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A Puzzle about Laws, Symmetries and Measurability

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ABSTRACT

I describe a problem about the relations among symmetries, laws and measurable quantities. I explain why several ways of trying to solve it will not work, and I sketch a solution that might work. I discuss this problem in the context of Newtonian theories, but it also arises for many other physical theories. The problem is that there are two ways of defining the space-time symmetries of a physical theory: as its dynamical symmetries or as its empirical symmetries. The two definitions are not equivalent, yet they pick out the same extension. This coincidence cries out for explanation, and it is not clear what the explanation could be.

1 The Puzzle: Symmetries, Measurability and Invariance

My aim here is to point out the existence of a deep puzzle about symmetries in physics that has not been widely recognized, and to sketch a strategy for solving this puzzle. This puzzle has nothing to do with the difficult interpretative problems of gauge invariance that have lately received much attention from philosophers. It can be seen simply by considering the relatively simple topic of the space-time symmetries of the laws proposed by various physical theories. Indeed, the whole problem can be seen just by focusing on the familiar case of the space-time symmetries of Newtonian mechanics. In the interest of keeping things simple, I will concentrate almost exclusively on the puzzle as it arises there.

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1.1 The symmetries and the measurable quantities of Newtonian mechanics

It is a familiar fact that the space-time symmetries of Newtonian mechanics are a group of transformations including rigid spatial and temporal translations, rigid rotations, reflections, Galilean velocity boosts and all compositions of these.[1] What is it about all these transformations that makes them symmetries of Newtonian mechanics? There are at least two possible answers to this question.

One answer is that these transformations make no difference to the correlations among events. Thus, Wigner writes:

> If it is established that the existence of the events A, B, C, ... necessarily entails the occurrence of X, then the occurrence of the events A', B', C', ... also necessarily entails X', if A', B', C', ... and X' are obtained from A, B, C, ... and X by one of the invariance transformations [i.e., one of the symmetries]. (Wigner [1967], p. 43)

The necessity of the necessary entailments Wigner refers to is the necessity of the laws of nature; thus, Wigner characterizes the symmetries as features of the laws of nature (Wigner [1967], p. 16). So Wigner's account of the symmetries of Newtonian mechanics can be reformulated thus: A symmetry transformation is one that, if applied to all physical events consistently, leaves all the implications of the laws of nature intact. More succinctly, these transformations all necessarily preserve the truth of the laws of Newtonian mechanics.

What this means depends on whether we think of the transformations as active or passive. An active transformation is an operation on possible worlds. For example, a rigid temporal translation, thought of as an active transformation, is an operation that takes a possible world as input and returns a possible world that differs from the first only in that all events occur earlier or later by some constant amount. A rigid spatial translation, thought of as an active transformation, is an operation that takes a possible world as input and returns a world that differs from the first only in that all physical objects at all times are displaced relative to their positions in the first by some constant vector. (In order for such operations to be meaningful, we must assume the existence of a common set of coordinates that can be used to give locations in space and time across different possible worlds.) An active transformation preserves the truth of the laws of Newtonian mechanics just in case it never takes a world in which those laws are true as input and returns a world in which they are false as output.[2]

[1] Perhaps they also include time reversal, but this is controversial. For some of the controversy, see (Albert [2000]; Arntzenius [2000]; and Earman [2002b]). I'll ignore the issues raised by time reversal except in the notes.

[2] This is essentially equivalent to Earman's ([1989], pp. 45–6) definition of a *dynamical symmetry*, substituting possible worlds for models. It is also very similar to the definition of the *symmetries*

A passive transformation, on the other hand, is an operation on coordinate systems. Thought of as a passive transformation, a rigid temporal translation is an operation that takes a given coordinate system and returns one that differs from the first only in that the temporal origin has been shifted forward or backward in time. A rigid spatial translation takes a given coordinate system as input and returns one that differs from it only in that the spatial origin, at each point in time, is displaced by some constant vector. Such a transformation makes sense only if we presuppose a common space-time manifold (or a common manifold of physical events, as relationalists would prefer to say) over which different coordinate systems can be defined. A passive transformation is a symmetry of Newtonian mechanics if and only if, given any possible world W and any coordinate system S such that the laws of Newtonian mechanics are true in W when the physical magnitudes that figure in them are expressed in terms of S, the very same laws (in their original mathematical form) are true in W when the physical magnitudes are expressed in the coordinate system that results from applying the passive transformation to S. In other words, a passive transformation is a symmetry just in case it never makes the laws (in their standard mathematical form) go from true to false.

So, whether we think of them as active or passive transformations, we can define the symmetries of Newtonian mechanics as those transformations that necessarily preserve the truth of the laws of Newtonian mechanics.[3] We can formulate this in a way that is neutral between the active and passive points of view by speaking of transformations as operations on *models* of Newtonian mechanics, where a model is a mathematical representation of a Newtonian world. When we apply a symmetry transformation to one of these models, we can think of that in either of two ways: Either the two models represent distinct possible worlds, or they represent the same possible world using different coordinate systems. A transformation is a symmetry of Newtonian mechanics just in case it necessarily preserves the truth of the laws of Newtonian mechanics in their standard mathematical form: Given any model that satisfies those laws as input, it returns another model that satisfies those laws as output.

There is also a second answer to the question of what makes a given transformation a symmetry of Newtonian mechanics. For any space-time

of a theory given by Ismael and van Fraassen ([2003], p. 378). But see footnote 3, where I will introduce a qualification not found in their definition.

3 Strictly speaking, we should add that the transformations we are concerned with are all space-time transformations that are *continuous* in the sense that if the space-time locations of two events are made arbitrarily close together, then their images under the transformation likewise become arbitrarily close together. (This is necessary in order to rule out counting arbitrary permutations of Newtonian worlds as symmetries.) In the text, 'transformation' should always be understood in this sense. Ismael and van Fraassen ([2003]) note that it would be undesirable to count arbitrary automorphisms of the physically possible models of a theory as symmetries of that theory, but they deal with this problem differently by focusing on the symmetries of the theory that preserve all 'qualitative features' of the models. See footnote 5.

transformation, whether we think of it as active or passive, some physical quantities are invariant under the transformation and others are not. (A quantity is *invariant* under an active transformation A just in case for any world W the value of the quantity in W is equal to its value in A(W); a quantity is invariant under a passive transformation P just in case for any coordinate system S, the quantity has the same value whether it is expressed in terms of S or in terms of P(S). Again, we can take a neutral approach by thinking of symmetries as operations on models.) The quantities that are invariant under the transformations that are symmetries of Newtonian mechanics include masses, distances, angles, temporal intervals, relative velocities and absolute (magnitudes of) accelerations, but not absolute velocities or absolute speeds. Absolute acceleration vectors are not invariant under these symmetries, since their directions are not preserved under rigid rotations. Absolute magnitudes of accelerations, however, do not vary under such rotations. Since none of the other basic symmetries of Newtonian mechanics (rigid translations, reflections and Galilean boosts) alter accelerations at all, it follows that the magnitudes of acceleration are invariant under all the symmetries of the theory.

The invariant quantities are all in principle empirically measurable if Newtonian mechanics is true; the ones that are not invariant are not empirically measurable, even in principle, if Newtonian mechanics is true. In fact, we could have defined a symmetry of Newtonian mechanics as a transformation under which all the quantities that are empirically measurable according to Newtonian mechanics are invariant, and we would have arrived at the same set of symmetries.[4]

Here it might be objected that there are some physical quantities that are measurable according to Newtonian mechanics, even though they are not invariant under all of its symmetries—namely vector quantities, such as relative velocities and absolute accelerations. The magnitudes of these vector quantities are indeed invariant under all the Newtonian symmetries, but their directions are not, since they vary under rotations. But can't we measure the directions of such vector quantities, in addition to their magnitudes? Doesn't this provide

[4] What if time reversals are considered a symmetry of Newtonian mechanics? They do not leave rates of change (such as velocities and accelerations) invariant, since they effectively multiply all rates of change by -1. They do, however, leave the absolute values of rates of change invariant. Is this damaging to the claim just made in the text? If the signs of rates of change are empirically measurable, then time reversals are a counterexample. There are two ways in which one might respond to this counterexample: first, one could deny that the signs of rates of change are measurable on the grounds that this requires an empirical determination of the absolute directionality of time, whereas all we can really determine empirically is a direction of time defined relative to some physical process (e.g. the temporal direction in which entropy increases or in which events stand to records of themselves), and this relative direction will be preserved under time reversals. Alternatively, one could restrict the claim made in the text to symmetries that are *continuous* in the sense that they belong to a continuously parametrizable sub-group of symmetries (this is a different sense of continuity than that invoked in footnote 3). These include translations, rotations and velocity boosts, but not reflections or time reversals.

a counterexample to my claim that the quantities that are measurable according to Newtonian mechanics are exactly the ones that are invariant under its symmetries?

No, it does not. When we measure the direction of an acceleration—say the acceleration of a rocket lifting off from the earth—what we really measure is the ratios among the components of this vector in a particular coordinate system. In the case of the rocket, we might be using a coordinate system in which the origin is the launch pad, the x-axis points due east, the y-axis points due north, and the z-axis points straight up, i.e. directly away from the center of the earth. If we measure the rocket's acceleration and find it to be a vector of magnitude A meters per second per second directed in the positive z-direction, then what we have really measured is the angle between the direction of the rocket's acceleration and the line extending from the center of the earth through the launch pad; we have found this angle to be zero. This angle, of course, will have the same value no matter which frame of reference we use, although the components of the rocket's acceleration vector (and hence the direction of that vector) will not. This angle will also have the same value in any possible world that results from applying an (active) rotational transformation to the actual world; hence, all that we really measure when we measure the direction of a vector quantity like acceleration is invariant under such a rotation. To suppose otherwise—to suppose that we can really measure the absolute direction of the rocket's acceleration, a quantity that fails to be invariant under rigid rotations—is to suppose that there is an empirical measurement we can make that would allow us to tell whether we live in world W or in world W′, where W′ is the world that results from applying a rigid rotation to W. But the hypotheses that we live in W and that we live in W′ are surely as empirically equivalent as the hypotheses that we live in U and that we live in U′, where U and U′ differ only by a rigid spatial translation five meters to the north.

Still, it might be objected that we can measure absolute directions of vector quantities in the following way: Pick out a direction in space demonstratively (by pointing in it), give it a rigid name 'D' and then empirically determine that some vector points in the direction D. We will have thereby empirically ascertained the absolute direction of this vector, for 'D' picks out a direction rigidly rather than by means of a description involving the bodies used to define a particular coordinate system. Of course, in the very same way, we can pick out a position in space demonstratively, baptize it with a rigid name 'P' and then observe that my chair is located at P. Since 'P' picks out a location in space rigidly, and not by means of describing it in terms of its relations with the origin and axes of some coordinate system, we have thus empirically identified the absolute spatial location of my chair. (Maudlin makes a similar point; see his [1993], p. 190.) Does this mean that in a Newtonian universe, absolute position is measurable after all? There is a sense in which the answer seems to be 'Yes': We can empirically determine, of some location, that it is the location of my chair. But there is also a sense in which the answer seems to be 'No', for there is no observation we can make that would distinguish between the actual world and a Leibniz-shifted world in which my chair has some other location (see Maudlin [1993]). It would be interesting to spend some time getting to the bottom of this, but we need not do so for present purposes. The Maudlinesque objection shows that Newtonian mechanics allows for the empirical measurement of absolute directions of vector quantities like acceleration only insofar as it also shows that Newtonian mechanics allows for the empirical measurement of absolute position—and for the measurement of absolute times, which can be treated in a similar way. So we have here no reason to reject my claim that only the magnitudes of absolute accelerations are measurable in a Newtonian universe that is not also a reason to reject the orthodox view, which I am taking for granted, that Newtonian mechanics makes absolute positions and times non-measurable. It would be worthwhile to pursue the question of whether this shows that the orthodox understanding is wrong. But not here. (And in any event, there is obviously a sense in which absolute positions and times are not empirically measurable in a Newtonian universe, even if there may be a sense in which they are; the former sense is the one I have in mind whenever I talk about what is empirically measurable in this paper, and in that sense, the absolute directions of vector quantities are not measurable.)

1.2 The puzzle

Thus, we have two possible definitions of 'symmetry of Newtonian mechanics':

1. A symmetry of Newtonian mechanics is a transformation that necessarily preserves the truth of the laws of Newtonian mechanics.
2. A symmetry of Newtonian mechanics is a transformation that necessarily preserves the values of all the quantities that are in principle empirically measurable according to Newtonian mechanics.

Let us call transformations that satisfy definition (i) *dynamical symmetries* of Newtonian mechanics and transformations that satisfy definition (ii) *empirical symmetries* of Newtonian mechanics. These definitions are not logically or analytically equivalent, yet they have the same extension. Is this just a coincidence? That is hard to believe. But if not, then why should it be so?[5]

[5] Ismael and van Fraassen ([2003]) address the problem discussed in footnote 3 by restricting their attention to symmetries of a theory that preserve all qualitative features of the theory's models. (See especially pp. 378–9.) Given their definitions of 'qualitative' and of 'symmetries of a theory', this entails that the symmetries they are interested in are, by stipulation, both empirical symmetries and dynamical symmetries in my senses. The puzzle I am concerned about here can

One direction of the extensional equivalence of the two definitions is not very surprising: that every empirical symmetry is also a dynamical symmetry. If a transformation T necessarily preserves the values of all measurable quantities, then it necessarily preserves the truth of all regularities in the values of such quantities. But the laws of Newtonian mechanics are regularities in the values of measurable quantities: They are universally quantified equations relating such quantities as distances, accelerations, masses and impressed forces. It follows at once that T necessarily preserves the truth of these laws. (Note that to say that the laws of Newtonian mechanics are regularities is not to commit to the regularity theory of laws. If P is a law of nature, then the fact *that P is a law* is not the same fact as the fact *that P*. The latter may be a regularity even if the former is not. The distinctive claim of the regularity theory is not that laws are regularities, but that their lawhood consists only in their being regularities.)

It is harder to understand why the other direction of the extensional equivalence holds—why, given Newtonian mechanics, every dynamical symmetry is also an empirical symmetry. One can easily verify that this direction of the equivalence does hold. To do so, first take note of quantities which are measurable (including masses, distances, times and everything that nomologically depends only on these) and those which are not (including absolute speeds, absolute position, absolute times and anything from which these could be inferred via the laws). The transformations that preserve the truth of the laws also preserve the values of the measurable quantities—e.g. rigid temporal translations preserve temporal intervals, as well as masses, forces, relative velocities and so on. Then, note that for every quantity that is not measurable, there is a transformation that does not preserve its value but does preserve the truth of the laws—e.g. absolute position in time is not measurable, and it is not preserved under rigid temporal translations, which do necessarily preserve the truth of the laws. But this is just to *show that* the extensional equivalence holds, not to *explain why* it holds. As far as this kind of verification shows, it could be a pure coincidence that every dynamical symmetry also turns out to be an empirical symmetry.

Of course, perhaps this is just a coincidence. But there are a number of reasons to be unhappy with that view. One is just that the coincidence would be such a surprising one. Another is that there is a strong and widespread intuition that the extensional equivalence of the two definitions is itself explanatory. It is sometimes noted, for example, that the unobservability of absolute speed is explained by the fact that speed can vary under transformations that preserve

be seen only if we do not begin by restricting our focus in this way. It begins with the observation that (if symmetries are required to *continuous* transformations in the sense of footnote 3, then) for typical theories of modern physics, we could choose to focus on *either* the dynamical symmetries *or* the empirical symmetries, and whichever choice we made we would end up looking at the very same group of transformations.

the truth of the laws.[6] But a mere coincidence cannot be the basis of such an explanation.

A further reason to be unhappy with the coincidence view is that the coincidence is not peculiar to Newtonian mechanics. We find it again for instance in classical electrodynamics. Here, the symmetry group is different, but it is still the case that every quantity that can be empirically measured is invariant under the symmetries of the laws. In fact, the generalization extends beyond space-time symmetries to gauge symmetries: The latter preserve the truth of Maxwell's equations and the Lorentz force law, introducing changes in no quantities other than the potentials, which are not empirically measurable. Again, in special relativity and quantum mechanics, the symmetries that preserve the truth of the laws also preserve all measurable quantities. For example, spatial distances and temporal intervals are not preserved under Lorentz boosts, which are symmetries of special relativity. But the space-time interval is Lorentz invariant, as are distances and temporal intervals relative to a specified inertial frame. And in special relativity, it is only these that are properly speaking empirically measurable. One does not measure the distance between two objects; one measures their distance relative to one's own rest frame. In general relativity, things are more complicated. The symmetries of the laws there include all space-time diffeomorphisms. Some physicists and philosophers have argued that only diffeomorphically invariant quantities should be considered to have empirical significance in general relativity (see Earman [2002a]). If true, this means that the general pattern we have seen so far extends to general relativity as well. But this claim, which leads to very difficult problems about time and change, is rather controversial (Earman [2002a]; Maudlin [2002]), and I do not wish to get into that controversy here. The important point is that many interesting and successful physical theories have respected the extensional equivalence of the two possible definitions of symmetry. If there is no deeper reason why these two ways of defining symmetries should pick out the same set of transformations, then we have not just a coincidence, but a coincidence of coincidences.

The puzzle about laws, symmetries and measurable quantities that I am concerned with here is the problem of explaining why every dynamical symmetry (of Newtonian mechanics and of many other theories as well) is also an empirical symmetry. The explanandum is logically equivalent to what I will call the *Measurability-Invariance Principle* (MIP):[7]

[6] For example, Huggett gives such an explanation: 'The equivalence, with respect to Newton's laws, of frames in constant relative motion is at the root of the undetectability of absolute velocities' (Huggett [1999], p. 162). The equivalence he notes is just the fact that Galilean velocity boosts, considered as passive transformations, are symmetries of Newtonian mechanics.

[7] Proof: Suppose that every dynamical symmetry is also an empirical symmetry. Let Q be any measurable quantity. Since every dynamical symmetry preserves the value of every measurable quantity, and Q is a measurable quantity, it follows that every dynamical symmetry preserves

MIP: Every quantity that is in principle empirically measurable is invariant under all the dynamical symmetries.

The MIP is not a formal tautology. Furthermore, it does not seem to be analytically true, since it relates the concept of an empirically measurable quantity (which is, broadly speaking, an epistemological concept) to the concept of a law of nature (which is, broadly speaking, a metaphysical concept). It is surprising that these two concepts appear to be linked in the way expressed by MIP. It would be interesting to find out if there is a reason why they must be so linked.

There are two ways of locating the explanatory problem here. The first way treats the MIP as a fact about our world and takes the problem to be that of explaining why the world should be like that, rather than otherwise. But what reason do we have to believe that the MIP is true? Well, there is a dignified lineage of physical theories that all agree in entailing that it is true, even though those theories disagree with one another about all kinds of other things. If you think that any of those theories, or any future theory in the same lineage that resembles those theories in the relevant respect, is likely to be true, then you have a reason to think that the MIP is likely true.

But perhaps we are not justified in believing any such thing. If so, that brings us to the second way of locating the explanatory problem. For the better part of the history of physics since the seventeenth century, the fundamental theories of physics have implied that the MIP is true. Indeed, the truth of the MIP seems to be regularly taken for granted. For example, the fact that absolute speeds are not invariant under Galilean boosts is commonly thought to explain why absolute speed is not empirically measurable in a Newtonian world. So an (at least) implicit commitment to the MIP appears to be a widespread feature in the practice of physics. Why should this be so?

In the final section of this paper, I will sketch a strategy for explaining the MIP that rejects both of these ways of looking at the problem. But first, I will examine some other possible strategies for explaining the MIP and explain why they will not work.

2 Two Easy Answers

There are two quick and relatively obvious ways of trying to solve the puzzle that collapse upon closer scrutiny. One of these is that if a space-time transformation

the value of Q. That is, Q's value is invariant under every dynamical symmetry. But Q was chosen arbitrarily, so it follows that every measurable quantity is invariant under every dynamical symmetry, which is what the MIP says. Thus, the explanandum entails the MIP. Conversely: Suppose that the MIP is true, i.e. that every measurable quantity is invariant under all of the dynamical symmetries. Let *f* be a dynamical symmetry. Then every measurable quantity is invariant under *f*. So *f* is an empirical symmetry. But *f* was chosen arbitrarily. Therefore every dynamical symmetry is an empirical symmetry. Thus, the MIP entails the explanandum.

could introduce a change into the value of some measurable quantity, then that transformation can hardly be expected to preserve the truth of all the laws. For the laws are expressible as regularities or equations satisfied by the values of measurable physical quantities. (This is so even if the fact that they *are* laws is not thus expressible.) If you start fiddling with the values of the quantities, then you cannot expect the laws to stay true. Hence, any transformation that made the value of a measurable quantity vary could not be expected to be a symmetry of the laws.

This answer has some intuitive appeal, but it is not convincing. For there is no contradiction in the supposition that a certain space-time transformation introduces changes in more than one measurable quantity simultaneously, in a coordinated manner, keeping the lawful correlations between their values the same even while the values themselves vary. Since this is logically possible, there must be some reason why it isn't true in any Newtonian world. Our question remains unanswered.

A second quick solution goes as follows. If you start with a possible world W and modify it by means of a space-time transformation that is a symmetry of the laws of nature, then the resulting world W* must be empirically indistinguishable from W. For example, if W is a Newtonian world, and W* is the result we get if we start with W and shift everything five meters to the right—or five seconds later in history—then obviously, there is no experiment we can do that could tell us whether we were in W or W*. So, these two worlds cannot differ on the values of any measurable quantities. For if they did, then we could determine whether we were in W or W* just by making the right measurement. But this argument does not solve our puzzle, because it simply takes for granted that two worlds related by a dynamical symmetry must be empirically equivalent, without explaining why this should be true. And the point thus taken for granted is evidently equivalent to the very fact we want to explain.

For example, suppose for the sake of simplicity that W is a world where Newtonian mechanics is true. If we perform a rigid spatial translation on W, shifting everything, say, five meters to the east at all times, then obviously the result will be empirically indistinguishable from the actual world. Everything having been five meters to the east of its actual location at every time would obviously not make any difference to anyone's experience. Similar observations apply to the other symmetries of the Newtonian laws. But if the shifted world W* is empirically indistinguishable from the original world W, then they cannot differ on the values of any empirically measurable quantities. Recall that W is an arbitrarily chosen Newtonian world, and W* is any world that is related to W by a dynamical symmetry of Newtonian mechanics. Hence, every pair of possible worlds that are related by a symmetry of the laws must agree on the values of all empirically measurable quantities. In other words, every empirically measurable quantity must be invariant under every symmetry of the laws.

This argument is sound. But it fails to explain why its conclusion is true. For one of its premises is just too close to the proposition that we want explained. The argument assumes as a premise that if W* is the result of applying a dynamical symmetry to W, then W* and W will be in principle empirically equivalent. But to start out by assuming this is not very different from starting out by assuming that W* and W must agree on the values of all empirically measurable quantities. The most that can possibly be achieved by this argument is to shift the explanatory burden, ever so slightly: Before, we wanted to know why any two possible worlds related by a dynamical symmetry must agree on the values of all empirically measurable quantities; now, we have reduced this problem to that of explaining why any two such possible worlds must be empirically indistinguishable. But it is not clear that there is much difference between two possible worlds' agreeing on the values of all empirically measurable quantities, and their being empirically indistinguishable. So if we have made any explanatory gain here, it is a meager one.

It might be objected that this argument need not *just assume* that two worlds related by a dynamical symmetry of the laws must be empirically indistinguishable; for it can be supplemented with an *argument that* for any symmetry transformation, any two worlds related by that transformation must be empirically indistinguishable. We started giving such an argument above, for the case of Newtonian mechanics: We argued that if W and W* are related by a rigid spatial translation, then they must be empirically indistinguishable; we could give a similar argument for the case where W and W* are related by a rigid temporal translation and so on, for all the symmetries of the laws of Newtonian mechanics. But if we carried out this argument, what we would end up with is a demonstration that in the case of Newtonian mechanics, the MIP *is* true. We wouldn't have an explanation of *why* it is true. In order for a demonstration of the truth if the MIP be explanatory, it would have to do more than establish that, for each and every space-time transformation T that is in fact a symmetry of the laws, T preserves the values of all the quantities that are in fact empirically measurable. For that leaves it open that it is *just a coincidence* that every single symmetry of the laws has this feature. What we want is an account of what it is about the symmetries of the laws *as such* that guarantees that they all preserve the values of all the measurable quantities.

3 Another Unsuccessful Solution: Appeal to Geometrical Symmetries

Another apparent possible solution appeals to the proposition that the symmetries of the Newtonian laws are also the symmetries of the space-time structure proper to Newtonian physics. If this proposition is true, then there can be no meaningful difference between a Newtonian possible world where a given object has a given absolute velocity at a certain time and a second Newtonian world where it has some other absolute velocity at that same time, though all distances and accelerations in the two worlds are exactly the same. Two such worlds are really the same possible world; the right space-time for Newtonian physics (the so-called Neo-Newtonian or Galilean space-time) just does not have enough structure to allow the difference between these worlds to be drawn (Earman [1989], p. 33; Huggett [1999], pp. 193–5). The case is the same with any other quantity that is not invariant under the symmetries of the Newtonian laws. So there is a simple answer to the question why quantities that can vary under the Newtonian symmetries cannot be empirically measured in any Newtonian world: Those quantities are not even definable in a Newtonian world. They require more space-time structure than any such world has to offer.

But how do we know which space-time structure is proper to Newtonian physics? The standard view is that the space-time structure should share all the symmetries of the laws of physics (Earman [1989], p. 46). In other words, every space-time transformation that necessarily preserves the truth of the laws of nature also preserves all of the well-defined geometrical structures. It follows that no quantity whose value can vary under a dynamical symmetry of a given theory can be well defined in any world where the space-time structure is the one proper to that theory. It seems plausible enough that a quantity that is not even well defined is not empirically measurable. So this would seem to solve our puzzle.

In fact, this does not solve our puzzle, though it does cast some light on it. To see why, first note that whereas before we were concerned with two kinds of symmetries, we now have a third, which we might call *geometrical symmetries*: These are space-time transformations that necessarily preserve all well-defined geometrical properties (which, if Newtonian mechanics is true, include distances, temporal intervals, relative velocities and so forth). We can now formulate three principles:

D → G: Every dynamical symmetry of Newtonian mechanics is a geometrical symmetry of the space-time structure proper to Newtonian mechanics.

G → E: Every geometrical symmetry of the space-time structure proper to Newtonian mechanics is an empirical symmetry of Newtonian mechanics.

D → E: Every dynamical symmetry of Newtonian mechanics is an empirical symmetry of Newtonian mechanics.

D → G and G → E entail D → E, which is equivalent to the MIP. So it seems that we have an explanation of why the MIP is true. But the worry now is that we have merely relocated the explanatory problem, for now we want to know why D → G and G → E should be true.

It is not very hard to see why G → E should be true. If it were false, then there would be a geometrical symmetry that was not an empirical symmetry, which is to say that there would be a space-time transformation that preserved all geometrical structure but introduced an empirically detectable difference. But a space-time transformation cannot change anything except geometrical properties and properties that depend on these. So, we would have an empirical difference that does not correspond to any difference that can be represented in our theory. Under these circumstances, it would be clear that we ought to be working with a richer geometry. The space-time structure proper to a given physical theory must allow for distinctions among possible physical situations to be drawn at least as finely as empirical observations would be able to draw were the theory true.

The real worry that arises now is why D → G should be true. Why would it be improper to formulate Newtonian mechanics within a space-time framework in which not every dynamical symmetry is a geometrical symmetry—in which, for example, Galilean velocity boosts are not symmetries, so that absolute velocities are well defined?

The obvious and traditional answer is that in physics we want to avoid positing surplus structure (Teller [1995]; Ismael and van Fraassen [2003]). But this is a good answer only if we have some reason to believe that positing a space-time structure that does not share all the symmetries of the laws of nature would involve positing surplus structure. The extra structure we would get would be embodied in the values of certain quantities (such as absolute velocities) whose values can vary under the dynamical symmetries. What makes those quantities count as 'surplus'? Presumably, that they are expendable—that we do not need to use their values in any genuine empirical application of the theory of Newtonian mechanics. But if some of those quantities are in principle empirically measurable, then we might well have an interest in predicting and explaining their values, and Newtonian mechanics would be a useful tool for doing so. So, the only reason why the extra structure we would posit by positing a structure that supports quantities (such as absolute velocities) that can vary under the dynamical symmetries would be surplus structure is that those quantities cannot in fact be empirically measured. But that, of course, is the very fact we wanted to be explained. We are moving in a tight circle.

To see this more clearly, note that we can offer the following explanation of why D → G is true: It is entailed by the conjunction of D → E and E → G.[8] It is not difficult to see why E → G should be true: If it were false, then there would be an empirical symmetry that was not a geometrical symmetry.

[8] By analogy with the definition of G → E, E → G is the proposition that every empirical symmetry of Newtonian mechanics is a geometrical symmetry of the space-time proper to Newtonian mechanics.

This would be a transformation that produces a difference in real geometrical properties (and other properties that depend on these) that does not correspond to any difference that can be empirically detected, even in principle. So our physical theory would contain surplus structure: It would distinguish among possible situations that we could never distinguish in any empirical application of the theory, even in principle. If we respect the imperative to avoid positing surplus structure, we will not end up in this situation. Hence, the space-time structure proper to a given physical theory will always have enough geometrical symmetries to make E $\rightarrow$ G true.

The upshot is that if we assume either D $\rightarrow$ G or D $\rightarrow$ E, then we can offer a compelling explanation of the other, for we have reason to believe that the empirical symmetries and the geometrical symmetries must coincide (that is, that E $\rightarrow$ G and G $\rightarrow$ E). But without taking one of them for granted, it is not clear how we can explain either of them. We can move the bump under the rug where we will, but the puzzle will not go away until we offer an explanation of one of these principles that does not depend on the other. It might turn out that the easiest way to solve the puzzle is to offer an independent explanation of D $\rightarrow$ G and rely on it to explain D $\rightarrow$ E (which is equivalent to the MIP). Here, I am betting on the opposite strategy of finding an independent explanation of the MIP and thereby explaining D $\rightarrow$ E and thereby D $\rightarrow$ G.

4 Locating the Puzzle

Whether we view the puzzle as a puzzle about why the world respects the MIP, or about why physicists often seem to presuppose that it does, there is something to be learned by further considering what kind of explanation we should expect to get. An argument that the MIP is a logical or conceptual truth would provide one kind of explanation. But it seems perfectly conceivable that the MIP should fail to be true, so that avenue does not look particularly promising. The next obvious strategy to try is to explain the MIP by showing that it is a consequence of the laws of nature. This strategy will not work, but it is instructive to see why it will not work.

In the case of Newtonian mechanics, the MIP is not a law of nature nor is it a consequence of the conjunction of all the laws of nature. This can be seen quite easily: The MIP is a logically contingent claim that makes ineliminable reference to what can and cannot be measured, but measurement is not a concept that figures in any of the Newtonian laws. The MIP is, however, a consequence of the Newtonian laws' *being all* of the laws of nature, together with the proposition that a certain set of quantities is empirically measurable (e.g. distances, temporal intervals) and that nothing else is empirically measurable unless there are circumstances in which it is correlated with one of these. This shows something interesting: Namely that the truth of the MIP depends on both the formalism of our theory and the empirical interpretation of that formalism.

We can think of the formalism of a theory as a catalog of mathematical quantities used to characterize the physical state of a system, together with the dynamical laws that govern the evolution of these quantities. Alternatively, we can think of the formalism as specifying a class of mathematical models of the world, each of which is supposed to represent some physically possible way the world could be according to the theory. For present purposes, it does not matter which way we think of the formalism; given the physical quantities and the dynamical laws, we can generate the class of models that represent physically possible evolutions of the universe.

Considered in itself, the formalism of a physical theory is an abstract, mathematical object. In order to make it a representation of the world we live in, we need to give it an empirical interpretation. How exactly this is done is a big question I cannot hope to answer here. But one thing that the empirical interpretation must deliver is a specification of which of the quantities that figure in the formalism correspond to quantities that can be empirically measured and at least some information about how those quantities can be empirically measured. Once we have been told how to measure some of these quantities, we can exploit the formalism of the theory to figure out ways of measuring other quantities—this is what happens when we rely on the laws provided by a theory to figure out how to design an instrument for measuring something. But unless we start out with an empirical interpretation that tells us how to measure some of the quantities that are featured in the formalism of the theory, we will never be able to get started in the task of designing new ways to measure things.

The MIP is a principle that has to do with the relation between the formalism and the empirical interpretation. The formalism gives us the physical quantities and the laws of nature, and these are enough to enable us to determine which space-time transformations necessarily preserve the truth of the laws. That is, the formalism determines what the dynamical symmetries are. The empirical interpretation, on the other hand, is what tells us which physical quantities are empirically measurable, and how we can measure them (or at least, how we can measure some of them). The MIP is a relation between the formalism and the empirical interpretation. The dynamical symmetries come from the formalism, and the empirically measurable quantities come from the empirical interpretation; the MIP requires these two things to be coordinated in a certain way: Every quantity that is empirically measurable has to be such that no dynamical symmetry alters its value.

So the MIP does not belong wholly to either the mathematical formalism of a theory or to its empirical interpretation. Neither a specification of the laws of nature nor a specification of which quantities can be empirically measured and how they can be empirically measured is sufficient to guarantee that the MIP is true. That the MIP is satisfied by a particular physical theory is a function of both its laws and its empirical interpretation. For this reason, the MIP cannot simply *be* a law of nature or a consequence of the laws of nature—for if it were, then it would belong to the formalism of the theory. Similarly, it cannot simply be a fact about our empirical perceptual capacities—for if it were, then it would simply be a constraint on the empirical interpretation of theories. The MIP has a peculiar hybrid status: It is not a fact about the laws of nature alone, nor a fact about what we are capable of observing and measuring alone, but a fact about how these two things fit together.

Incidentally, this heads off what may have occurred to some readers as a promising strategy for explaining the MIP: appealing to Noether's theorem, which states that every symmetry of the Lagrangian of a system corresponds to a conserved quantity (Lanczos [1970/1986], pp. 384–6). It is widely recognized that this theorem tells us something deep and important about the role of symmetries in physical theories. But this theorem pertains solely to the formalism of a theory. It tells us something about the relations between symmetries of the Lagrangian of a system and the conservation laws that system will exhibit. This is a matter of the mathematical structure of a physical theory; it is completely independent of the empirical interpretation of that theory. In particular, it is independent of the question of which quantities are empirically measurable.[9]

5 The Relation between Laws and Measurability

We have seen that the MIP is a fact about the way in which the formalism of a physical theory is related to its empirical interpretation. So if we want an explanation for why the MIP holds true in a wide range of physical theories, we will need to look for some more fundamental fact about the way in which the form of the laws of a theory relates to the ways in which that theory can be empirically interpreted—in particular, the ways in which the form of the laws of a theory is related to the ways in which quantities that figure in the formalism of the theory can be identified as measurable. With the (controversial) exception of quantum mechanics, the laws of a theory don't explicitly say or entail anything about what can be empirically measured and what cannot; empirical measurement is not a concept one expects to find doing any work in the statement of a physical theory (as opposed to its interpretation and application). This can make it hard to see how there could be any constraints on how theoretical laws are combined with claims about which quantities are measurable. But there is a promising line of thought that might reveal that there are such constraints.

[9] The theorem tells us something about which quantities will be conserved, but surely being conserved is neither necessary nor sufficient for being measurable.

This line begins with the thought that if any physical quantity is empirically measurable, then the laws of nature will have to be sensitive to that quantity in a certain way. In particular, if we are able to measure the quantity Q, then the present value of Q must make some difference to what the laws of nature imply about the future state of the world. For if we can measure Q, then the value of Q will make a difference to what result we will obtain when we measure it; hence, it will make a difference to any actions that we might later undertake on the basis of the result of this measurement.

To make the intuition more vivid, let's consider an example. Suppose that there is a possible world W where the dynamical symmetries are exactly those of Newtonian mechanics—rigid spatial and temporal translations, rigid rotations, uniform velocity boosts, etc. Is it possible that in W, some quantity that is not invariant under all these space-time transformations is nevertheless empirically measurable? Some examples of such quantities are absolute position in space, absolute position in time and absolute speed. What would it be like if in the world W, we (or our counterparts) could measure one or more of these quantities empirically?

Perhaps it would be like this: There exist certain devices that humans are able to build. For example, there are *absolute speedometers*—these are devices that detect their own absolute speed and register these speeds by means of the position of a needle that moves back and forth across a dial, just like the analog speedometers common in cars. Perhaps there are also *absolute locators*: These are devices that are sort of Global-Positioning-Satellite (GPS) consoles. They have a digital display that shows their current coordinates. But unlike GPS consoles, which display latitude and longitude, the absolute locators indicate by means of coordinates (in some coordinate system whose origin and axes are absolutely at rest) their current locations in absolute space. Or, perhaps there are *absolute clocks*, which always display the absolute time by means of either a digital display or by means of the positions of several hands moving around a dial.

But things could not really be like that. If there were absolute speedometers in W, or absolute locators, or absolute clocks, then presumably we would be willing to call them reliable only if the laws of nature guaranteed that, so long as they were not broken or defective, their readouts faithfully reported what they were supposed to be measuring. But their readouts are all registered by things that are invariant under all the dynamical symmetries—the relative position of a needle with respect to a dial, for example, and the pattern of illumination on a digital display.

To see why this is a problem, suppose that in world W, someone actually employs an absolute speedometer to measure her own absolute speed at time t. Now apply a uniform velocity boost to W, resulting in the world W*. Uniform velocity boosts are symmetries of the laws of W, so in W* all the laws of W are true. Hence, the absolute speedometer should be reliable in W*. (At least, this will be true if the absolute speedometer is not broken or defective in W*. But it isn't broken or defective in W, and the only difference between W and W* is in the absolute velocities of things. Let's assume that this kind of difference cannot make a difference to whether the speedometer is broken or defective.) The readout on the absolute speedometer will be the same in W* as it is in W, even though the absolute speed of the instrument is different from its speed in W. So, if the speedometer is a reliable instrument for measuring absolute speed in W, then it is not reliable in W*. Therefore, the absolute speedometer is both reliable and not reliable in W*. We have derived a contradiction from our supposition that there could be absolute speedometers in a world where the dynamical symmetries are exactly those of Newtonian mechanics. Arguments of exactly the same form could be given to show that there could not be an absolute locator or an absolute clock in a world where the symmetries are the Newtonian ones; assuming that such instruments can be built in world W leads to a contradiction. Now we seem to be getting somewhere: On the assumption that the laws of nature at W have a certain set of symmetries, we have proven that it is impossible in W to build devices that reliably measure quantities that are not invariant under those symmetries.

But not so fast: We did not really prove that there is *no way at all* of building devices in W that reliably measure absolute speed, absolute location and absolute time. We only proved this subject to two provisos: First, we required that the devices display their results by means of the relative position of a pointer with respect to a dial or the pattern of illumination on a digital display. What is really important here is that the results are encoded in physical quantities that are themselves invariant under the dynamical symmetries. If it were not for this assumption, then we could not have inferred that the absolute speedometer gives the same result in worlds W and W*. Second, we required that whether or not the devices are properly functioning must itself be invariant under the dynamical symmetries. In particular, in the case of the absolute speedometer, we assumed that whether a speedometer is properly working cannot be altered simply by altering its velocity. Without this assumption, we would not have been able to derive our contradiction, because we would not have been able to infer that in W*, the speedometer is not broken or malfunctioning. So we were overhasty to conclude that it is impossible in W to build a device that reliably measures a quantity that is not invariant under the symmetries of the laws of W.

We can generalize what we have learned here into a general argument that, subject to three assumptions, it is logically impossible to measure a quantity that is not invariant under the symmetries of the laws. The assumptions are as follows:

Assumption 1: A quantity Q is measurable at world W only if there is a procedure for measuring Q that it is physically possible to implement in W and that is guaranteed to be reliable by the laws of nature at W. What this requires is that there are conditions C (the set-up conditions of the procedure, which specify how the equipment is to be constructed, how it is to be shielded from interference and how it is to be used) and a physical quantity P (the 'pointer variable' for the procedure, which serves to register the result of the measurement—paradigmatically, the position of a needle with respect to a dial) such that the laws of W guarantee that whenever C is satisfied, the value of Q is equal to some function of the value of P, f(P).[10]

Assumption 2: The set-up conditions C in any measurement procedure that can be used in world W must be invariant under the dynamical symmetries at W.

Assumption 3: The pointer variable P in any measurement procedure that can be used in world W must be invariant under the dynamical symmetries at W.

If these three assumptions are true, then we can give a compelling argument that in any world W, quantity Q is measurable only if Q is invariant under the dynamical symmetries at W: Suppose that Q is a quantity that is measurable in an arbitrarily chosen possible world W_1. Then by Assumption 1, there is a measurement procedure with set-up conditions C and pointer variable P such that the laws of W_1 guarantee that if C is satisfied, Q = f(P) for some function f. Moreover, at W_1 it is physically possible to implement this procedure. So, there exists a possible world W_2 where the laws of W_1 are all true, C is satisfied and Q = f(P). Now, suppose for *reductio* that there is some dynamical symmetry T of the laws of W_1 that does not preserve the value of Q. Let us use 'W_3' to denote the result of applying T to W_2, $T(W_2)$. So, Q has different values in W_2 and W_3. By Assumption 2, C is invariant under the symmetries of the laws of W_1, so since C is true at W_2, it must also be true at W_3. Of course, the laws of W_1 are all true at W_3 (since it was generated by applying a symmetry of these laws to W_2, where all these laws are true, and such symmetries by definition preserve the truth of these laws). By Assumption 1, these laws guarantee that if C is true, then Q = f(P), so this equation holds in both W_2 and W_3. But, by Assumption 3, P is invariant under the symmetries of the laws of W_1, so P has the same value at world W_3 that it has at world W_2. It follows that Q must have the same value at world W_3 that it has at world W_2. But this contradicts what we saw above, that Q has different values in W_2 and W_3. This completes the

[10] This requirement can be relaxed to allow for measurement errors, by requiring only a sufficiently strong statistical correlation between the values of Q and P.

reductio. Hence, given that Q is measurable in world W_1 and that Assumptions 1–3 hold, Q could not fail to be invariant under all of the space-time symmetries of the laws of W_1.

This argument does not depend in any way on what the laws at world W_1 happen to be. And it demonstrates that, if Assumptions 1–3 are all true, the MIP necessarily follows. Where does this leave us? Well, if we can find some reason to think that Assumptions 1–3 are all necessary truths, then we will have an argument that the MIP is a necessary truth, quite independent of which propositions are laws of nature. So we will have solved our puzzle: The MIP will turn out to be not a strangely pervasive coincidence at all but a necessary truth.

Of course, that might be too much to hope for. We need not set our hopes so high. Suppose we can find some reason to think that, although Assumptions 1–3 are not all necessary truths, they are all consequences of some important fundamental feature that we take our world to have, other than that it happens to be governed by a certain set of laws of nature. Then we will have at least made some headway. For we will have shown that the MIP is not just a brute coincidence; it will have turned out to be a consequence of another important fundamental feature of our world. And if that important feature of our world is one that physicists are clearly entitled to take for granted, then we will have shown that physics has a good rationale for consistently formulating theories that satisfy the MIP.

6 A Possible Solution

I think there might be a way of explaining why Assumptions 1–3 are all true, and thereby explaining why the MIP is true. But how well this explanation succeeds will depend on exactly what it takes for an explanation to be satisfying. Here I must be content with offering a sketch of the explanation. A full evaluation of it would require a lengthier treatment.

A case can be made that Assumption 1 is a conceptually necessary truth. The concept of an empirical measurement is the concept of a reliable method for making the value of one physical quantity reveal itself in the value of another physical quantity—for example, making the weight of a human reveal itself in the position of a needle that is free to move back and forth across the dial on a bathroom scale or making the pH of a solution reveal itself in the visible hue of a piece of litmus paper. What kind of reliability is required for empirical measurement? We do not expect our bathroom scales to be reliable indicators of our weight in all possible circumstances and certainly not in all metaphysically possible worlds. What we demand is that, given the circumstances in which the scale was designed to work and given the actual laws of nature, we can count on the scale as a reliable instrument. Thus, the concept of an empirical measurement is one of those rare concepts that seems to yield easily to conceptual analysis, and a conceptual analysis of it underwrites Assumption 1.

Matters are less straightforward with Assumptions 2 and 3. It is not at all obvious that it is conceptually necessary that empirical measurements only ever involve set-up conditions and pointer variables that are invariant under the dynamical symmetries of our world. However, perhaps we can find an argument that these assumptions must be true.

In order to count as an empirical measurement procedure, a procedure must be such that we can use it to acquire empirical knowledge. We can hardly do that if we cannot determine, ultimately on the basis of perception, that the procedure is being used, and what the value of its pointer variable is. So, we have reason to believe that set-up conditions and the values of the pointer variables must be facts that we can ascertain by means of perception. If only we could explain why the facts that are perceptible by us are all necessarily preserved under the dynamical symmetries of our world, we would have an explanation of the truth of Assumptions 2 and 3, and thereby an explanation of the MIP.

It does seem to be a fact about us that we cannot detect via perception any fact that is not preserved under the dynamical symmetries. For example, we perceive not our own absolute motions and positions but our motions and positions relative to the conspicuous objects in our environments. But is there any reason why it had to be this way? There seems to be no contradiction in the hypothesis of a universe where there are creatures that can perceive that certain facts obtain, although those facts are not invariant under the dynamical symmetries of that universe. If it is just a brute coincidence that the facts we can detect via perception all happen to be invariant under the dynamical symmetries of our universe, then we have made little explanatory progress so far.

There is more to be said, however. In order for a procedure to count as a legitimate empirical measurement procedure, its set-up conditions and the value of its pointer variable must not only be detectable by means of perception; this information must also be communicable in a public medium. This claim can be defended on broadly Wittgensteinian grounds: Nothing can count as a genuine perception unless it can be made manifest in public behavior, at least in principle. But even if one rejects Wittgensteinian considerations and insists that we can have ineffable private mental states whose contents are not communicable in a public medium, surely such states could not constitute measurements for scientific purposes. Anything that could count as making a measurement for scientific purposes must be such that its result can be effectively conveyed to others.

Once we have taken note of this, we can see that if we were able to perceive facts that are not always preserved under the dynamical symmetries of our world, then things would be very strange indeed. Imagine a possible world where there are intelligent creatures who engage in science, and who unlike us can directly perceive certain facts that are not invariant under the dynamical symmetries of their world. For the sake of definiteness, let us suppose that the dynamical symmetries of their world are those of Newtonian mechanics, and that they are able to perceive their own absolute speeds by means of internal speedometer organs (though nothing in what follows will depend on this particular choice of example). Suppose that one of these creatures—call her Sally—perceptually ascertains her own absolute speed at time t and communicates it to her friend Harry by writing him a letter. Suppose that Sally is honest and reliable, that her perceptual capacities are not impaired and that Harry knows all this and so is inclined to trust her report. Further, suppose that Sally's perception and her report are accurate. Call the possible world in which all this takes place U_1.

Now consider the world U_2, which results from applying a uniform Galilean velocity boost to U_1. In U_2, Sally's absolute speed at time t is very different from what it is in U_1. But everything that is invariant under the Newtonian symmetries is the same in U_1 and U_2, and this includes the geometrical pattern of ink molecules on the paper that Sally sends to Harry. In U_2, then, Sally's report is not accurate. (Clearly, the same thing would follow if Sally had given Harry her report by telling him what she had perceived or by sending him an email or by using any other familiar public medium of communication.) Furthermore, there is a continuum of Galilean boosts, any one of which would result in a world where Sally's report is inaccurate if applied to U_1. The set of physically possible worlds where Sally gives her report and it is accurate is evidently of measure zero within the set of physically possible worlds where she gives her report at all.

What is going on here? Perhaps Sally's internal speedometer is malfunctioning in U_2 (as well as all the other worlds that are related to U_1 by a Galilean boost), even though it was functioning perfectly well in U_1, and the only differences between U_1 and U_2 lie in the absolute velocities of things. But that would be very strange. If that were what was going on, then it would seem that any change in the absolute velocities of objects would interfere with the workings of the internal speedometer organs. The proper functioning of the internal speedometer organs would be so sensitive to the very things they are supposed to be reliable indicators of that any change in the latter would render them unreliable. The accuracy of these speedometers would be counterfactually fragile in the extreme, which ought to lead us to doubt that these creatures really can reliably perceive their own absolute speeds at all. So this cannot be the right way to think about the case.

What other possibilities are there? Well, Sally could be lying in U_2. Or, the mechanism of writing could be such that Sally is somehow unable to write an accurate report. Either way, we get the result that the creatures in U_1 and

U_2 are not able to establish a reliable, effective means of communicating the results of their absolute speed self-measurements to each other. Slight changes in the initial conditions (in particular, in the absolute velocities of all particles) would inevitably either upset the mechanism of communication or else render the communicating parties themselves untrustworthy.

It does not follow that these creatures are unable to report the results of their absolute speed measurements to one another at all. Perhaps they have some other medium of communication available to them, in which messages are encoded by means of manipulating some quantity that can itself vary under Galilean boosts (e.g. the absolute speeds of certain blocks that can be easily manipulated). But even if that is so, the fact remains that many of the media of public communication available to these creatures cannot be used to reliably report one sort of information, namely information about the results of their measurements of their own absolute speeds.

So, one of two things must be true of Sally, Harry and their fellows: Either (i) there are some facts that they can perceive, even though there is no effective and reliable way for them to communicate what they thereby perceive in a public medium, or else (ii) they cannot, in principle, use every public medium available to them in order to effectively communicate all of the information they can communicate; some information can only be communicated via certain media, even though other media can be used to communicate other kinds of information. This is not due to bandwidth limitations or security concerns or social mores; it is a consequence of the dynamical symmetries.[11]

We are not like Sally and Harry and their fellows; neither (i) nor (ii) is true of us. Furthermore, it is clear that if either (i) or (ii) were true of us, then we would be very different kinds of creatures than we are; very fundamental features of our cognitive and communicative natures would be missing. For we can communicate in a public medium about any empirical fact we can ascertain

[11] Strictly speaking, there is a third logical possibility: That the language Sally and Harry speak in U_2 is distinct from the one they speak in U_1, and Sally's report is true in both worlds. In particular, in U_2, the utterance 'My speed was s' has the truth value 'My speed was $s + D$' where D is the difference in Sally's speeds in U_2 and U_1. But this possibility could be ruled out by choosing a more complicated example: Suppose that in addition to Sally and Harry, there is also Tommy, who detects his own absolute speed at time t and writes a letter to Verna telling her the result. Further suppose that Tommy and Verna are in the same linguistic community as Sally and Harry, and that the velocities of Tommy and Sally are orthogonal at t. Then, suppose that the velocity boost that generates U_2 is in the direction of Sally's velocity. In U_2, Tommy's original report is still true. If we suppose that the language spoken in U_2 differs from that in U_1 in such a way that Sally's report is true in both worlds, then Tommy's report will no longer be true in both worlds. So the supposition of linguistic differences between U_1 and U_2 might solve the problem Sally and Harry pose, but it cannot simultaneously solve the problem of Tommy and Verna. (Of course, one might suppose that the relation between the languages spoken in U_1 and U_2 differs in some more complicated way. But we can create further problems by putting more characters and reports in the story. It seems doubtful that all such problems can be solved in a way that preserves the compositionality of the language.)

by means of perception.[12] Furthermore, if we abstract away from limitations of bandwidth, social propriety and other petty practical considerations, we can in principle use any public medium available to us to communicate any information that we can communicate at all.

It is very hard to imagine what it would be like if things were otherwise. Try to imagine that you have a message that you want to send which consists of a single piece of quantitative data, and that you have a channel of communication that can be used quite effectively and reliably for sending messages conveying lots of other kinds of quantitative data, but for some reason you cannot use this medium to communicate the particular piece of quantitative data you have on hand. Furthermore, this is not because of practical considerations, such as worries about data security or limits in bandwidth or anything like that; rather, the laws of nature being what they are, the medium in question is in principle unreliable as a means of conveying the kind of information you want to send. It is perfectly fine for sending other kinds of information, just not the kind that you want to send. (If you try to use it to send the message you want to send, then unless the universe is in a very special state, you will send a false message in spite of your best efforts to send a true one.) There is no formal contradiction in any of this. But it is clear that any creature that found itself in this predicament would have communicative abilities that are very different from the kinds of communicative abilities that we have.

The upshot is this: Suppose that (a) whenever we can measure a physical quantity, we can communicate the result of our measurement to others using a public medium; further suppose that (b) we can in principle communicate any message in any public medium available to us; further suppose that (c) some public media we can use involve encoding messages in the values of quantities all of which are invariant under the symmetries of the laws of nature (such as the relative positions of ink molecules on paper). Then, it could not be that we are able to perceive any fact that is not invariant under the symmetries of the laws of nature. For otherwise, we would be in the predicament of Sally and Harry.

(a), (b) and (c) are thus the premises of a deductive argument whose conclusion implies Assumptions 2 and 3. We have already seen that we have reason to believe that Assumption 1 must be true. So, we have an argument from (a)–(c) to the conclusion that the MIP is true. How explanatory is this argument? (a)–(c) seem to be contingent facts about humans. But they are not mere trivia. They are central structural features of our ‘form of life’, in that were they not true we would be very different kinds of creatures than we are. Hence, given that we are the kind of creatures we are (viz., creatures for whom (a)–(c) are all true), we could not fail to find ourselves in a world where the MIP is true.

[12] In principle, anyway. Of course, some of us are better at it than others.

This does not show that the MIP is a necessary truth, but it does show that it is a consequence of some other general and fundamental truths. So it provides a kind of explanation.

Some readers may worry that this explanation smacks of idealism or constructivism or transcendentalism, since it purports to derive features of the physical world from features of ourselves. This worry would be misplaced. The explanandum here is not a fact that is exclusively about the physical world; it is a fact about the relation between the formalism of a typical physical theory and that theory's empirical interpretation. In the case of a true theory, it is a fact about a relation between the structure of the physical world and the ways in which we can encounter that world empirically. Since we are present in the explanandum, it should be no surprise that we are present in the explanans.

Note that for this reason, the explanation I have offered does not really fit either of the two ways of identifying the problem that I distinguished at the end of section 1: 'Why is the universe such that the MIP is true?' versus 'Why do physicists tend to assume that the MIP is true?' Rather, the proposed explanation answers the question, 'Why do creatures such as we have to find themselves in a world where the MIP is true?' The MIP did not have to be true, but if it were not, then we would be very different creatures from what we are. And the ways in which we would be different have to do with features of us qua observers and communicators that seem at first glance to have nothing to do with the topic of symmetries and laws of nature. So we seem to have made an explanatory gain: We have explained the MIP as a necessary consequence of something else, something which is central to our experience but which seemed to have no connection to what we were trying to explain.

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