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Laws of nature according to some philosophers of science and according to chemists

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Abstract
The article contrasts the way that laws are regarded by some philosophers of science with the way that they are regarded by scientists and science educators. After a brief review of the Humean and necessitarian views of scienfic laws, I highlight difference between scientists who regard laws as being merely descriptive and philosophers who generally regard them as being explanatory and, in some cases, as being necessary. I also discuss the views of two prominent philosophers of science who deny any role for scienfic laws. I conclude that science educators should be wary of adopng the necessitarian view of scienfic laws.

Keywords Scientific laws · Hume · Van Fraassen · Necessitation · Periodic law · Gas laws

Introduction

For many years numerous scholars have been advocating the value of including the views of philosophers of science into the teaching of science.[1] This is an endeavor which I too have attempted to further in several books and articles (Scerri 2000; Erduran, Scerri 2002, Scerri 2020). Although I am a firm supporter of the value of importing some aspects of the philosophy of science into science teaching, I wish to question the value of considering the views of a particular school of philosophy. I would like to consider the relevance, or otherwise, of the necessitarian view of laws of science given what I see as the large gulf that separates this view from what I take to be that of scientists. In science education an aphorism is sometimes used to distinguish the nature of scientific laws and theories. It states that "laws describe, whereas theories explain". This view of the matter appears to contrast rather sharply with that of many philosophers of science who consider that laws are themselves explanatory. In science education one teaches that many laws are encompassed by one theory and not vice versa. However, the role of scientific laws would seem to be far more 'elevated' according to philosophers of science such as Hempel who consider that scientific laws provide explanations rather than mere descriptions (Hempel 1965).

[1] For example, the Springer journal *Science and Education* which was founded in 1992 has this goal as its mission. https://en.wikipedia.org/wiki/Science_%26_Education#cite_note-1

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I will therefore concentrate on one major theme in modern philosophy of science, namely the nature of scientific laws or laws of nature in general. I do not propose any new philosophical account of the nature of scientific laws and my article is mostly descriptive of the current view among philosophers and science educators.

In philosophy this topic has a long and complicated history which has included the question of whether laws of nature are essentially matters of epistemology and observed regularities or whether they entitle us to claim the existence of necessary and inherent connections in the world. The first view was made famous by the philosopher David Hume, and has generally fallen out of favor among professional philosophers.

The need for an alternative view to that of Hume's comes from the perception that we need to distinguish between genuine regularities, or true laws of nature, and accidental generalizations. For example, articles on laws of nature almost always begin by discussing the difference between versions of these two frequently cited examples.

1. There are no spheres of gold that are heavier than 10,000 kg.
2. There are no spheres of uranium-235 that are heavier than 10,000 kg.

These two potential laws of nature are regarded as being fundamentally different because of some simple scientific facts about gold and this particular isotope of the element uranium. The absence of spheres of gold that weigh more than 10,000 kg may well be true of the present as well as the past. However, there is no reason in principle, so the account continues, why humanity could not decide to cooperate together in order to break this putative law. If all the wealthy people in the world, as well as their governments were to give up all their gold reserves, it might be possible to construct such an enormous piece of pure gold. Statement 1 is therefore regarded as being an accidental law. To put it into different words, it so happens that no such large sphere of gold has ever been assembled together, but that is not to say that such an act is forbidden by nature.

Let me now turn to the second case of ^{235}U. Given the fact that this isotope is known to decay radioactively, there is no conceivable way in which a mass of 10,000 kg could ever be assembled together from the world's reserves of uranium. More specifically, the critical mass of this isotope is about 56 kg which means that a greater mass would produce an explosion.

Philosophers of science have long regarded the difference between examples such as 1 and 2 as being deeply problematical and in need of a further analysis. Indeed, attempts to distinguish between accidental or coincidental laws, such as 1, and genuine laws such as 2, have generated a large literature and a cottage industry dedicated to getting to the bottom of this issue.

In my view such an approach does not sit comfortably with the way that scientific laws are regarded by scientists. Moreover, it is rather far removed from the manner in which science educators, who admittedly have different aims, present the nature of scientific laws or the difference between laws and theories in science. As I see it the metaphysical concern regarding laws and accidental generalizations may be irrelevant when it comes to gaining a better understanding science and for furthering science education. I say this because on my understanding accidental laws are are eventually rooted out and discarded. There is no harm in regarding an accidental law as being of the genuine variety until it becomes clear through observations that it is in fact accidental. And when such an event occurs, all that it means is that something that was once believed to be a genuine law would have served its purpose and would need to be superseded by a more general law. Alternatively, one would have learned how to stipulate the limitations of what was formerly believed to be a genuine law of nature.

Metaphysicians may well object to my scientific reading of the situation since they consider that whether something is a natural law or merely a constant regularity is a metaphysical question. For a metaphysician, if counterexamples to the putative law are found, it would no longer strictly be called an accidental generalization but rather, not a law. In this article I am denying this distinction and claiming that the metaphysical question is irrelevant to scientists and science educators.[2]

Before moving on, I would like to return to the spheres of gold and of ^{235}U as discussed above and consider the matter from a more purely scientific perspective. What does the contrast between the two statements mean to a chemist for example? I would suggest that to a chemist, or any scientist, the contrast between the two cases is a consequence of the fact that ^{235}U decays radioactively, whereas gold does not. Alternatively, such contrasting cases in general might tell the scientist that there may be other laws of nature that are also acting such that a comparison between the two cases becomes inappropriate.

However, this glib dismissal of the philosophical work that regards the difference between cases such as 1 and 2 has been a little too quick, and I am getting ahead of myself. We need to pause to examine how philosophers in general and many philosophers of science have explored this issue.

Sophisticated regularity view of laws of nature

The sophisticated regularity view of laws of nature claims that there must be something at play outside a particular regularity that distinguishes it from an accidental regularity, which lacks this special attribute. This view has been developed by Dretske and consists of regarding genuine laws are universal generalizations that satisfy an additional criterion which this author labels X (Dretske 1977). Unfortunately, it is by no means clear what the identity of X might be, and authors have differed as to how to regard it. According to Nelson Goodman the X factor is the ability to make successful predictions, which is something that an accidental generalizations lack. Going even further back historically, Braithwaite's view from 1953 falls under the umbrella of sophisticated regularity in the sense that he claimed to identify the X factor with the ability to function in successful explanations, again unlike accidental generalizations that fail to do so.[3]

One virtue of these approaches, at least to some authors, is that there is no appeal to modal concepts (e.g., the counterfactual conditional, causation, dispositions) and no overt appeal to modality-supplying entities (e.g., universals). The systems approach, as it is sometimes termed, is the centerpiece of David Lewis's view that,

> "… all there is in the world is a vast mosaic of local matters of particular fact, just one little thing and then another" (Lewis 1986).

Another influential account of the laws of nature which remains within the regularity or Humean view is the one also suggested by David Lewis.[4] For this author, and many others, the feature that distinguishes genuine laws from accidental regularities is that the

[2] I am grateful to a reviewer for drawing my attention to this point.

[3] Further examples consist of the views of Skyrms who speaks of the resilience of genuine laws as compared with accidental generalizations, Skyrms (1980) and David Lewis' talk of genuine laws having the ability to be integrated into the best systemizations of the facts in question.

[4] David Lewis 1986, *Philosophical Papers*, Volume II, New York: Oxford University Press.

former remain true in all possible worlds. Needless to say, this approach is plagued with problems concerning what it even means to speak of other possible worlds and how one might have access to such worlds if they exist. In the following section I will discuss some views on laws of nature that require laws to be ontologically stronger than mere regularities.

Universals and necessitation

In the late 1970s, there emerged a competitor for the systems approach and all other Humean attempts to say what it is to be a law. Led by Armstrong (1978, 1983, 1991, 1993), Dretske (1977), and Tooley (1977, 1987), the rival approach appeals to universals (i.e., certain kinds of properties and relations) to distinguish laws from non-laws.

Focusing on Armstrong's development of the view, here is a concise statement of the universals approach:

> Suppose it to be a law that *F*s are *G*s. *F*-ness and *G*-ness are taken to be universals. A certain relation, a relation of non-logical or contingent necessitation, holds between *F*-ness and *G*-ness. This state of affairs may be symbolized as '*N*(*F*,*G*)' (Armstrong 1983, 85).

This framework promises to address the puzzle that was cited in the introduction to the present article. Maybe the difference between the uranium spheres generalization and the gold spheres generalization is that being uranium necessitates being less than one mile in diameter, but being gold does not. (Armstrong 1991; Dretske 1977).

But If necessity is always associated with laws of nature, then it is not clear why scientists cannot operate with *a priori* methods. The response by necessitarians is to appeal to Saul Kripke's (1972) arguments meant to reveal the existence of certain aposteriori necessary truths in order to argue that the *a posteriori* nature of some laws does not prevent their lawhood from requiring a necessary connection between properties.

Chemists and other scientists are not typically familiar with Kripke's category of aposteriori necessary truths. Briefly put, the fields of logic and mathematics are generally taken to deal with necessary truths. The fact that $2+2=4$ is a necessary truth that does not depend on anybody making that discovery through experimentation. Aposteriori truths, on the other hand, are those that need to be discovered, such as the fact that grass is green. Grass did not have to be green, it has just turned out to be so and it has been an 'after the facts' discovery that it bears this color. Kripke's cleverly crafted view, which has its origins in the field of logic and philosophy of language, seeks to combine these two classical approaches to kinds of truths and has been hugely influential in modern philosophy but not in science or science education.

Ellis' new essentialism

The Australian philosopher Brian Ellis provides an interesting twist on the entire debate when he writes,

> In the eighteenth century, secularized versions of the divine command theory were developed. Instead of thinking of God as the source of all power and order, some natural philosophers of the period began to speak of the "forces of nature" as the source of nature's activity. But, in an important respect, the theory remained unchanged. The

> things in the world were just as passive as ever, only now they were being pushed or pulled around, willy-nilly, by forces. The philosopher David Hume, who was an atheist, took the further step of eliminating the forces, but he too retained the concept of nature as essentially passive. According to Hume, things do not move as they do because they are caused by anything to do so. They just do so move; and this is a brute fact about the world. Causes are illusions of causal powers in action, he argued, but really there are no such things as causal powers (Ellis 2002, 2).

> The view that things in nature are essentially passive, and obedient to nature's laws, was very widely shared by philosophers of all persuasions in the eighteenth century, as indeed it has been ever since. It was accepted not only by Descartes, Newton and Hume, but also by Locke and Kant, and therefore by the founding fathers of all of the major philosophical traditions of western Europe. Let us call this still-dominant world-view "passivism" (Ellis 2002, 2).

For Ellis, a passivist believes that inanimate objects are only capable of acting as directed by forces of nature or by the laws of nature. These laws are regarded as being imposed from the outside. The forces are regarded as acting between the objects but the same objects are never considered to be the source of such activity.

By contrast, a new essentialist such as Ellis believes that objects act in the way that they do, not because they are directed by the laws of nature, but because that is the way they are intrinsically disposed to act. New essentialists think that inanimate objects are genuine causal agents which have the power or disposition to act.

> Essentialists take the opposite view to this. They argue that things must behave in the sorts of ways they do not because the laws of nature require them to, but rather because this is how they are intrinsically disposed to behave. The causal powers, capacities and propensities of things, they say, are genuine properties, which they are bound to display in their various actions and interactions. (Ellis 2002, 4).

Given the manner in which Ellis draws a contrast between passivism and essentialism it would seem to be a foregone conclusion that essentialism is the more organic and the more natural or plausible view to take. However, it would also seem that both passivists and the new essentialists are committed to thinking about laws of nature in a way that could never be settled by any form of experimentation or observation. The more scientifically inclined observer might therefore be equally comfortable in rejecting both of these supposedly opposed views that they are being asked to choose between.

Ellis concedes that the new essentialism is not even widely accepted by philosophers and adds that one must return to Aristotle to find a true defender of essentialism. He then immediately suggests that essentialism is precisely the sort of view that a modern realist should accept, given that, in Ellis' view, modern science shows us that the world is not intrinsically inert.

> The world, according to modern science, seems to be not innately passive, but fundamentally active and reactive. It is certainly not a mechanistic world of things having only the attributes of extension and impenetrability, as Descartes's and Locke's worlds were. Rather, it is a dynamic world consisting of more or less transient objects that are constantly interacting with each other, and whose identities appear to depend only on their roles in these causal processes (Ellis 2002, 4).

Needless to say, one can reject a mechanistic view of the world while also embracing a dynamic world view, but still not accept any role for laws of nature, regardless of whether they be passive or active.

Returning to the opening question

Let me turn to the motivation for the present article. How is this philosophical work on the question of laws of nature of value to scientists and science educators, each of whom have somewhat different objectives? Should they familiarize themselves with at least some of the main arguments that so occupy the philosophers? What does it mean to claim that laws of nature may be necessary and somehow immanent in the world, rather than just a matter of epistemology? Is it of value for scientists and science educators to move beyond issues that can be experimentally resolved while stepping into a metaphysical world to which we may never have genuine access?

My response to these questions is that it does not serve science and science education to follow philosophers into this domain, however logically and carefully the philosophers go about conducting this kind of pursuit. This is not at all to deny the role and usefulness of philosophy of science in science education. Nor am I denying that metaphysical considerations may lie at the heart of scientific developments. I am certainly not proposing a return to positivistic notions that all that matters is grounding one's views fully in experimental observations. I am making the more circumspect observation that philosophers as opposed to scientists and science educators, who I am lumping together for the sake of expediency, have somewhat different views about the nature and role of scientific laws. I am suggesting that these differences deserve greater scrutiny from those of us who advocate for a greater role of philosophy of science in the teaching of science.

Laws of nature from a more scientific perspective

In this and the following section I will examine what I take to be a scientific but non-philosophical perspective on laws of nature that one might encounter in a science textbook. According to scientists and science educators the discovery of laws of nature are among the first stages in the development of any scientific discipline. I take it that scientists and science educators consider laws of nature to be descriptive rather than explanatory and that the 'heavy lifting' of providing explanations is achieved by theories rather than by laws. In science one takes a more historical perspective on these matters, and a set of independently discovered scientific laws is seen as eventually leading to a scientific theory. In this respect scientific laws may be seen to play a less powerful role than scientific theories do. This is of course a reversal of the layperson's view whereby scientific theories are regarded as being somewhat flimsy and lacking of any real power, except for the possibility that some such theories might eventually develop into becoming scientific laws.

There are many examples of laws and theories in science that show conclusively that the layperson's view is altogether the wrong way round. What I am suggesting here, with some temerity, is that a somewhat analogous view is held in philosophy, in the sense that laws are considered to be of fundamental importance and of being explanatory.

Some examples of scientific laws

Consider for example the discovery of the laws of chemical combination. One of the first to be discovered, and usually attributed to Lavoisier, is the law of conservation of mass, namely the realization that in the course of chemical reactions matter is never created nor destroyed. In 1797 Joseph Proust discovered the law of constant composition according to which two or more elements that combine to form any particular compound will always do so in precisely the same ratio of masses. In the case of sodium chloride, for example, one gram of sodium always combines with 1.333 grams of chlorine, regardless of whether the source of the compound might be in rock salt, from sea water or anywhere else.

Thirdly, the law of multiple proportions dictates that if a particular element such as carbon combines with another element, say oxygen, to form more than one compound, the masses of the second element which combine with a fixed mass of the first one, constitutes a simple ratio according to their masses.[5] In the case of this example, involving the formation of carbon monoxide and carbon dioxide, the masses of oxygen that combine with one gram of carbon are 1.33 grams and 2.66 grams, respectively which represents a ratio of one to two between the masses of oxygen.

These three laws remained somewhat mysterious until the development of Dalton's atomic theory which succeeded in unifying them, as well as explaining why all three laws are what they are.[6] The postulates of Dalton's atomic theory are quite well known but worth repeating here in order to illustrate how they explain the three named laws of chemical composition as well as other facts about chemical reactions.

1. All matter is composed of extremely small particles called atoms.
2. Atoms of a given element are identical in size, mass, and other properties. Atoms of different elements differ in size, mass, and other properties.
3. Atoms cannot be subdivided, created, or destroyed.
4. Atoms of different elements can combine in simple whole number ratios to form chemical compounds.
5. In chemical reactions, atoms are combined, separated, or rearranged.

The law of conservation of mass can be explained by appeal to postulates 3 and 5. If atoms cannot be created or destroyed, it follows that the total mass of the products of any chemical reaction is equal to the total mass of the reactants. Proust's law of constant composition is explained by postulate 2. Atoms of sodium and chlorine, for example, have different and fixed weights which are reflected in the relative weights of these elements which occur in macroscopic samples of the compound that they form. Thirdly, the law of multiple proportions is explained by appealing mainly to postulate 4.

I wish to highlight how different this view is from the way that philosophers of science, such as Hempel, came to belive that laws themselves are explanatory. A further point about

[5] This example of a law of chemical combination is somewhat ahistorical in that it was actually predicted by Dalton, rather than first being discovered, and then explained by his theory.

Nevertheless, matters could well have been the other way round and would not therefore detract from the force of my argument.

[6] Paul Needham has disputed the commonly held notion that Dalton's laws are in fact explanatory. (Needham 2004).

the relationship between laws and theories, that is emphasized in science education, is that many laws are explained, as well as encompassed, within one particular theory. This fact which is also taken to imply the greater generality and more fundamental status of scientific theories as compared with laws.

The obvious consequence of this view is that laws by themselves do not provide explanations but only describe scientific states of affairs. In addition, scientific theories are seen to be explanatory, more general and more fundamental than laws.

Another classic example of a set of laws that eventually found their explanation in the form of a theory is that of the gas laws of Boyle, Charles and Avogadro which are unified within the framework of the kinetic theory of gases (Maxwell 1867).

In 1662 Boyle published a law that now bears his name, although it had been noticed by others. It states that the volume of an ideal gas is inversely proportional to the applied pressure. In 1687 Newton attempted an explanation for Boyle's law but it is now considered to have been inadequate. The satisfactory explanation only became available when kinetic theory was developed over the next two centuries by Bernoulli, Clausius, Maxwell and Boltzmann.

In 1812 Amadeo Avogadro announced a gas law that states that the volume of an ideal gas is directly proportional to the number of moles of the gas. In the 1870s the French scientist Jacques Charles discovered that the volume of an ideal gas is directly proportional to its temperature. As in the case of Boyle's law, attempts were made to explain these laws but it was not until the development of the kinetic theory that this feat was achieved. Simply put, the kinetic theory of gases provides a fundamental explanation and unification of what had previously been individual and seemingly disconnected relationships involving several properties of gases.

My third example concerns the periodic law and the associated periodic table of the chemical elements. In the 1860s a number of chemists noticed that if the elements were arranged in order of increasing atomic weight, the result was an approximate periodicity or recurrence in their chemical and physical properties. The periodic law was represented graphically in the form of periodic tables which have become one of the central guiding principles in the whole of chemistry and related sciences. However, it was not until the development of the old quantum theory, and Bohr's application of it to chemical periodicity, that any underlying explanation became available. This explanation was placed on a more secure foundation with the advent of axiomatic quantum mechanics that was developed in the 1920s, some 60 years after the initial discovery of the periodic law (Scerri 2019).

Admittedly, the view that I have defended thus far is biased in favor of that of scientists on laws of nature. It would seem that some philosophers who invoke the necessity of laws of nature are taking a view that is somewhat akin to that of laypersons in elevating the role of laws of nature, which are regarded as being more fundamental that scientific theories (Chen 2021). But not all philosophers of science share this view. In the next section I will enlist the support of two prominent philosophers of science who deny the importance or even the very existence of scientific laws.

Philosophers of science opposed to the very notion of laws of nature

I now discuss two highly influential philosophers of science who have entirely rejected the very notion that laws of nature play any role in science, and the way in which philosophers should think of science. These authors consist of the late Ronald Giere and Bas Van Fraassen.

In an article titled "Science without laws of nature", Giere begins by examining the recent historical origins of the notion of laws of nature (Giere 1999). He starts his account with the views of Descartes and Newton, both of whom believed that laws of nature were given by God. Consequently, these authors regarded laws to be true, universal and necessary. In addition, they regarded laws of nature to be independent of human observation and belief, since humans themselves were subject to God's laws.

Giere points out a problem with Newton's belief in the universality of his own laws of motion, or should one say God's laws as discovered by Newton? Newton's laws seemed to apply to terrestrial objects as well as comets and the planets in the solar system. However, he could not explain why the fixed stars did not appear to experience mutual attraction between themselves.

As Giere also points out, the rejection of God's agency regarding laws of nature was questioned long before the time of Newton and Descartes by the likes of Roger Bacon, Robert Boyle and more famously by Galileo Galilei. Other skeptics who came after Newton included Laplace who did not need the hypothesis of a God, and Darwin whose rejection of a deity caused such a stir in England and continues to do so in many countries to this day.[7] But returning to philosophers, Giere considers that the complete divorce of so-called natural laws from God's laws was carried out by Mill and later Bertrand Russell.

Giere's own view of laws is nicely summarized in the following passage from his article,

> The main issue for most of this century and the last, has been what to make of the supposed "necessity" of laws. Is it merely an artifact of our psychological makeup, as Hume argued; an objective feature of all rational thought, as Kant argued; or embedded in reality itself? My position, as outlined above, is that the whole notion of "law of nature" is very likely an artifact of circumstances obtaining in the seventeenth century. To understand contemporary science, we do not need a proper analysis of a law of nature, but a way of understanding the practice of science that does not simply presuppose that such a concept plays any important role whatsoever (Giere, 1999, 90).

Next, Giere considers some examples of what are typically referred to as laws by scientists, including Newton's laws, Ohm's law, the Second Law of Thermodynamics. His claim is that they are neither necessary, nor universal or even true. As for Newton's laws, Giere points out that only in a universe that consists of just two bodies would Newton's law of attraction be strictly true, given that the presence of other bodies invariably complicates the attraction between the two bodies in question. Moreover, the bodies in question would have to be perfectly spherical and would need to have no electrical charge for their attraction to be described exactly by the putative law of attraction.

[7] Interestingly, the debate is far more pronounced these days in the US than it is in the UK.

Of course, it is possible to add provisos and clauses to the laws in order to disqualify such interferences but this would mean including an infinite list of such provisos. In addition, there are some provisos that could not possibly have been included by the discoverers of the alleged laws. For example, Newton would have needed to specify the absence of charges on his two perfectly spherical bodies, and yet electrical charge had not been sufficiently characterized or even imagined in Newton's time.

Giere proceeds by turning the attention to Newton's *equations* of motion rather than Newton's laws. Thinking in terms of Newton's laws imply a direct connection between the terms used in the law and the world. It also implies the presence of a universal quantifier of the form "for all massive objects…". Consequently, the resulting statement is simply true or false.

If we focus on Newton's equations of motion however, the connection to the world becomes more abstract and indirect in the following way. We can associate a term m with the mass of any body and the terms v and t with velocity and time etc. The equations can then be used to consider a mechanical system such as a two-body system, that is only subject to gravitation. In other words, we now have an abstract system that can be termed a model.

To quote Giere,

> By stipulation, the equations of motion describe the behavior of the model with perfect accuracy. We can say the equations are exemplified by the model or, if we wish, that the equations are even strictly *true,* even *necessarily* true for the model. For models, truth, even necessity, comes cheap. (original Italics) (Giere, 1999, 92).

Van Fraassen's on laws

In his highly cited book, *Laws and Symmetry*, the leading constructive empiricist Bas Van Frassen begins his eighth chapter titled "What if there are no laws?" with a quotation from David Armstrong.

> There is one truly eccentric view. This is the view that, although there are regularities in the world, there are no laws of nature (quoted in Van Fraassen 1989, 183)

Van Frassen then sets about countering this view which he very understatedly claims to be "no longer being quite so eccentric" in the remainder of his book. Van Frassen then sets about countering this view which he very understatedly claims to be "no longer being quite so eccentric" in the remainder of his book.

In an interview with Robert Kuhn, Van Fraassen explains how laws were important in the 17th century both in theology and in science (Van Fraassen 1989).[8] However, although the theological connotation was gradually abandoned in the context of scientific laws, the term law itself continued to be used. He gives the example of the current usage of the terms Ohm's law and Schrödinger's equation and wonders why the latter is not also known as a law given that it is more fundamental. According to Van Fraassen the term law is used as an honorific epithet and inconsistently so.

[8] An interview of Bas van Fraassen conducted by Robert Maxwell Kuhn. https://www.youtube.com/watch?v=zFSEMap5AiY

Van Fraassen categorically rejects the notion that scientific laws represent necessary connections and points out the simple fact that scientists never consider their laws as having anything to do with necessity. He believes that laws carry the baggage of necessity which should be excised. When asked what has to be added to a genuine regularity to turn it into a law his response is "something like necessity". For an empiricist such as Van Frassen things just happen and regularities suffice to provide explanations, predictions and manipulation of the world. If necessity is removed from putative laws what remains is models or theories. The only way to test necessity would be to examine a putative law in all possible circumstances, or in all possible worlds, which is of course impossible to do.

To conclude this section, I should stress that while I support the views of Giere and Van Frassen when it comes to their denial of the role of laws in scientific practice, I do not necessarily agree with their model-centric approach to understanding scientific theories.

Seifert on laws in chemistry

To return specifically to the field of chemistry, I now briefly consider the views of Seifert who has attempted to make a case for invariable and necessary nature of laws in chemistry. In a recent article titled "Does the periodic table reveal laws of nature?", Seifert writes,

> Where the periodic table has been disregarded though, is philosophy. This is surprising not just because of its important role in chemistry. The periodic table is often mentioned in textbooks, chemical articles and popular texts as a representation of the so-called 'periodic law'. This term suggests that at least in chemical discourse the periodic table has a status that few classificatory schemes enjoy in science: it shows, to put it boldly, a law of nature (Seifert 2023).

According to the present author, the claim that philosophers of chemistry have neglected discussing the periodic table is patently false given the numerous publications on this topic (Scerri 2012, 2021, Scerri, Restrepo, 2018). Seifert proceeds to claim,

> Interestingly, the periodic table involves numerous potential law-like statements. There are statements about elements and also about groups of them, like 'All metals conduct electricity' and 'All noble gases are unreactive under standard conditions'. Each statement is encoded in the table as the periodic classification is based on the underlying electronic structure of elements. So one could argue that each represents a candidate law of nature (Seifert 2023).

One can readily agree that the periodic table embodies, and graphically represents, a grand generalization about the behavior of all the elements in terms of their approximate repetition. However, I doubt that any chemists would concur with the view that statements such as "all metals conduct electricity" can be said to constitute a law of nature, even if one accepts the commonplace understanding of scientific laws, since it is a well-known fact that not all metals do so. Whether or not either of the statements that Seifert cites are based on the underlying electronic structure of the elements in question, does not make such candidate laws any more law-like than they might be according to a classical view of the macroscopic properties of elements.

In other places Seifert has claimed that the manner in which any given element such as sodium reacts with another element, say chlorine, may also be regarded as a law of nature (Seifert 2023b). However, such a proliferation in the number of laws runs the risk of making the very nature of laws redundant. Are we to believe that the reaction of every element with any other one constitutes a separate law? If so then one would currently have a total of [(118)(117)/2] or 6,903 distinct laws, just counting the reactions between any two elements.[9] The further question then arises as to whether one should consider the reaction between any given two elements under different conditions of temperature and/or pressure as constituting a further set of distinct laws. The clear danger of acquiescing to such a profusion of chemical laws would be to render very the very notion of laws as generalizations completely redundant.

Returning to Seifert, she further states,

> In general, the idea that there is a certain way in which the world is compelled to behave (either by an agent or not) has persistently intrigued human civilisation. Second, there is a debate in metaphysics about whether things are the way they are in the universe by necessity or just by accident. If they are by necessity, is there something in the nature of things that compels them to behave as they do? Or do laws necessitate that things behave in a certain way? Some contemporary philosophers even argue that we might need both laws and the powers of things.

Although Seifert does not go so far as to claim that chemical laws are indeed a matter of necessity in this article, it seems clear that she is wanting to apply the views of some necessitarian philosophers of science when it comes to the nature of chemical laws.

Conclusions

The fact that laws are regarded as leading to theories by scientists emphasizes the lesser role that laws play in the scheme of things. In metaphysics the situation is regarded in the opposite fashion. Laws are considered to be necessarily true, thus adding to their iron-clad validity and invariability. It appears that scientists accept the historical and developmental aspects of science whereby laws are a step towards greater understanding whereas metaphysicians seem to take a timeless view of the matter.

Cases involving accidental regularities are somewhat irrelevant to scientists since such false laws are soon rooted out and do not pose any serious threat to the growth of knowledge. As in the case of the flagpole and the shadow example, so beloved of causal theorists, metaphysicians love their imaginary spheres of gold and uranium weighing or not weighing 100,000 kilograms. These examples from folk philosophy are of no great interests to scientists and nor are all the elaborate schemes that seek to rule out the asymmetry of explanaon or the existence of accidental generalizations. Science deals with behavior observed over many, many, instances, rather than flagpoles, coins in my pocket or unusually large spheres of gold. For some philosophers like Van Fraassen and Giere there are no laws of nature. According to these authors, a better way to examine scientific practice is to focus on scientific models which are accepted from the outset as being neither true nor false, or to focus on equations which may or may not bear the name of a law.

[9] If one considers the presence of n bodies, the number of two-body interactions is given by the formula [(n)(n – 1)]/2]. There are currently 118 elements that either exist naturally or have been produced synthetically, which leads to the figure of 6903 that is cited in the main text. However, the extreme instability of the superheavy elements precludes the notion of their reacting with any other element from the periodic table such as to reduce the value to somewhere in the region of about 4000.

The metaphysical view of laws of nature which regards bodies and particles as having essential properties, powers, dispositions etc. seem to deny the interconnectedness of all things. These views fail to recognize the underlying unity in the world of physical events which makes it that every action is influenced by the environment in which the action is taking place and by competing laws of nature, if one must speak in terms of any laws. The putative laws that are supposed to exist between particular objects such as masses in Newtonian gravity for example, thus represent abstractions which cannot be invariably 'true' in the way that metaphysicians suppose them to be.

Scientists use the word "law" as an honorary epithet and as a throwback to an age in which laws of nature had a religious connotation. But even when the religious connotation was abandoned the secular laws of nature were still regarded as being invariant. We propose, in agreement with the likes of Van Fraassen and Giere that this view represents a grand illusion.

And even when scientists continue to use the term law, such as in Boyle's law, Snell's law, Newton's laws etc., they do not intend these relations to be endowed with invariable necessity. Many other scientific principles such as Pauli's Exclusion Principle or the Schrödinger equation are similarly not known as laws for historically contingent reasons, even though they may have a wider range of application than the so-called laws of science.

For example, chemists have long abandoned using the term "periodic law". In any case the repetition in the properties of elements that this law was once supposed to capture is highly irregular in that it involves sequences of 2, 8, 18 and 32 elements. Moreover, any such repetitions are approximate and frequently show anomalies, such that one is clearly not dealing with any form of necessity. Furthermore, the so-called periodic law appears to break down in the case of high atomic numbers.[10] However, these features do not render it an accidental generalization. Chemical periodicity represents a genuine regularity albeit with limitations, just as like so many putative laws of nature. Meanwhile a metaphysical view of laws of nature would not seem to lend itself to such capricious behavior on the part of some, if not all, scientific laws.

Finally, some recent research in physics and cosmology adds yet a further argument against the necessitarian view of laws. For some time now physicists have begun questioning whether the known laws of physics apply in all parts of the universe and whether they may have changed with the passage of time. This work has recently focused on the spectra of a class of celestial objects known as quasars. A close examination of the spectra of these objects is revealing a possible variation in the value of the fine structure constant, or the ratio which is equal to e^2/hc, where e is the charge on the electron, h the Planck's constant and c the velocity of light (Liu et al. 2021). If the constants of nature, or a combination of them in this case, do vary it implies that the laws of physics are also variable and therefore far from invariant as necessity would require.

To conclude, I urge philosophers of science education in particular to face up to the gulf between the scientific view that laws describe as opposed to the majority of philosophers who believe that they are explanatory and in some cases a matter of necessity. I offer one possible reason for this difference which was alluded to in earlier parts of this article. The scientific view would appear to be based on a more historical understanding of how laws are initially discovered and collected together, only to eventually be explained jointly by

[10] Relativistic effects are known to modify the properties of elements having high atomic numbers, a field pioneered by Pyykko 1988. For example, elements 104 and 105 or rutherfordium and dubnium respectively do not behave similarly to the elements placed above them in the periodic table (Scerri 2019).

one underlying theory. I have given three examples of this kind of development, namely the laws of chemical combination, the individual gas laws and the periodic law, which were sometime later explained by Dalton's theory, the kinetic theory of gases and quantum mechanics respectively.

Meanwhile, the philosophical views on scientific laws and laws of nature in general appear to be based on timeless considerations. This is perhaps why philosophers remain convinced that scientific laws are explanatory by themselves. It is because they have failed to take into account the historical or evolutionary development of science. One is reminded of the clash of styles between the titans of 20th century philosophy of science, namely Popper who sought a timeless logical approach, and Kuhn who relied heavily on the historical development of science for his own equally influential position.

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