, for example $5\,\mathrm{m/s^2}$ to the north), the equation does change (it transforms into a new equation with an additional term). In this case, we say that constant accelerations are not symmetries of this equation and thus are not symmetries of

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[1] For a very detailed mathematical treatment of the symmetries of differential equations, see Olver [2000]. For a conceptual discussion that goes into more detail than the one covered here, see Hall and Murgueitio Ramírez [2024, §2].

Newtonian gravitation.[2]

So far, this is a purely mathematical way of thinking of the symmetries of a theory, as we focus on the invariance of the equations of the theory under transformations of the variables. But given that these equations and their variables are used to represent physical systems (and their properties), there is also a more “physical” way of thinking of the symmetries of a theory, namely, by considering the kinds of situations or states of affairs that the solutions (or models) of the equations represent. For example, if a specific solution of equation 1 represents the behavior of a moon around a planet, then the fact that this equation is invariant under shifts can be interpreted as saying that if the moon and the planet had had different locations from their actual ones, then the behavior of the moon around the planet would have been given by another (shifted) solution of the very *same* equation (so the moon’s motion would have satisfied the same laws). Similarly, the invariance of 1 under boosts can be taken as representing the fact that in a Newtonian universe, two massive bodies that behave according to a solution of equation 1 would have behaved according to a (boosted) solution of the *same* equation if their absolute velocities had been different. In contrast, the lack of invariance of equation 1 under accelerations can be taken as representing the fact that two massive bodies that behave according to a solution of equation 1 in a Newtonian world would have behaved according

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[2] Constant accelerations are not symmetries of Newtonian gravitation provided one takes the laws of the theory to be given with respect to inertial frames, as it is common in standard presentations (e.g., see Weinberg [2021, 90]). But some scholars (e.g., see Saunders [2013]) have appealed to Corollary VI (to the laws) of the *Principia* to motivate an alternative formulation of Newtonian gravitation according to which constant and time-dependent accelerations are also symmetries of the laws of the theory. In that case, one must express the theory in terms of equations that are indeed invariant under accelerations.

to a model that is *not* a solution of the *same* equation had they had an additional acceleration while preserving everything else, including the forces (in that new world, the total acceleration of the moon would not be accounted for by the gravitational forces acting on it, and so 1 would not be satisfied). In short, then, symmetry-related models are often read as representing alternative histories of the same objects satisfying the same laws.[3] This is why philosophers in this literature often talk about symmetries in terms of possible worlds, as the symmetry-related models of a theory can be read as representing possible worlds that satisfy the laws of that theory.[4] For example, it is said that possible worlds that satisfy the laws of Newtonian mechanics are "shifted worlds" if all that distinguishes them are the absolute locations of the (same) objects. Similarly, we say that possible worlds that satisfy the laws of Newtonian mechanics are "boosted worlds" if they only differ in the absolute velocity of all objects.

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[3] This is a common reading, but it is certainly not universal. For example, various philosophers have argued that symmetry-related models represent the very same world, in a way analogous to how maps of different color can represent the same city (see Hall and Murgueitio Ramírez [2024, §4] for a detailed discussion of this view). However, in the particular literature on symmetries and measurements that concern us here, the idea that symmetry-related models can represent different possible worlds is widespread, as we will see soon (in fact, I do not know of any argument from symmetries to the non-measurability of absolute motion that assumes that symmetry-related models represent the same world).

[4] What about models not related by symmetries? What would they represent? Sometimes scholars introduce a distinction between the "dynamical models" of a theory T, which correspond to those mathematical objects that are *solutions* of the law-equations of T (these are models of T in the more familiar sense), and "kinematical models" of T, which include both the dynamical models of T and also putative models of *other* theories. The upshot is that if m is a dynamical model of T, and if it is related by a *non-symmetry* transformation to a kinematical model m', then m and m' can be interpreted as representing alternative histories of the same objects that do not satisfy the same laws. One model, for instance, might represent an isolated object moving with uniform velocity (as Newton's laws require), while the other model might represent the same isolated object as accelerating (in a way incompatible with Newton's laws). See Hall and Murgueitio Ramírez [2024, §2] for an extensive discussion of the relationship between models (kinematical and dynamical ones), symmetries, and representation.

3 The structure of arguments

The main arguments for the thesis that absolute motion cannot be measured in Newtonian mechanics can be schematically understood as consisting of two main parts. One concerns the fact that boosts are symmetries of Newtonian worlds. The second part centers on addressing the question of what, exactly, is a measurement. After all, if one wants to show that absolute motion cannot be measured, one should be very clear about what a measurement is. The two parts are then put together in order to build an argument that appeals to premises about measurements and symmetries and allegedly deduces the thesis that absolute motion cannot be measured.

The first part is relatively uncontroversial, and for reasons of space, we will leave it aside, except for noting that the following claim, which is typically believed to follow from the first part, is usually emphasized at this point:

> EQUIVALENCE: Newtonian worlds that only differ in the absolute velocity of their objects (at all times) are observationally indistinguishable from one another.

In other words, boosted worlds are observationally indistinguishable from one another. Although important, establishing EQUIVALENCE is the easy part of the arguments in question.[5] The more difficult part is to show that

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[5] Recent work shows that one cannot easily generalize the inference from symmetries to empirical equivalence in the case of other symmetries (Belot [2013], Belot [2017], Wallace [2022]), but such inference is widely accepted in the case of Newtonian boosts. Also, see Murgueitio Ramírez [2024] for a recent argument according to which EQUIVALENCE can be true even when boosts are *not* symmetries of mechanical systems (this argument casts doubts on the claim that one ought to explain EQUIVALENCE by appealing to symmetries).

EQUIVALENCE entails that it is impossible to measure states of absolute motion (together with other premises). In order to do this, a discussion of measurement seems inevitable. Indeed, we can understand the last 15 years of this debate as centered around two main issues: (i) what is a measurement, and (ii) whether a specific analysis of measurement does entail, together with EQUIVALENCE, that it is impossible to detect absolute motion. These two points will be the focus of our discussion.

Regarding (i), it is convenient to follow Luc (2023b) and distinguish between an "externalist" analysis of measurement and an "internalist" one (the terminology is inspired by the internalist-externalist debate in epistemology). The former approaches measurement purely from the perspective of the physical interaction between the measurement device and the physical system that is being measured; if the interaction satisfies certain physical or metaphysical conditions (e.g. if there is counterfactual dependence of some sort between the device and the target system), then we can say that the device measures the system (or, more precisely, that it measures a property of the system). The internalist perspective, on the other hand, approaches measurement from the perspective of whether the physical interaction between the device and the system is such that it can be used to gain knowledge of the properties we are attempting to measure. For example, according to the externalist approach but not the internalist one, a very strange device that simply pops into existence could be said to measure the temperature of a body provided some physical or metaphysical conditions are satisfied, even if nobody in the world is justified in believing that the device responds to changes in temperatures.[6]

Before we move on, two remarks regarding (i) need to be made. First, the externalist-internalist distinction introduced by Luc closely tracks the difference between *indication* (such as the position of a pointer) and *measurement outcome* (what property can an agent attribute to the system based on the pointer's position) found in the recent philosophical literature on measurement Tal [2013, p. 1165]. Second, philosophers have approached the question of what measurements are from very different perspectives, ranging from questions about what kinds of mathematical objects can be used in order to represent the properties of a system, to questions about how theoretical concepts like mass or charge can be coordinated with empirical procedures (for a good overview, see Tal [2013]). Somewhat surprisingly, however, not much has been said in the literature on measurement regarding the conditions that must be met so that a certain instrument does in fact *indicate* (or measure, in Luc's externalist sense) the correct properties of a system. Is mere correlation between some properties of the instrument and some properties of the system enough for measurement (in the sense of indication)? If not, what else would be needed, exactly? Should we develop an analysis of measurement that also works in nearby possible worlds? As we will see in the remainder of this paper, these somewhat more abstract questions, which have not been studied much in the broader literature on the

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[6] It is worth noting that one can consistently hold internalism about measurements (as defined by Luc) and externalism about justification. The crucial distinction between internalism about measurement and externalism about measurement has to do with whether a measurement of a property P requires that an agent acquires knowledge about P by reading the outcomes of the device (whether the agent's justification for believing that property P has some value is understood along internalist or externalist lines in the epistemological sense is a different matter).

philosophy of measurements, are the kinds of considerations that led philosophers working on symmetries to develop the analyses of measurements that we will study now.

4 Externalist Arguments

4.1 Nomological worlds

It seems that for a device to measure a property of a system, the device must be able to instantiate another property whose values or *determinates* covary with the values of the property being measured (up to some margin of error). For example, if my body's temperature is 37.5°C at 3:00 pm and 38.2°C at 4:00 pm, a good digital thermometer would indicate on its screen the symbols "37.5°C" at 3:00 pm and "38.2°C" at 4:00 pm, respectively provided that it was put in my mouth (or it will indicate those symbols some seconds afterward). To simplify the discussion, let's call whatever is the property of the device whose values covary with the values of the quantity that we want to measure "pointer property" (we will assume that pointer properties are observable). Thus, having symbols showing on a digital screen (such as "37.5" in the case of a thermometer, or "REST" in the case of a speedometer) will be pointer properties. The pointer property of a good device must be responsive to (i.e. must covary with) changes in the property being measured.

Notice that although the covariation between pointer properties and some properties of the target system might be necessary for measurement, it is not sufficient. For there could be a world where a broken thermometer outputs temperature values in a random manner and, by mere chance, produces a sequence of readings that perfectly covary with the actual values of my body's temperature at the times of the measurement. We do not want to say that in such a world, the thermometer in question measures the temperature of my body. Motivated by these considerations, consider the following analysis of measurement:

> NOMOLOGICAL: A device measures a property Q of a system iff it has a pointer property whose values covary with the values of Q in all nomologically possible worlds in which both the device and the system exist.[7]

This kind of analysis, relatively common in the absolute velocity literature (Dewar [2015, p. 320], Dasgupta [2016, p. 855-6]),[8] allows us to put forward a simple argument for the undetectability of absolute motion. Consider again the Basic World where at 2:00 pm the train starts off being parked on the railroad so its speedometer indicates "REST," and one minute later starts moving, so it indicates "MOVING." From EQUIVALENCE, it follows that in all boosted worlds the device also indicates "REST" at 2:00 pm, and "MOVING" one minute later, even though in the boosted worlds, the device should have indicated "MOVING" at both times (the device's indication, being a relative position between a pointer and other objects in the device, is invariant under boosts). So in boosted worlds, the pointer

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[7] All the analyses discussed in this paper can be adjusted to incorporate a margin of error, a range of application, and time delays in the measurement (e.g., a speedometer is not entirely accurate, will not display all possible velocities of an object and will not respond instantly).

[8] One might also interpret Baker [2010] along these lines, although it is not explicitly about measurement.

property does not covary with variations in states of absolute motion. Finally, to complete the argument, one needs to argue that boosted worlds are nomologically possible, which follows directly from the fact that, as symmetries, boosts preserve Newtonian laws. Hence, from NOMOLOGICAL, it follows that the speedometer in the Basic World does not measure states of absolute motion.

Middleton and Murgueitio Ramírez argued [2020, p. 808] that the previous argument is valid but unsound because, contrary to NOMOLOGICAL, it is false that a necessary condition for measurement is that the pointer property covaries with the property being measured in *all* nomological possibilities. It certainly seems clear that no devices in our world would count as measuring properties were we to require that kind of condition. After all, it is nomologically possible for a device to fail (that is, there could be two worlds with the same laws and the same objects but in one, a certain measurement device fails to covary with the properties of the system). Interestingly, we will see now that a reasonable way of weakening NOMOLOGICAL seems to entail that it is indeed possible to measure absolute velocities.

4.2 A counter-example with a counterfactual

Very recently, Middleton and Murgueitio Ramírez [2020] presented an argument that challenges the orthodox position.[9] According to the authors, absolute velocities in Newtonian worlds are measurable. In order to show this surprising result, they appeal to the following analysis of measurement

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[9] See also Wallace [2022, p. 335].

(once again, simplified for our purposes):

> COUNTERFACTUAL: A device measures a property Q iff (1) the values of the pointer property covary with the values of Q (in the world of the measurement), and (2) if the values of Q had been different, then values of the pointer property would have been different and they still would have covaried with the values of Q.

In other words, COUNTERFACTUAL requires that the values of the pointer property counterfactually depend on the values of the quantity that is being measured. Notice that COUNTERFACTUAL seems to recover everyday instances of measurement while at the same time allowing room for the nomological possibility of measurement error. For example, we take it to be important for a good balance in the supermarket that it (i) indicates different things as we place bags of different weights on it, and that (ii) if we had placed bags of different weights from the ones we actually placed, then the balance would have indicated different things (this rules out cases where the balance indicates the right things by mere luck). For example, we want the balance to register "1 kg" if the bag weights 1 kg. Likewise, if my bag had weighed 0.5 kg, then we would want the balance to register "0.5 kg." Also, in contrast to NOMOLOGICAL, we are not willing to say that the balance in the supermarket is a bad one just because there is a possible world with the same laws as our world in which the balance's mechanism malfunctions when I place the fruits on it. And note that COUNTERFACTUAL also seems capable of accommodating a widespread approach to measurements in physics that goes, roughly, like this: a measurement is an interaction between a device and a target system such that the pointer property of the device goes from an initial ready state (before the interaction takes place) into a final state (after the interaction) that counterfactually depends on the initial state of the system that we wanted to measure (had the initial state of the system been different, the final state of the device would have been different). In physics jargon, the interaction *couples* the pointer's states to the target system's states. For a recent discussion, see Wallace [2022].

By stipulation, in the Basic World the speedometer outputs "MOTION" and "REST" when the train is in absolute motion and absolute rest, respectively. Hence, condition (1) of COUNTERFACTUAL is satisfied. The more interesting question is whether the speedometer would have indicated the right things had the train possessed a different state of absolute motion than what it has in the Basic World. Suppose that at 2:00 pm the train is parked on the railroad in the Basic World and its speedometer indicates "REST." Now consider this question: had the train been moving with respect to absolute space at 2:00 pm, would the device have indicated "MOVING" at that time? According to Middleton and Murgueitio Ramírez [2020], the answer is "yes" because the closest possible world in which the train has some absolute motion is one in which the train moves on the railroad while the railroad remains at absolute rest. And in such a world, the speedometer does output "MOVING" as the train is moving on the railroad Middleton and Murgueitio Ramírez [2020, p. 812]. Hence, it follows from COUNTERFACTUAL that the speedometer in the Basic World does measure the states of absolute motion of the train, contrary to orthodoxy.

Note that whether COUNTERFACTUAL entails that the speedometer in the Basic World succeeds in measuring states of absolute motion depends on whether the closest world to it in which the train has some absolute motion is indeed a world where the railroad remains at absolute rest and the train moves on it. Call any such world a "Rest World." From EQUIVALENCE, it follows that in all boosted worlds the train will have some absolute motion even though the speedometer will indicate "REST" at 2:00 pm (as it does in the Basic World). So if the world closest to the Basic World in which the train has some absolute motion were to be one (any!) of the boosted worlds instead of a Rest World, it would be false that if the train had been moving with respect to absolute space at 2:00 pm, the speedometer would have indicated "MOVING." And so it would follow from COUNTERFACTUAL that the speedometer in the Basic World does not measure states of absolute motion.

To motivate that a Rest World is closer to the Basic World than any boosted one, Middleton and Murgueitio Ramírez [2020, p. 813] go back to the example of temperature. Suppose we ask: if my body's temperature had been one degree higher at 2:00 pm than what it actually was, would the thermometer have indicated so? In order to evaluate such a counterfactual, we do not consider a world where the temperature of all bodies (mine included) at 2:00 pm is increased by one degree. Rather, we consider a world where the temperature of my body is increased by one degree and where the other bodies stay with whatever temperature they actually had at 2:00 pm. For the same reason, Middleton and Murgueitio Ramírez [2020, p. 813] believe that to decide whether the speedometer would have indicated "MOVING" at 2:00 pm had the train been moving at 2:00 pm, we must consider a world where the train is moving at 2:00 pm and everything else, including the railroad, has the same motion as it has in the Basic World at 2:00 pm (e.g., no motion).[10]

But not everyone agrees. Jacobs [2020, p. 205] responds to the temperature analogy by pointing out that we do not have enough evidence from scientific practice to determine how counterfactuals about absolute motion like the ones considered here should be understood. Why? According to Jacobs [2020, p. 205], this is because scientists do not believe that absolute motion is detectable, but they believe temperature is. However, a natural way to understand the temperature example is as motivating how counterfactuals of the sort relevant to this debate are evaluated in science and everyday life, not as motivating that scientists would have evaluated a counterfactual about absolute velocity in the way described in their paper (Middleton and Ramírez [2022, p. 7-8]). Another way by which Jacobs argues against Middleton and Murgueitio Ramírez [2020] is by proposing that empirical similarity between worlds is a suitable metric for evaluating closeness among possible worlds Jacobs [2020, p. 204], and, given EQUIVALENCE, boosted worlds are empirically identical to the Basic World (and so are the closest according to this criteria).[11] However, it is well-known that maximizing empirical similarity between worlds can lead to the wrong result when evaluating certain counterfactuals (e.g., see Fine [1975]), and so

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[10] See Middleton and Murgueitio Ramírez [2020, Sect 4.1.2] for a different argument for the claim that a Relative World is closest than any boosted one.

[11] Jacobs [2020, p. 206] offers a different argument against Middleton and Murgueitio Ramírez [2020] that appeals to counterpart theory. For a reply, see Middleton and Ramírez [2022, pp. 11-14].

much more would have to be said on this particular point.

Motivated by an analogy with Nozick's account of knowledge, Jacobs [2020] puts forward an analysis of measurement that is very similar to COUNTERFACTUAL except for the inclusion of one more condition that says that in all nearby worlds in which the value of property Q is as it actually is, the value of the pointer property is as it actually is. For reasons of space, we cannot discuss this view in any detail here, but it is worth pointing out that whether or not it entails that absolute velocity is measurable (Jacobs thinks it entails that it is not measurable) crucially hinges on whether worlds in which, for example, the railroad is moving and the train remains at absolute rest correspond to nearby possibilities.[12]

5 Internalist Arguments

5.1 Set-up conditions

Although "externalist" approaches to measurement are popular in the literature on variant quantities (and absolute motion), the first paper fully dedicated to the non-measurability of absolute velocities adopted an "internalist" approach: "In order to count as an empirical measurement procedure,

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[12] Notice that if one already believes that any boosted world is closer to the Basic World than any world on the basis of EQUIVALENCE (e.g., Jacobs [2020, p. 204]), then it seems that one has good reasons to believe that worlds in which the railroad moves and the train remains at absolute rest are not nearby worlds (we have to go through infinitely many boosted worlds before reaching this kind of world!). If one believes this, it seems like the nearby worlds would be those in which both the railroad and the train remain at absolute rest but some other things change slightly, such as the size of the wheels, the colors in the railroad, etc. In any of these words, the speedometer will indicate "REST," and so condition (3) of Jacob's account will be satisfied. See Jacobs [2020] and Middleton and Ramírez [2022] for a more extended discussion.

a procedure must be such that we can use it to acquire empirical knowledge" [Roberts, 2008, p. 163]. For Roberts, to acquire knowledge of the values of any property we are attempting to measure, an agent must be able to verify that the device is operating under the right "set-up conditions" (e.g., that the temperature is not too hot or the device is not wet). This is why Roberts proposed the following analysis (simplified below):

> SET-UP A device measures a property Q iff there are some set-up conditions for the device such that (i) the set-up conditions are observable, (ii) the values of the pointer property covary with the values of Q in all nomologically possible worlds in which the device (and the system) exists, and the set-up conditions are satisfied.

Armed with SET-UP, one can mimic the argument presented earlier in the context of NOMOLOGICAL, except that now we restrict the argument to those nomological possibilities in which the speedometer satisfies certain set-up conditions. Assume for the sake of the argument that the set-up conditions are satisfied in the Basic World and that they are preserved by boosts. Then, due to EQUIVALENCE, the pointer property will not covary with states of absolute motion in some nomologically possible worlds (the boosted ones that satisfy the set-up conditions). Hence, it follows from SET-UP that the speedometer does not measure absolute motion in the Basic World.

As presented, a good case can be made that SET-UP is too strong. As Middleton and Murgueitio Ramírez [2020, p. 810] point out, there is a nomological possibility (even if remote) in which a thermometer that is operating under the right conditions undergoes a fluctuation at the moment of the measurement. We certainly do not want to say that no thermometer in the actual world measures temperature just because of such a nomological possibility. This is not a devastating objection, however, as one could modify SET-UP so that it only considers nearby possibilities ([Roberts, 2008, fn. 10] and Middleton and Murgueitio Ramírez [2020, p. 810]). But if we modify SET-UP along these lines, then we face a another challenge, namely, to establish that boosted worlds are indeed *nearby* (since if they are not, it does not seem that SET-UP would support orthodoxy).[13]

5.2 Measurement and Justification

In a spirit similar to that of Roberts [2008], Luc [2023b] recently suggested an analysis of measurement that takes into account the epistemic side of things. According to Luc, agents can't measure a property Q with a device D if they do not have good reasons to believe that D responds in the right way to values of Q. In particular, Luc says that "for our measurement of Q the fact that the functional relationship $Q = f(P)$ [between Q and the pointer property P] is satisfied does not suffice; we also need some reasons to think that it is indeed satisfied." Motivated by these considerations, Luc proposes the following analysis (slightly modified and simplified below):

> JUSTIFICATION A device measures a property Q iff there are some set-up conditions for the device such that (i) the values of

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[13] For opposite positions on what worlds count as nearby, see Jacobs [2020] and Middleton and Ramírez [2022].

> the pointer property covary with the values of Q and (ii) we can provide some reasons, ultimately based on observation, that (i) obtains

Luc says that (i) can be satisfied in different ways, for example by requiring covariation in the actual world or nearby worlds. What is more important for our purposes is to note that, according to Luc, (ii) cannot be satisfied in the Basic World due to EQUIVALENCE. Why? In order to answer this question, Luc appeals to the framework developed in Chang [2004] regarding the (very complex) process by which scientists end up determining that a certain procedure does allow them to measure a property Q. For our purposes, it suffices to stress that, according to Luc's reading of Chang [2004], the beginning of such process requires noticing an "observational difference between at least two values of the quantity under investigation." For example, in order to determine that a procedure that employs a device D is suitable for measuring temperatures, scientists needed to check, according to this framework, that at least two different values of temperature made a difference to the outputs of the procedure (up to a margin of error). Once this is established, then the scientists have some reasons (based on observations) to believe that the pointer of D does indeed covary with temperature (and so condition (ii) is satisfied).

Let's assume for the sake of Luc's argument that in order to satisfy (ii), it is indeed necessary that some agents can determine that at least two values of property Q make a difference to the outputs of the relevant device. What implications does this assumption have regarding measurements of absolute motion? According to Luc:

> There is no pair of values of absolute velocities such that it makes an observational difference that one of them is instantiated rather than the other. However, this is precisely what is needed for the [...] process to take off. [Luc, 2023b]

Notice, however, that contrary to what Luc says here, there seems to be a pair of values of absolute velocities such that it would make an observational difference if one, and not the other one, is instantiated. In the Basic World, if the train has some non-zero absolute velocity, the speedometer indicates "MOTION." And if the train has zero absolute velocity, then the speedometer indicates "REST." So different states of absolute motion of the train do lead to observational differences in this case.[14] More importantly, however, notice that at the end of the day, Luc's argument (and really any internalist-kind of argument like it) seems to rely on this thesis: it is *impossible* for scientists of the Basic World to have good reasons (based on observations) to believe that the railroad is at absolute rest. For if scientists in the Basic World were to have good reasons to think that the railroad is at absolute rest, then that would go a long way towards justifying the claim that the speedometer does indeed covary with states of absolute motion of the train, in which case (ii) will be satisfied. But it seems at least conceivable that scientists of the Basic World could have good reasons to believe that

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[14] Luc seems to neglect this case by considering boosts of all the objects, including the railroad. But it is not clear why we should do that if we are considering measurements of the train in the Basic World (to the very least, more would have to be said about what the set-up conditions of this case are, and about what kinds of other things we are allowed to vary).

the railroad is at absolute rest. Just think of the many reasons very smart people gave many centuries ago to argue why the Earth could not be moving around the Sun. Of course, now we know that these reasons are wrong, but this does not mean that they were all bad when first proposed. In any case, for an argument like this one to succeed, it would need to show that it is indeed impossible for the scientists of the Basic World to have good reasons for believing that the railroad is at rest. Doing this seems particularly hard given the history of our own science, and also given that we can modify the Basic World in different ways that can make it less vulnerable to this kind of argument (e.g., imagine that the scientists in that world have developed a "railroadcentric" model of the universe according to which the railroad is at absolute rest).

6 Concluding Remarks and Future Directions

To conclude, I would like to (1) briefly consider how the arguments about absolute motion can be generalized to other properties and symmetries, (2) address a potential concern, and (3) suggest some new directions for development. I will start with (1).

This paper has overviewed the connection between measurement and symmetries for the particular case of absolute velocity. This is not a coincidence, of course, as the case of absolute velocity in Newtonian mechanics is one of the simplest examples of properties that vary under symmetries in physics, and one, furthermore, that has drawn the attention of philosophers and physicists since the publication of the *Principia* (e.g., it is discussed already in the Leibniz-Caroline-Clarke Correspondence from 1714-1716 [Brown, 2023]). But there are good reasons to believe that similar considerations would apply for the case of other variant properties. For example, it is widely assumed by physicists and philosophers that absolute values of the electric potential of electromagnetic theory are not measurable. The reason is supposed to be that the relevant instruments cannot be sensitive to absolute values of the potential of an object but only to relative values of the potential between two or more objects. For example, when we use a voltmeter to measure the voltage of an object, that device is normally taken to be measuring the *difference* between the object's potential and another object like the ground. In particular, a voltmeter would have produced the same outcome in two worlds whose only difference is that they are shifted in terms of the value of the potential of *all* objects. The parallel with the case of absolute velocity is evident: just as boosts are symmetries of Newtonian mechanics, shifts in electric potential are symmetries of electromagnetism. Moreover, similar to the case of boosts, shifts in the potential preserve all observations. In other words, a constant shift of the potential of all objects leads to a state of the universe empirically equivalent to the original one.

A proper treatment of the measurability of the electric potential in the context of electromagnetism lies beyond the scope of the current paper, but let me add that, as far as I can tell, the arguments would be exactly parallel to the ones developed for the case of absolute motion. For example, applied to the case of absolute values of the potential, NOMOLOGICAL would entail that no device could ever measure absolute values of the electric potential because there are infinitely many "shifted" worlds (shifted in the values of the potential) in which such a device would produce the wrong result. In addition, one can imagine a case just like the one of the Basic World but where the road (or another object serving as "the ground") always has a potential value of exactly zero. In that world, a voltmeter calibrated to measure voltages relative to the ground would read the right absolute values of the potential of objects. Hence, one might imagine an argument that employs COUNTERFACTUAL for the conclusion that absolute values of the potential are indeed measurable in that particular world, against conventional wisdom in both physics and philosophy. Finally, one can imagine someone saying that even in the world in question, absolute values of potential are not measurable on the grounds that agents in that hypothetical world would not be able to know the values of the potential of objects simply by reading the device (e.g., one might think that agents would not be justified in believing the road's potential is zero). This, of course, is just a quick first pass, and it would be worth exploring in the future if the arguments about the measurability of absolute motion really transfer so easily to other cases.

Let me now consider point (2). The concern I want to address is this: the question of whether or not absolute motion can be detected is a matter for physics and not for philosophy. Put another way, the worry is that the philosophical arguments presented in this paper are too far removed from the types of considerations that led physicists to claim that absolute motion cannot be detected. Wallace [2022, pp. 322-324] takes this kind of concern seriously and attempts to develop arguments about detectability and symmetries that are more closely aligned with physical and mathematical practice. However, I would like to suggest that one of the reasons for this apparent clash in methodology is that philosophers and physicists seem to be discussing two different claims related to the detectability of absolute motion (claims that Wallace [2022] also distinguishes).

One claim is that it is impossible to detect absolute motion from within a closed system (e.g., a spaceship in outer space without windows or sensors, far from other objects). Imagine that you are inside such a spaceship and you are given some mechanical systems such as a pendulum, a ball, or a spring, along with a device that can track the motion of these systems. Due to EQUIVALENCE, it seems impossible for there to be any covariation between the pointer property of the measurement device in question and the absolute motion of the spaceship itself (see Wallace [2022, Sect. 13.4] for a novel proposal aimed at establishing this point). If such covariation is not possible, then according to all of the measurement analyses we discussed earlier, it can be concluded that measuring the absolute motion of the spaceship from within is impossible, regardless of whether the analysis is externalist or not. This, I believe, is what many physicists mean when they say or imply that it is impossible to detect states of absolute motion or when they say that one cannot detect the motion of a certain system, such as a ship or the Earth, from within (e.g., Newton in Corollary V [(1687/1999, p. 423], Galileo in his ship thought experiment [1632/2022, p. 187], Feynman and Wilczek [2017, ch. 15]).

Another claim is that it is impossible to measure absolute motion *simpliciter*. As we saw in this paper, philosophers have been discussing this claim for about 15 years, but it can be challenging to find examples of physicists who endorse it explicitly, as they typically consider only the case of an isolated subsystem, such as the spaceship mentioned earlier (e.g., Feynman and Wilczek [2017, p. 89]). Notice that this second claim is considerably stronger, as it does not require the measurement device to be confined to the interior of, say, the spaceship. If the spaceship had a radar that was able to track its motion with respect to external objects such as the railroad in the Basic World, then of course, the radar can be used to determine if the spaceship is moving with respect to the railroad. And on a purely externalist conception of measurement, this might be all that is required for saying that the spaceship can measure states of absolute motion in the Basic World (indeed, Wallace [2022, p. 335] himself seems to agree with this). For an internalist conception, however, more is required for us to say that a device measures absolute motion. For example, we might require that we have good reasons to believe that the railroad is at absolute rest. The problem is that what counts as a good reason seems rather sensitive to background information. For example, one might argue that if the agents in question understand Newtonian mechanics and believe that their observations are insufficient to establish if the railroad is at rest, then those agents will not have good reasons to believe that the railroad is at absolute rest (e.g., one could try to defend this by following a "hermeneutic-like" reasoning similar to the one developed in Read and Møller-Nielsen [2020]). But what if the agents do not understand Newtonian mechanics, or what if they understand it but have independent reasons to believe that the railroad is indeed at absolute rest? What if they are like Newton himself, who took the hypothesis that "the center of the system of the world is at rest" [(1687/1999, p. 816] to be a serious one, or like the physicists in the late 19th century who believed that one could experimentally detect the motion of the Earth relative to the ether by means of certain optical experiment? In order to answer these questions (and now this is about point (3)), we need to have a more thorough conversation about epistemology and also consider historical and sociological aspects of science and metrology (e.g., when does a scientific community agree that a certain kind of device can indeed measure a certain quantity?). These are topics that extend beyond the mere physics of measurement devices, the symmetries of the laws of physics, and similarity metrics for possible worlds, and I believe that considering them will enrich the current discussion.

References

David John Baker. Symmetry and the Metaphysics of Physics. *Philosophy Compass*, 5(12):1157–1166, 2010. ISSN 1747-9991. doi: 10.1111/j.1747-9991.2010.00361.x.

Gordon Belot. Symmetry and Equivalence. In Robert Batterman, editor, *The Oxford Handbook of Philosophy of Physics*, pages 318–339. Oxford University Press, 2013.

Gordon Belot. Fifty Million Elvis Fans Can't be Wrong. *Noûs*, pages 946–981, 2017. ISSN 1468-0068. doi: 10.1111/nous.12200.

Gregory Brown, editor. *The Leibniz-Caroline-Clarke Correspondence.* Oxford University Press, 2023. ISBN 978-0-19-287092-6.

Hasok Chang. *Inventing Temperature: Measurement and Scientific Progress.* Oxford Studies in the Philosophy of Science. Oxford University Press, New York, 2004. ISBN 0-19-517127-6.

Shamik Dasgupta. Symmetry as an Epistemic Notion (Twice Over). *The British Journal for the Philosophy of Science*, 67(3):837–878, 2016. ISSN 0007-0882. doi: 10.1093/bjps/axu049.

Neil Dewar. Symmetries and the philosophy of language. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 52(Part B):317–327, 2015. ISSN 1355-2198. doi: 10.1016/j.shpsb.2015.09.004.

Richard Feynman and Frank Wilczek. *The Character of Physical Law, with New Foreword.* The MIT Press, Cambridge, Massachusetts ; London, England, reprint edition edition, March 2017. ISBN 978-0-262-53341-6.

Kit Fine. Critical Notice of Lewis' Counterfactuals. *Mind*, 84(335):451–458, 1975. doi: 10.1093/mind/LXXXIV.1.451.

Galileo Galilei. *Dialogue on the Two Greatest World Systems.* Oxford University Press, 1632/2022. ISBN 978-0-19-884013-8.

Geoffrey Hall and Sebastián Murgueitio Ramírez. Symmetries and Representation. *Philosophy Compass*, 19(3):e12971, 2024. ISSN 1747-9991. doi: 10.1111/phc3.12971.

Caspar Jacobs. Absolute Velocities Are Unmeasurable: Response to Middleton and Murgueitio Ramírez. *Australasian Journal of Philosophy*, 0 (0):1–5, 2020. doi: 10.1080/00048402.2020.1849327.

Joanna Luc. Motivationalism vs. interpretationalism about symmetries: Some options overlooked in the debate about the relationship between symmetries and physical equivalence. *European Journal for Philosophy of Science*, 13, August 2023a. doi: 10.1007/s13194-023-00539-4.

Joanna Luc. The Unmeasurability of Absolute Velocities from the Point of View of Epistemological Internalism. *Erkenntnis*, 2023b. ISSN 15728420. doi: 10.1007/s10670-023-00679-2.

Ben Middleton and Sebastián Murgueitio Ramírez. Measuring Absolute Velocity. *Australasian Journal of Philosophy*, 0(0):1–11, 2020. doi: 10.1080/00048402.2020.1803938.

Ben Middleton and Sebastián Murgueitio Ramírez. Absolute velocities are measurable: Response to Jacobs. July 2022. URL `<http://philsci-archive.pitt.edu/22413/>`.

Thomas Møller-Nielsen. Invariance, Interpretation, and Motivation. *Philosophy of Science*, 84(5):1253–1264, 2017. ISSN 0031-8248. doi: 10.1086/694087.

Sebastián Murgueitio Ramírez. On Symmetries and Springs. *Philosophy of Science*, pages 1–37, January 2024. ISSN 0031-8248, 1539-767X. doi: 10.1017/psa.2023.170.

I. Newton. *The Principia: Mathematical Principles of Natural Philosophy.*

The Principia: Mathematical Principles of Natural Philosophy. University of California Press, Berkeley, (1687/1999. ISBN 978-0-520-08816-0.

P.J. Olver. *Applications of Lie Groups to Differential Equations.* Applications of Lie Groups to Differential Equations. Springer New York, 2000. ISBN 978-0-387-95000-6.

James Read and Thomas Møller-Nielsen. Redundant epistemic symmetries. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 70:88–97, 2020. ISSN 1355-2198. doi: 10.1016/j.shpsb.2020.03.002.

John Roberts. A Puzzle About Laws, Symmetries and Measurability. *British Journal for the Philosophy of Science*, 59(2):143–168, 2008. doi: 10.1093/bjps/axn009.

Simon Saunders. Rethinking Newton's Principia. *Philosophy of Science*, 80 (1):22–48, January 2013. ISSN 00318248, 1539767X. doi: 10.1086/668881.

Eran Tal. Old and New Problems in Philosophy of Measurement. *Philosophy Compass*, 8(12):1159–1173, 2013. doi: 10.1111/phc3.12089.

David Wallace. Observability, redundancy and modality for dynamical symmetry transformations. In James Read and Nicholas Teh, editors, *The Philosophy and Physics of Noether's Theorem*, pages 322–353. Cambridge University Press, Cambridge, 2022. ISBN 978-1-108-66544-5.

Steven Weinberg. *Foundations of Modern Physics.* Cambridge University Press, Cambridge, United Kingdom, 2021. ISBN 978-1-108-84176-4.