**Physics and the Principle of Sufficient Reason**

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**Abstract**

The Principle of Sufficient Reason (PSR) holds that, for everything that exists or occurs or holds true, there is a reason why that is the case. I consider three possible ways of relating physics to the PSR: past states as reasons for present states, reasons why the laws of physics take the form that they do, and reasons why there is anything at all. In each case I suggest that the PSR is not the best way of thinking about how and why physics works.

According to the Principle of Sufficient Reason (PSR), for everything that exists or occurs or holds true, there is a reason why that is the case. At first glance, this seems perfectly reasonable; certainly we do often demand to know why something is the case, taking for granted that such a reason exists. But upon further thought, it seems potentially dangerous or at least overly presumptuous. If everything comes with a reason, we would seem to require either an infinite regress of reasons, or circularity in our reasoning. And who is to say that there aren’t brute facts, without any reason behind them, underlying most of our casual demands for explanation?

Physics has an ambiguous relationship with the PSR. On the one hand, the laws of physics seem to be universal and unbreakable, and they can play a crucial role as part of standard explanations for why various things happen. On the other, physics is an empirical science; it proceeds by imagining that there are many ways things could be, and turns to experimental data to decide which is actually true. In this brief piece I offer some reflections on what current physics and its practice might teach us about how to think about the PSR. Upshot: there may be a limited sense in which the PSR holds, but that sense is extremely limited indeed, barely enough to qualify for “principle” status.

When talking about lessons gleaned from physics, we find ourselves in the tricky situation of not knowing what the final laws of physics actually are. But there is a certain pattern into which promising laws of fundamental physics have traditionally fallen, what might be called the “Markovian” picture: we completely specify the state of the world at one moment of time, and the job of the laws is to tell us what the state will be at the next moment (or the instantaneous rate of change, if time can be considered to be smooth).[[1]](#footnote-1) This conception was elucidated by Pierre-Simon Laplace (1814), who emphasized the deterministic and time-reversible nature of Newton’s laws of classical physics – given the current state, the laws tell us exactly how the universe evolves into both past and future. But even if we allow for stochastic laws or potential future theories that might be irreversible or discrete, the basic Markovian paradigm of initial-conditions-plus-dynamics could hold. There are speculative scenarios that abandon this approach, not to mention laws of constraint that hold at each time rather than connecting different times, but for our present purposes it suffices to think about this Markovian picture.

Whether or not the PSR is true or relevant clearly depends on how we construe the kinds of “things” that might exist or occur or hold true, as well as what qualifies as a “reason” why something might be the case. Within the Markovian paradigm for physics, there are at least three categories of PSR-adjacent questions to ask:

1. Can we think of the prior states of the universe, in particular initial conditions, plus the laws of physics as the reasons why various events happen in the universe?
2. Are there reasons why the laws of physics are what they are?
3. Are there reasons why there are laws at all, or anything at all?

Let’s consider them in turn.

**Previous states as reasons for subsequent states**

Is it right to think that the Markovian nature of the laws of physics, chugging on from one moment to the next, can be thought of as supporting a version of the PSR?

Classical Newtonian/Laplacian physics is deterministic (up to some set-of-measure-zero ambiguities: see Norton 2003). For isolated systems, including the universe as a whole, the state at any one time completely determines the state at all other times. Within this context, it is tempting to support a version of the PSR in which the “reasons why” the universe was in its current state were simply its initial conditions plus the deterministic dynamical laws. We could ask for reasons behind the initial conditions and the laws, but the present state of the universe would be accounted for.

There are two problems with this view. The first problem is that there is a mismatch between the formalism of fundamental physics and how we usually think about “reasons” in the sense of the PSR. If you are late for work, your boss will not accept the excuse that your lateness was baked into the initial conditions of the universe. The reasons we tend to give are more coarse-grained and macroscopic: you were late because traffic was unusually slow.

This is because the microscopic dynamics of fundamental physics differs in important ways from our usual way of thinking about cause-and-effect relations, especially the idea that causes precede effects in time. Reversible dynamics do not have an arrow of time; the information necessary to determine conditions at any one moment is present at any other moment, past or future. If fundamentally reversible dynamics suggested that we could offer past conditions of the universe as a reason for present conditions, we would be forced to classify future conditions as such a reason as well, which nobody is tempted to do.

The usual idea that causes precede effects relies on the arrow of time, which these days is conventionally understood as something that only arises macroscopically, because of coarse-graining and the low entropy of our early universe. Relating the emergent thermodynamic arrow of time to the temporal asymmetry of causation is an interesting and ongoing project (Albert 2000; Carroll 2010; Fernandes 2023; Rovelli 2023). But the upshot is the standard practice of associating present conditions with specific past “causes” is not a matter of fundamental physics, but an emergent higher-level notion.

Therefore, to the extent that we think of the PSR are relating to the kinds of reasons we usually offer for familiar macroscopic events, fundamental physics isn’t especially relevant. The laws of fundamental physics represent rigid patterns obeyed by events, but those patterns don’t fit into the traditional framework of “things that happen” and “reasons why they happen.” The natural numbers are a rigid pattern, but the number five is not the reason for the number six; it is simply the number that comes before.

The second problem with thinking of past states as reasons for present ones is that we don’t know whether the fundamental laws of physics are deterministic, and it seems most likely that they are not, at least from the point of view of physical agents. The reason why is quantum mechanics, which is currently our best understanding of how nature works at a fundamental level.[[2]](#footnote-2) In quantum mechanics, one first replaces the classical state (positions and velocities of each component) by a quantum state or “wave function.” Then there are two distinct kinds of evolution. One is a familiar kind of deterministic dynamics, according to which quantum states obey the Schrödinger equation, just as classical states obey Newton’s laws. But, infamously, quantum mechanics posits a separate kind of evolution that takes place when a system is measured or observed. In that process, the quantum state “collapses” onto some state with a definite value for the observable being measured.[[3]](#footnote-3) A spinning particle can be in a superposition of spin-up and spin-down, but allowed measurement outcomes are one or the other, not any superposition. Collapse is irreversible and indeterministic. The best we can do is to specify the probability of various possible outcomes using the Born Rule – the probability is given by the square of the corresponding wave function.

Is this failure of determinism real, or only apparent? Unfortunately, the foundations of quantum mechanics is an unsettled subject. Certain popular theories, including Everettian (Many-Worlds) and Bohmian (hidden-variables) approaches, feature underlying dynamics that are perfectly deterministic, and measurements only seem stochastic because observers have incomplete information. In others, such as objective-collapse models, the dynamics are truly random. So the fundamental status of determinism and reversibility in quantum mechanics remain unclear.

What we can say, at least according to all currently popular formulations of quantum theory, is that the world *as experienced by agents* is not deterministic. Perhaps there are hidden variables or other worlds that restore underlying determinism, but those additional elements are unobservable to us. To the best of our current knowledge, physics seems to be unable to allow us to predict the future from the present with certainty, even in principle.

Whether this undermines the PSR depends on how strongly one chooses to construe what the PSR is trying to say. One attitude would be that an event, such as the measurement of a quantum spin, that can only be predicted probabilistically should qualify as an exception to the PSR: there is no “reason” why this spin is observed to be up rather than down, there was merely a probability for each possible outcome (Nozick 1983). Alternatively, we could choose to loosen the requirements for being a “reason” to include situations where there is merely a probabilistic relationship between events and the reasons why they have come to pass. Fundamental randomness doesn’t mean that anything goes; indeed, most events in the macroscopic world are well-approximated by deterministic classical physics (because random events average out in macroscopic systems with many particles), so there is at least some justification for associating past states with present conditions. But such a conception would be weaker than a picture in which the future followed deterministically from the past.

As a final point, we recall that laws can play an explanatory role, not just of events at moments in time, but of features of the universe overall. Emmy Noether famously proved a theorem to the effect that every continuous symmetry of the underlying laws implies the existence of a conserved quantity. The “reason” for energy conservation, in this view, is that the laws of physics are invariant under translations in time. But while such relationships may be illuminating, they can be fairly characterized as folding one empirical fact (energy is conserved) into another one (time-translation symmetry), without eliminating the need for empirical facts.

**Reasons for the laws of physics**

When we turn to the question of whether there are reasons why the laws of physics take the form they do, the relevant considerations are much murkier. There is a tradition of physicists hoping that their most recent formulation of the laws of physics is “inevitable” (Wolchover 2019). But this is not what any philosopher would think of as “inevitable.” What the physicists typically mean is “granting the following set of manifestly disputable assumptions, we can derive a certain form the laws must take.” It is indeed remarkable that many features of modern quantum field theories, for example, can be derived from a small set of basic principles. But those principles could easily be otherwise. We can conceive of possible worlds that are classical rather than quantum, or worlds that are discrete, or non-relativistic, or non-local, or don’t have Laplacian laws at all. There is no known sense in which the laws of physics have any sort of true inevitability, and it is very hard to imagine what kind of sense might apply.

It is nevertheless worth distinguishing, when talking about the laws of physics, between “frameworks” and “models.” Classical mechanics is a framework, as is quantum mechanics; within those frameworks there are many possible specific models. If we take an appropriate framework as given, it is sensible to ask why a particular model accurately describes the world we observe. Once again, such considerations tend to fall far short of inevitability, but they may give some guidance. An example is the anthropic principle: if a framework (such as a cosmological multiverse, or branches of a quantum wave function) permits multiple regions with different local “laws,” intelligent observers will only arise in regions that are compatible with the existence of such observers (Carter 1974). One could then appeal to a selection effect as the reason why we experience laws that are compatible with our existence. This would not, of course, explain why there was a framework that allowed for such multiple regions in the first place.

Within the Markovian picture, PSR supporters would also need to give a reason why our universe has the specific initial conditions it does, as well as the specific laws. In particular, our universe had a very low entropy near the Big Bang, which is responsible for the subsequent arrow of time. Explaining why this is true is a major challenge for contemporary cosmology (Carroll 2010).

One might guess – as did Ludwig Boltzmann – that the universe is eternal and subject to random fluctuations, giving rise to all conditions eventually, and then invoke the anthropic principle to explain why we observe a low-entropy past. But that fails on quantitative grounds. If the universe was simply randomly fluctuating, there would be no need for the initial entropy of our region to be anywhere close to the extraordinarily low value it had. It would be overwhelmingly likely that we would find ourselves in much a higher-entropy environment than we do (Carroll 2020). Alternatively we could suggest that our specific initial conditions are somehow more “simple” or “natural” than they otherwise might have been, and that this special status explains the conditions we had. Much like the case for our specific laws of physics, however, these arguments don’t actually amount to a reason. Pinpointing a special feature of the initial conditions (if it could be done) does not explain why those conditions actually obtained, unless one has a separate reason why the conditions should be so special.

Yet another attitude toward the initial conditions is to suggest that this particular fact should be excused from the need for explanation, as the arrow of time is a necessary condition for macroscopic notions of cosmology. But this move is undermined by the fact that plausible (though admittedly speculative) explanations have been suggested, not to mention the above fact that the observed fine-tuning is much greater than required. One might classify the initial conditions as a different kind of “law of physics,” but by the lights of the PSR we would still want to know the reason for that particular law.

**Reasons for the universe**

Which leads us to the question of why there are laws at all, and the related issue of why there is anything at all. Is there a reason the world exists, and exists in this way?

The laws of physics certainly seem remarkable in their universality. We can deduce a law by doing experiments here on Earth, within a relatively small window of space and time, and successfully extend it to the edge of the observable universe or conditions seconds after the Big Bang (Wigner 1960). And as far as we know, the laws are exceptionless; there is no known law of the form “the following almost always happens, but there are rare and unpredictable deviations from it.”

This state of affairs might seem strange if there were no reason for it to be the case. Philosophers distinguish between Humean views, in which laws of nature are merely convenient summaries of what happens in the actual universe, and anti-Humean views, according to which the laws have a separate existence and play a role in governing what happens (Psillos 2003). The challenge for Humeans is to understand why nature exhibits such remarkable regularities at all. We could imagine possible worlds in which there is no relationship between (for example) the state of the universe at one moment of time and its state at the next. Humeans have to accept the existence of universal, rigid, simplifying patterns as a brute fact. Anti-Humeans can explain these regularities by noting that there are laws that enforce their existence. But one is still left without a reason why there are such laws. It is unclear whether anti-Humeanism actually represents an increase in explanatory power, or merely pushes the question back one level.

Similar considerations apply to the existence of the universe itself. Purported explanations have been put forward, based on claims that existence is somehow more natural or more simple than non-existence. (Precisely the opposite view has also been defended.) But as with the laws of physics, these arguments are at best highlighting features of the universe’s existence, not establishing its necessity (Carroll 2020). It seems more defensible, at least given our current state of understanding, to admit that the existence of the universe is not something for which there is going to be a “reason why.”

In sum, the remarkable success of the laws of physics in describing apparently-unbroken regularities in the physical world bears some resemblance to the kind of reasoning that often undergirds defenses of the PSR. But there are also important differences, and the nature of the specific laws we have, the appearance of laws at all, and the existence of the universe itself, all seem to ultimately come down to a certain set of brute facts. Not all physicists agree; Lee Smolin has advocated for a modern version of the PSR (Smolin 2013), although his argument is more reflective of a preference than a logical or empirical deduction. Most of us are willing to accept that the universe could have been otherwise; some of its features are brute facts, and our task is to uncover the specific way that things actually are.

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1. The word “Markovian” is most often used in the context of stochastic processes, but the idea of dynamics only depending on the current state rather than the past history applies equally well if the dynamics are deterministic. [↑](#footnote-ref-1)
2. Quantum field theory, string theory, and other popular approaches are all specific models within quantum mechanics. There is currently no strong evidence for any physical framework that would replace quantum theory. [↑](#footnote-ref-2)
3. “Measurement” is an absolutely central concept in textbook presentations of quantum mechanics, but those presentations generally do not specify what kind of events actually count as measurements. Very roughly measurements occur when quantum systems become entangled with the macroscopic world. Physicists label this the “measurement problem” and don’t think about it too hard. For further discussion see for example Adlam (2021). [↑](#footnote-ref-3)