Constructive theories and explanation by structural necessitation

Abstract

Einstein famously distinguished between constructive and principle theories. He believed that only the former are explanatory. Lange has recently argued that principle theories explain too, by virtue of putting necessary constraints on the laws of physics. In this paper, I want to draw attention to the fact that constructive theories also offer explanations in terms of necessities: they represent contingent regularities as necessities. I call this feature 'structural necessitation' and the understanding afforded by it 'how-necessarily' understanding. In contrast to the necessities of Lange's explanations by constraint, structural necessitation can be brought about by causal mechanisms.

1 Introduction

Einstein, in a letter to the London *Times* in 1919, famously drew a distinction between two kinds of theories: constructive and principle theories. Constructive theories, according to Einstein, "attempt to build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme from which they start" (Einstein 1993/1932, 167-168). Principle theories, in contrast, are based on principles which are "not hypothetically constructed but empirically discovered ones" (ibid.; added emphasis). Even though Einstein classified his own special theory of relativity as a principle theory, he characterized constructive theories as the "most important class of theories" and claimed that "when we say that we have succeeded in understanding a group of natural processes, we *invariably* mean that a constructive theory has been found which covers the processes in question" (ibid.; added emphasis).

Einstein's distinction has recently been hotly debated in the context of whether Minkowski spacetime in Einstein's special theory of relativity really explains the relativistic phenomena of length contraction and time-dilation (Balashov and Janssen 2003, Brown 2005, Brown and Pooley 2006, Janssen 2002, 2009). Although it is generally accepted in this debate that constructive theories explain and principle theories don't (or at least to a lesser extent), Lange (2017) has recently questioned this consensus. In his book *Because without Cause* Lange has argued that principle theories explain by virtue of what

Lange calls "explanation by constraint": they put necessary constraints on the laws of physics.

The purpose of this paper is to shed further light on the prinicple / constructive theory distinction as an interesting *general* distinction and irrespective of the role it has played in the debate about the explanatory status of spacetime. In particular, I will argue that an important element of the explanation provided by *constructive* theories is the representaiton of regularities as necessities. I call this feature *structural necessitation*.

The structure of this paper is as follows. In Section 2, I will provide some historical and contempory background to Einstein's distinction. In Section 3, I will briefly review Lange's case for the explanatory power of principle theories in virtue of their provision of *necessary* constraints. In Section 4, I will argue that an important aspect of the explanatory power of Einstein's example of a constructive theory, namely the kinetic theory of gases, is its structural necessitation, namely its representation of empirical regularities as necessities. In Section 5, I will elaborate the notion of structural necessitation and provide further examples of constructive theories that explain by necessity. In Section 6, I will compare the necessities afforded by constructive theories to the necessities of principle theories. In Section 7 I will briefly revisit Einstein's distinction in the context of discussions of spacetime to outline several possible views that are given rise to by the discussion of this paper. In Section 8 I conclude this paper.

2 Brief background: constructive vs. principle theories in physics

Einstein's distinction between constructive and principle theories becomes particularly clear by the examples Einstein himself mentioned: thermodynamics and the kinetic theory of heat. Whereas thermodynamics *at the observational level* lays out principles that any physical system must obey, such as that entropy in a closed system always increases, the kinetic theory of heat postulates *unobservable* entities behind the phenomena that account for the behavior of gases (cf. Balashov and Janssen 2003). By saying that when we have a theory that gives us understanding of a set of phenomena "we invariably mean that a constructive theory has been found", Einstein clearly singled out constructive theories as explanatory and also seems to suggest that principle theories do not help us to further our understanding. It would however be a mistake to think that Einstein saw no value whatsoever in principle theories. On the contrary, he praised them for their "logical perfection and security of the foundations" and thought that some principles, such as the second law of thermodynamics, "will never be overthrown" (Einstein 1993/1932, cf. Klein 1967). By implication, constructive theories are less epistemically secure and more prone to revision.

It is interesting to note that Einstein was not the only scientist to draw a distinction between these two kinds of theories. As Frisch (2005) pointed out, the famous Dutch physicist H. Lorentz made a very similar distinction already in 1900: he distinguished between theories that postulate "general principles" or "general laws" and those that postulate "a mechanism of the phenomena". Similarly, the physicist James Jeans drew a line between constructive and "destructive" theories and even used Einstein's example of thermodynamics to illustrate the latter (Lange 2017). In fact, the distinction was made even much earlier by the physicist W. J. Rankine, who distinguished between hypothetical and 'abstractive' theories (Rankine 1855).[1] In other words, Einstein's distinction seems to be one that was recognized also by his contemporaries and predecessors.

As mentioned, Einstein's distinction has played an important role in discussions about the explanatory merit of spacetime in special relativity. Brown (2005) and Brown and Pooley (2006) have called spacetime a 'non-glorious entity' that is explanatorily as inert as the aether was in early electromagnetic theories: it explains neither why bodies follow the geodesics of spacetime (it just postulates it) nor why bodies contract and time is dilated. Brown and Pooley argue that an explanatorily more complete theory that really explains why objects obey the Lorentz invariance of the dynamical laws will have to be a constructive theory that refers to the microproperties of physical objects.

At the other side of the debate, Janssen (2009) has argued that the special theory of relativity *already* provides a constructive explanation in terms of Minkowski spacetime. In particular, Janssen has suggested that spacetime provides a 'common origin' explanation: it explains why several seemingly separete phenomena obey the Lorentz invariance. At the same time, Janssen rejects Brown's assumption that Minkowski spacetime must be interpreted as an ontologically autonomous entity—a view also known as substantivalism—for it to qualify as a constructive theory. Acuña (2016) however has recently argued convincingly contra Janssen that spacetime cannot be construed as such an explanation without committing to some kind of substantivalism. He furthermore goes on to suggest that the relation between spacetime and and the Lorentz invariance of the dynamical laws is an analytic relation; there is no explanatory arrow in either from spacetime to the laws nor vice versa.

Despite much disagreement between the partakers of this debate, it is generally accepted that only constructive theories explain and provide understanding. This consensus has been questioned by Lange (2014, 2017). In his book *Because without Cause,*

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[1] Interestingly, Pierre Duhem explicitly drew on Rankine's distinction in his well-known praise of 'French' abstract theories and dismissal of 'British' mechanical models (Duhem 1954/1991).

Lange (2017) argues that that principle theories explain too, namely by virtue of what Lange calls "explanation by constraint": they put necessary constraints on the laws of physics.[2] The next section is dedicated to exploring what that might mean.

3 How principle theories might explain

Lange's preferred example of an explanation by constraint is inspired by remarks by R. Feynman and concerns the explanation of why various force laws conserve energy. Why do electrical and gravitational forces, despite their different range, different strength and different objects they apply to, all conserve energy? Either this is a mere coincidence, or the forces all conserve energy *because* they obey the principle of conservation of energy. That is, either the forces conserve energy because *each* of the force laws *separatly* requires them to do so, for separate reasons, or those two kinds of interactions conserve energy *for the same reason*: because energy conservation requires them to do so (49-50). Another way of putting this point is in terms of 'explanatory priority': if it was a mere coincidence that various force laws conserved energy, then the various force laws would be explanatorily prior because they would be "partly responsible for its holding" (50). On the other hand, if energy conservation is prior to the force laws, it constrains *all* of them to have a certain feature (namely energy conservation), even though energy conservation does not entail any of the particular force laws there happen to be (50). Although Lange states that he does not want to committ to either view, he maintains that much of what scientists say suggests that they view principles like energy conservation not as coincidences but as constraints (46).

For Lange, explanations by constraints are thoroughly non-causal: there is nothing about the forces themselves that would cause them to be such that they conserve energy. So by the virtue of what do they explain? Obviously, explanations by constraint unify: they give a common explanation to seemingly rather distinct phenomena. But that's not all. Explanations by constraint explain by virtue of 'natural necessity', which Lange also describes as physical or nomological necessity. By virtue of natural necessity, it is not only the case that extant force laws must conserve energy, but also any force laws that 'might have been' would have had to. As Lange puts it, explanation by constraint

> transcends the grubby, pedestrian details of the various particular force laws […] It does not depend on the kinds of forces there actually happen to be. Rather, it limits the kinds of forces there could have been […] certain kinds of forces that

[2] See also Frisch (2011), who borrows the idea from Lange (2007, 2011). For further discussion of the explanatory power of the special theory of relativity and Einstein's distinction see also Acuña (2016) and references therein.

> are not among the kinds there actually are nevertheless qualify as possible in virtue of satisfying these constraints, whereas others qualify as impossible […]. (51)

Likewise, Lange claims, energy conservation explains the fact that there is no law of nature that posits force fields that pop alternatively in and out of existence every other second, since that would imply that the potential energy of all bodies in a field would change while their kinetic energy stays the same, which would be inconsistent with energy conservation (57). On the coincidence view, there is no reason why no such force fields exist.[3] Thus, Lange concludes, "a constraint possesses a certain distinctive kind of invariance under counterfactual perturbations" (49). Since the relevant counterfactuals are those whose antecedant contains a 'natural impossibilty' Lange also refers to these kinds of counterfactuals as 'counterlegals' (74).

Despite what the 'invariance under counterfactual distubances' may suggest, Lange considers constraints to be inexplicable on a standard account of explanation (Woodward 2003), because constraints like conservation principles do not identify circumstances in which the explanandum (such as the fact that different forces conserve energy) would have been different (that is, circumstances, in which conservation would *not* hold), nor do they identify *what* would have obtained in the actual explanandum's stead (48-9; 86-8). It is thus hard to answer what-if-things-would-have-been-different questions, which are essential to Woodward's account of explanation.

Explanation by constraint, Lange points out, is not the only kind of explanation that explains by way of necessities. There are arguably also mathematical explanations as in Lange's widely discussed example of Mother failing to distribute 23 strawberries evenly among her 3 children because it is impossible to evenly divide 23 by 3. Although the necessities in explanations by constraint are not quite as strong as the necessities in such mathematical explanations, they are stronger than the necessities of 'ordinary' laws of nature, or so Lange claims (51). Lange also speaks of a metaphysical "pyramidal hierarchy" of necessities, whose levels can be determined on the basis of counterfactual conditionals, such as the ones considered above. If the counterfactual antecedant contains natural impossibilites, then the associated necessity is stronger than when the counterfactual antecedant contains just 'subnomical' facts.

The special theory of relativity—Einstein's own principle theory—according to Lange, is also a theory that explains by constraint. On that theory, the fact that the

[3] One might remark critically here that a lot of things that do not exist are not explained by our theories.

dynamical (force) laws are Lorentz-covariant (viz. invariant under Lorentz transformations), either is an accident or the dynamical laws must be Lorentz-covariant because the principles of the special theory of relativity (in particular, the principle of relativity) constrain the dynamical laws in such a way that they *have to be* that way (103). Just like energy conservation would have held if the forces had been different, Lorentz-covariance would have held in such circumstances too (109). Lorentz-covariance would thus inhabits a similar space on Lange's pyramidal hierachy as principles of conservation. Lange furthermore cites evidence that scientists actually believe that Lorentz covariance is of a stronger necessity than the force laws in this sense (106-107). With regards to the debate about the explanatory status of Einstein's theory, Lange sides with those who have affirmed that the theory is explanatory (Janssen 2009) and rejects Brown's view that a genuine explanation would have to be a *constructive* explantion, i.e., an explanation that would provide a microphysical and causal explanation of why rods contract and clocks retard.

I am persuaded by Lange's slightly provocative case for principles such as energy conservation – despite first appearances – actually being explanatory. Likewise, I do think that we can accept that principle theories give us *some* understanding of the target system. But how does the understanding principle theories give us compare to the understanding that constructive theories can bring about? In order to address this question, we need to know more about constructive theories and the way they explain.

4 How does the kinetic theory of gases explain?

Consider the kinetic theory of gases (KT), Einstein's favorite example of constructive theories. KT postulates that gases consist of molecules in motion and makes a number of idealizing assumptions about their properties, such as that the extension of the molecules is negligible. KT's explanandum is the ideal-gas law (IGL), namely $PV = nRT$, where P=pressure, V=the volume of the gas container, T=temperature, R=the ideal gas constant, and n=the amount of substance of gas in moles. How does KT explain IGL? Many leading philosophers of explanation have discussed this example. Hempel (1970) argues that KT explains IGL by offering bridge-laws that connect macro- with micro-variables. Salmon (1984) suggests KT explains IGL by correctly identifying the causal structure or mechanism underlying IGL. Friedman (1974) argues that that it is KT's unifying power that explains IGL (and other laws). Cushing (1991) claims that KT is explanatory because it provides us with a visualisable picture that underlies IGL. Elgin (2004, 2007) believes that IGL (that can be derived from KT's highly idealized assumptions) gives us understanding by virtue of misrepresenting the target. Woodward (2003), as we shall see in a moment, argues that there is a sense in which IGL is in fact more explanatory than KT.

In spite of the extent of philosophical engagement with KT and the plethora of views of its – largely undisputed – explanatory power, I believe that one important element of KT's explanation of IGL has been overlooked, namely the representation of IGL in KT as a necessity.

IGL is a summary of two empirical laws: Boyle's law and Gay-Lussac's law. The former states that the pressure of a gas is inversely proportional to the gas volume and the latter tells us that pressure is proportional to temperature. It is easy to see that these relations support Woodwardian counterfactuals: had we decreased (increased) the volume of a gas in a container, the pressure of the gas would have increased (decreased). This is Boyle's law. Also, had we increased (decreased) the temperature, the pressure would have increased. This is Gay-Lussac's law. Woodward (2003) has pointed out that these relations give us understanding of causal dependencies between the relevant macro-variables (250ff.). But how does KT figure on his account, given that KT is normally taken to explain IGL? Curiously, Woodward has not much to say about this question, at least not much positive. Although he admits that since KT "provides information that allows us to answer what, in some respects, is a wider, more detailed range of w-questions" and that KT therefore gives us a sense of "deeper explanations" (223), he believes that the explanation offered by KT for IGL is deficient, as it "omits information that is crucial to an explanation" of changes in the values of macro-variables. More specifically, Woodward believes that KT fails to give us much understanding of IGL because for any particular value of a macrovariable such as pressure, there is not one determinate microstate, consisting of initial positions of molecules, their momenta and molecule trajectories. Because of that, there is no determinate answer to the question of what the value of the pressure-variable would have been, had the microstate been different, because, again, any macrostate is compatible with a multitude of microstates. Woodward concludes that KT "fail[s] to provide the explanation of the macroscopic behavior of the gas we are looking for" (232) and that IGL does a "better job" at explaining changes in macrovariables than KT (232). Woodward believes that this lesson is a general and that it is often the case that lower-level explanations do worse than upper-level explanations (233).

I believe Woodward does not do full justice to KT; at the very least, he is at odds with not only many philosophers studying explanation (see above), but also with the way in which KT is normally perceived amongst scientists, namely as explanatory of IGL, as any textbook introducing statistical mechanics will reveal.

Notice that, on a higher level of abstraction, we *can* identify counterfactual dependencies between KT and IGL. For example, an increase in the frequency of molecule-wall collisions will result in a higher value in the pressure variable, no matter what the initial conditions of the molecules might have been. Thus, contra Woodward, we *can* say how the pressure would have changed, had the frequency of the molecule-wall collisions have changed. In fact, we can say even more than that: we can also say why the relation of the macrovariables summarized in IGL *has got to* be the way that it is. Let me explain.

IGL, as an empirically discovered relationship, is contingent. We came to know of it by investigating the world in which we actually live in. In a different world, the laws describing the behavior of gases might have been different. In another world, for example, it might have been the case that a decrease in gas volume would not result in an increase in pressure (as in our world) but in a *decrease*. So how come that in our world the gas macrovariables are related in the way they actually are? This is where KT comes in: it tells us that IGL *must* have the form that it does and that, for example, a gas's pressure *must* increase when the volume is decreased. It is *not possible*, within KT, to increase a gas's volume and thereby to decrease its pressure. In other words, KT represents IGL as a necessity. I take this to be an important feature of explanations offered by constructive theories. Because KT tells us why the *relations* between the variables of IGL have to be the way they are, I shall call this feature of KT *structural necessitation*. How does KT bring about structural necessitation? Consider the following truncated partial derivation of IGL within KT.

The number of collisions of a molecule with the container wall per second for a molecule on a 'round trip' between opposite sides of the container wall is ${v_x}/{2l}$, where l = the distance between two opposite container walls and v_x = the molecule velocity along the x-axis. The total momentum change per second for all molecules (N) in the container with average speed $\overline{v_x}$ is $N\frac{m\overline{v_x}^2}{l}$. By Newton's second law, this is equivalent to the average force exerted by the molecules on a container wall per second. Since pressure is defined as the force exerted perpendicularly on an area (here: l^2), $P = N\frac{m\overline{v_x}^2}{l^3}$. Since l^3 is the volume of a cubical container, $P = \frac{Nm{v_x}^2}{V}$. Assuming that there is no preferred direction for the molecule's path, $P = \frac{1}{3}\frac{Nm\overline{v^2}}{V}$. Since the total kinetic energy of translation KE_{trans} of all molecules is $\frac{1}{2}m\overline{v^2}$, this gives us $P = \frac{2}{3V}KE_{trans}$. It is easy to see that the smaller (larger) the volume, the higher (lower) the gas pressure. It is also apparent from this derivation that this relationship is a necessity within KT: it is not possible for the pressure to rise when the volume decreases. This is explained qualitatively by the distances between the container walls which the molecules have to traverse before hitting the walls being shorter and the number of the molecule-container wall collisions per time interval thereby increasing. Conversely, it is not possible, in KT, for the gas pressure to *decrease* (rather than to increase) when the volume increases, because that would mean *fewer* molecule-wall collisions when there is actually more space for the molecules to travel in the container before hitting the wall, which is ruled out on KT. Analogous points hold for KT's explanation of Gay-Lussac's law. Tab. 1 summarizes KT's representation of IGL as structural necessities.

IGL regularity	Explanation in terms of structural necessitation in KT
$P \propto {}^{1}/_{V}$ (Boyle's law)	FC ∝ gas density *Not possible*: FC ∝ 1 / gas density
$P \propto T$ (Gay-Lussac's law)	FC ∝ speed of molecules *Not possible*: FC ∝ 1 / speed of molecules

Tab. 1: KT and Boyle's and Gay-Lussac's laws (as parts of IGL). In KT contingent regularities are represented as necessities. FC= frequency of molecule-wall collisions. KT presupposes the following relations between macro- and microvariables: P ∝ FC, V ∝ 1/gas density, and T ∝ molecular speed.

5 What kind of explanation, what kind of understanding?

The structural necessitation afforded by KT, Einstein's prime example of a constructive theory, tells us why an empirical law like IGL *must* have the form that it does have. Without KT, we would only know *that* the relation between the relevant macrovariables would be as it is, but we wouldn't know *why*. So, although we can appreciate that IGL itself is in some sense explanatory (since it allows us to answer Woodwardian *w*-questions), KT provides a deeper explanation of IGL and of the relationship of macrovariables that it describes than we could have had by virtue of IGL alone. This seems very much in tune with how scientists themselves think about the relationship between KT and IGL.

The kind of understanding KT gives us of IGL is not just a 'how-actually' understanding, which has often been focused on by theorists of explanation (Machamer et al. 2000, Salmon 1984, Strevens 2008), but also 'how-necessarily' understanding. Thus, KT helps us understand not only how it is that certain changes in, say, pressure, depend on changes in volume (because with a reduced volume the between-wall distances decrease and therefore the number of molecule-wall collisions per time increases, which in turn increases the pressure), but it also helps us understand why this *has to be* the case (because it cannot be the case that the distances become shorter with a reduction in volume and nevertheless the pressure decreases).

KT is of course just one example of a constructive theory. Other examples I consider to be Dalton's explanation of the laws of constant proportion and Mendel's explanation of his three laws of inheritance. Dalton's atomism explains the laws of constant proportions, i.e., the law that chemical elements always combine in the same ratios (e.g. oxygen always making up 8/9 and hydrogen 1/9 of the mass of water), and the law of multiple proportions, i.e., the fact that whenever two elements form more than one compound, the ratio of those compounds will be multiples of each other (as in CO and CO_2, where a certain amount carbon combines with exactly twice as much oxygen in the first compound as in the second). Dalton's atomism explains not only the fact *that* we observe those ratios, but also why we do not observe any intermediate ratios (e.g., where carbon would combine with 1 ½ as much oxygen as in CO), as that is ruled out by the assumption of indivisible atoms. Mendel explained the laws he discovered in terms of genetic 'factors', as he called them, by showing that the self-hybridization of plants that resulted from the crossing of purebred white and purple flower peas would *have to* yield fixed probability distributions of the colour traits in the second filial generation (F2), namely a 3:1 ratio. Given the Mendelian model, a 2:2 ratio in F2, for example, would be impossible. It goes without saying that, under non-ideal circumstances (glitches in the experiments, impure samples), the experimental results one *actually* obtains may not reflect the results predicted by the theory. But that wouldn't undermine the explanatory power of the theory in question.

The kind of explanation afforded by constructive theories via structural necessitation is what Salmon (1984, 1998) called 'modal' explanation, and which he contrasts with ontic explanations, which he himself is concerned with. Salmon has in mind mostly the classical DN model, which he rightly criticizes. Salmon's main complaint is that the DN model cannot accommodate indeterministic events and events that have only a certain probability of occurring, as such events do not *have* to occur. It is also implausible to demand (in the 'inductive-statistical' cousin of the DN model) that there has to be a high probability of the events to occur (e.g., > 0.5), as sometimes the events explained by scientific theories (such as quantum states) have only a low probability of occurring.

These criticisms of Salmon's are sound, but do not apply to my model of modal explanations. Whereas Salmon and the DN model (and many other accounts of scientific explanation for that matter) are concerned with the explanation of *events*, the explananda of constructive theories are regularities, or more generally, *relations*. And that makes sense. Mendel's theory predicts that the distribution of flower colour in the aforementioned example will be 3:1. Thus, any given flower in F2 has a 1 in 4 probability of being white. This distribution is indeed necessitated by Mendel's theory: confounders aside, there cannot be any other distribution in F2. The theory does not say anything about what the colour of any particular plant has got to be. We may of course give a causal explanation of why a certain colour was expressed by the genes in any particular plant. But we shouldn't dismiss an account of explanation because it does not accommodate such causal explanations—as Salmon does. Again, Mendel's theory does not provide such an explanation either.

Thus far I have assumed that the regularities explained by constructive theories are contingencies. One may object, however, that on certain accounts of the laws of nature, laws of nature are not contingencies but necessities themselves, or more correctly that a relation of 'contingent necessitation' holds between the universals described by the law. (Armstrong 1978, 1983, Dretske 1978). This view, however, is notoriously begged by uncertainty about what this relation of necessitation is supposed to amount to and how it could possibly be inferred (Lewis 1983). Second, this view does not sit particularly well with the fact that many laws of nature are in fact not exceptionless universal generalisations but rather ceteris paribus laws that hold only under certain condition and only within certain ranges (Reutlinger et al. 2017). For example, the ideal gas law that we discussed above, is correct only up until a certain temperature and pressure (above which the van der Waals equation is more accurate). Still, such (limited) regularities can of course be *represented* as necessities (as in my account). Third, even if one were sympathetic to view laws of nature as relations of necessitation, on standard accounts these relations would still be *contingent* relations of necessitation. That is, on such accounts it would still be contingent that, in our world, a reduction in gas volume necessitates an increase in gas pressure. Hence, even on such accounts, constructive theories could still be appealed to in order to explain why the relation has the form that it does have in our world.

6 What kind of necessities?

As we saw in Section 2, Lange distinguishes between various sorts of necessities that may be involved in the explanation of the phenomena. On the highest level of his pyramidal hierarchy of necessities, we find mathematical necessities involved in explaining why Mother cannot divide 23 strawberries evenly among her 3 kids. On a lower rung of his hierarchy, we find explanations by constraint, such as conservation laws, which explain why the (actual and potential) force laws *have to* conserve energy. On a yet lower rung we find regular laws of nature (such as the force laws). Each level in Lange's hierarchy, as we saw, is individuated by counterfactuals. For example, we can ask whether energy conservation would have held, if the forces had been different. Since the answer is yes, the necessities in explanations by constraint are nomologically more 'stable' than the necessities at the lower levels. Now our question must be: where in Lange's hierarchy do the necessities figure with which constructive theories like KT?

Let us first of all emphasize some similarities and differences between the explanatory necessities identified by Lange. First, similar to Lange's explanations by constraint, whose objects are also relations (namely laws), KT explains *relations*, namely the relations described IGL. One may add that the explanation of IGL by KT is dissimilar from the explanation provided by ordinary laws, which, as Woodward pointed out, explain the (causal) interdependence of certain variables. Second, in contrast to Lange's explanations by constraint, we can say in the case of KT that the necessities in the explanations are brought about by causation. That is, whereas Lange insists that the reason why energy conservation holds has nothing to do with the ways in which the fundamental interactions are brought about, this is different in KT. That is, not only are the macrovariables pressure and temperature of gases brought about causally by the molecular mechanism postulated by KT, but also the relations between those variables (in the form of IGL) are brought about causally by KT. Third, nevertheless, we can say with some justification that KT 'constrains' the empirical laws in that it tells that certain relations between the macrovariables are ruled out. In virtue of that, KT explains by necessities. In that sense, KT is quite similar to explanation afforded by conservation laws, according to Lange. After these clarifications let us ask once more: where on Lange's hierarchy are the necessities of KT to be located?

On Lange's account, had there been different force laws than the ones we have, those force laws – whatever their form – would still have had to conserve energy. Of course, also the laws of KT must conserve energy, even if the laws figuring in KT would have been different. In that sense, conservation laws set necessary constraints also on KT and thereby explain the laws of KT. Now consider the relation between KT and IGL. In analogy with the necessary constraints placed on the force laws by conservation laws, we can say that, given the truth of KT, IGL *could not have* taken a different form than it does take in the actual world. Again, on KT it is not possible for gas pressure to increase when the volume increases and it is not possible for the pressure to decrease when the temperature increases. Thus, just like the necessities afforded by the conservation laws, the necessities engendered by KT are nomologically more stable than IGL (and the laws it summarizes). In contrast to the conservation laws, KT also offers a *mechanism for why* IGL must take the form that it does take: the pressure of a gas must increase (not decrease) when the gas volume is reduced because the frequency of molecular collisions will be increased, given that the intermolecular distances will decrease (not increase) when the gas volume is reduced. Thus, I think we're justified to say not only that KT offers a deeper explanation than IGL (contra Woodward), but also that KT offers us a deeper explanation of IGL than energy conservation, even though it is of course true that the conservation laws are located on yet a higher level of necessity than KT: even if the *mechanism* proposed by KT had been a different one, it would still have had to respect the conservation laws.

7 Einstein's distinction and spacetime revisited

As mentioned at the beginning of this paper, Einstein's distinction in the philosophy of science has figured most prominently in discussions about the explanatory status of spacetime. Since the main focus of this paper was on Einstein's distinction in its own right, this is not the place to develop a detailed re-assessment of this debate. Still, I want to outline a few possible options. First, if it is right what I pointed out about constructive theories, namely that they explain their targets by representing them as necessities, and if the special theory of relativity is a constructive theory with the Lorentz invariance as explanatory target, then spacetime ought to explain the Lorentz invariance of the dynamical laws by representing it as a necessity. Some of the remarks made by Janssen about the explanatory role of spacetime seem to be compatible with such an option. For example, he says that without spacetime it would be a "brute fact" that different dynamical laws are Lorentz-invariant (Janssen 2009, 48). Whereas Janssen believes that this fact is explained by spacetime because it serves as a "common-origin" explanation of various phenomena, it may in fact be that the "bruteness" or contingency of the Lorentz invariance of the dynamical laws is explained by spacetime because it represents this contingency as necessity. At least when it comes to the question of why bodies in inertia move along the "ruts or grooves" of spacetime (Brown and Pooley 2006), this seems to be a live option: bodies follow the trajectories that they do (contingently) because spacetime requires them to do so. Of course, one can– like Brown and Pooley – ask further why bodies should move along the geodesics of spacetime, but one can play this game with *any* explanation.

It is worth noting that if special relativity was such a constructive theory and spacetime an explanatory entity (whether in the way I just proposed or some other way), then this would show that constructive theories need not be theories that explain the phenomena by postulating *small*-scale entities – an impression one might get from Brown and Pooley's way of thinking about constructive theories in this context.

Another option is that special relativity is not a constructive theory after all – just as argued by Brown and Pooley. If that is so, then spacetime wouldn't be explanatory in the constructive sense considered here (i.e., explanation via structural necessitation). The special theory of relativity may nevertheless be explanatory by virtue of providing constraints for the laws of nature – as we saw, this is how Lange would have it. One may then still call for a genuinely constructive theory (as Brown and Pooley do), although it may also be the case that no constructive theory for the target in question is (metaphysically) possible (Acuña 2014).

8 Conclusion

In this paper, I argued that Einstein's constructive theories explain empirical regularities by representing them as necessities. I called this feature of constructive theories 'structural necessitation', which is arguably located between the necessities with which Lange's constraints explain on the one hand and phenomenological laws such as IGL on the other hand. Although the necessities of constraints seem to be stronger than the necessities of KT, KT – in contrast to energy conservation – does go beyond the phenomena and offers us a mechanism of how the phenomena are *necessarily* brought about. In that sense, it may indeed be considered to give us 'deeper' understanding than explanations by constraint.

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