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Explaining the modal force of natural laws

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Abstract
In this paper, I will defend the thesis that fundamental natural laws are distinguished from accidental empirical generalizations neither by metaphysical necessity (e.g. Ellis 1999, 2001; Bird in *Analysis, 65*(2), 147–155, 2005, 2007) nor by contingent necessitation (Armstrong 1983). The only sort of modal force that distinguishes natural laws, I will argue, arises from the peculiar physical property of *mutual independence* of elementary interactions exemplifying the laws. Mutual independence of elementary interactions means that their existence and their nature do not depend in any way on which *other* interactions presently occur. It is exactly this general physical property of elementary interactions in the actual world that provides natural laws with their specific modal force and grounds the experience of nature's 'recalcitrance'. Thus, the modal force of natural laws is explained by contingent non-modal properties of nature. In the second part of the paper, I deal with some alleged counterexamples to my approach: constraint laws, compositional laws, symmetry principles and conservation laws. These sorts of laws turn out to be compatible with my approach: constraint laws and compositional laws do not represent the dynamics of interaction-types *by themselves*, but only as constitutive parts of a complete set of equations, whereas symmetry principles and conservation laws do not represent any *specific* dynamics, but only impose general constraints on possible interactions.

Keywords Modal force · Natural laws · Elementary interactions · Necessity

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1 Introduction

It is a commonplace (at least within the realm of anti-Humean theories of laws) that laws of nature are distinct from accidental empirical generalizations by virtue of some sort of modal force that applies to them. I propose, in this paper, that laws of nature have modal force, but that this modal force be neither grounded in metaphysical necessity (e.g. Ellis 1999, 2001; Bird 2005, 2007) nor in a contingently instantiated necessitation universal (Armstrong 1983).[1] The only sort of modal force that demarcates natural laws from accidental empirical regularities, I will argue, arises from the peculiar physical property of *mutual independence* of elementary interactions exemplifying the laws. Mutual independence of elementary interactions means that the existence and the nature of the interaction in which some physical system is involved do not depend in any way on which *other* interactions the system is involved in at the same time. For instance, electrically charged particles fall differently in a gravitational field as compared to uncharged particles, but this difference is only due to the fact that the electromagnetic mass of the particle is distributed widely over the electromagnetic field. It is *not* due to any difference in *how* the particles' mass couples to the gravitational field, as described by the Lagrangian for gravitational particle-field interactions. In short, the nature of gravitational interaction a charged particle experiences is not different from that which an uncharged particle sees.

It is exactly the property of mutual independence of elementary interactions in the actual world that grounds the experience of nature's 'recalcitrance' and thus provides natural laws with their supposed modal force. The modal force of natural laws is thus explained by a contingent non-modal property of nature (see: Section 3). In the second part of the paper, I deal with some alleged counterexamples to my approach: constraint laws, compositional laws, symmetry principles and conservation laws. These sorts of laws turn out to be compatible with my approach: constraint laws and compositional laws do not represent the dynamics of interaction-types *by themselves*, but only as constitutive parts of a complete set of equations, whereas symmetry principles and conservation laws do not represent any *specific* dynamics, but only impose general constraints on possible interactions.

My Mutual Independence-approach (in the following for short 'MIA') preserves some core assumptions of Armstrong's theory of laws: Like the necessitation-approach I associate the modal force of laws not with *necessary truth* (truth in every metaphysically possible world), but with some kind of *causal productivity*. And, like necessitation, this causal productivity is conceived as contingent – its instantiation depends upon the fulfillment of general physical conditions in the actual world. Laws of nature are worldly objects owing their existence and their lawmaking nature to contingent circumstances of our world.

[1] There are also conceptions of necessity of laws that allow for *degrees*. Lange (2009), for example, claims that there are different sorts of laws which are distinguished by their possessing different degrees of necessity: meta-laws (e.g. the law of energy conservation) allegedly possess some higher degree of necessity as compared to 'common' laws because of their embracing a wider range of counterfactual stability; their validity would resist counterfactual variations even with respect to common *laws*, whereas common laws remain only valid against counterfactual variations with respect to non-lawful *facts*.

2 Lessons from Armstrong's theory of laws

The point of departure for my argument is Armstrong's theory of laws. According to Armstrong, a lawful regularity 'All F's are G's', where F and G are state-of-affairs types, is grounded in a second-order state of affair, a necessitating connection N (F, G), holding between first-order state-of-affairs types. Reacting to the inference problem van Fraassen[2] had opposed to his theory Armstrong points out that any instantiation of F, at the same time, realizes an instantiation of the causal pattern N (F, G) which is causation of G by F. Thus, any instantiation of F turns out to be accompanied by causation of G, and this explains why N (F, G) entails 'all F's are G's' (and thus solves the inference problem):

> "The theory being advanced is that when one particular state of affairs brings about another, then the *pattern* instantiated, one state-of-affairs type bringing about a further state-of-affairs type according to some pattern, is a 'direct' relation between the state-of-affairs types involved, *a relation that is the causality instantiated in the situation*. This would seem to solve the Inference problem. Whenever the antecedent state-of-affairs type is instantiated, then, assuming this law is a deterministic one, it must […] produce the consequent state of affairs."[3]

But now a further problem seems to arise: Is it not true that any causal connection can in principle be interfered with? If N is causation of G by F, it must be excluded that interferences may occur preventing the realization of G despite F's instantiation. If such interferences could not be excluded, the instantiation of the causal pattern N (F, G) *by itself* would not prevent a possible suspension of the regularity 'All F's are G's':

> "[…] even a deterministic connection of state-of-affairs types does not entail the corresponding universally quantified truth about particulars, at least not without qualifications. The entailment actually holds only for cases where it is given that *nothing further interferes*."[4]

Armstrong concludes[5] that two sorts of laws have therefore to be distinguished. The first sort is laws where it is empirically (nomically) possible that some interfering factor H occurs which, despite F's instantiation, prevents the occurrence of G. These laws he calls *defeasible laws* (*oaken laws* in earlier publications). A law that cannot be interfered with, is called an *iron law.*

Against this dual conception of laws Schrenk (2011) has rightly urged that it cannot be consistently defended within Armstrong's own metaphysics of laws. If one assumes that *any* law, iron or defeasible, between states of affairs F and G is grounded in some nomic necessitation relation N (F, G), and that this relation means causation of G by F, then how could some interfering factor prevent instantiations of F to produce some instantiation of G? If each instantiation of F is accompanied by an instantiation of N (F,

[2] Cf. Van Fraassen (1989), 96ff.
[3] Cf. Armstrong (1997), 228. See also Schrenk (2011), 579.
[4] Cf. Armstrong (1997), 230.
[5] Cf. Armstrong (1997), 231.

G), then, according to the premises of Armstrong's theory, it *must* produce G, come what may:

> "The difficulty is that N's instantiation is supposed to be causation, but causation exists only amongst actual events: *a* causes *b* only if both *a* and *b* are the case. In other words, unless G occurs, N cannot be the causation of G".[6]

It follows that defeasible laws cannot exist, according to Armstrong's theory, i.e. his notion of a defeasible law is internally incoherent.

Now, experience seems to tell us, that successful interference with causal connections can *always* occur, thus iron laws cannot exist either. Armstrong's notion of an iron law seems to be empirically inadequate.

What is wrong with Armstrong's dual conception of laws? First of all, the empirical intuition, according to which interference with causal connections is always possible, presupposes some notion of *singular* causation that is incompatible with Armstrong's causal interpretation of N. The latter conceives particular causal relations as instantiations of strict laws. One cannot have it both ways: taking the empirical intuition seriously *and* accepting Armstrong's law-dependent conception of causality.

In order to restore the notion of genuine, 'iron' laws, several possible ways are open: First, searching for replacement of the supposedly wrong identification of the lawmaking relation N with causation, such that the new identification would guarantee interference-free (iron) laws. This is one of the ways that has been tried in Schrenk (2011).[7]

I will choose a second path: preserving N's interpretation as causation, but replacing causation as law-instantiation (which is Armstrong's notion of causation) by singular causation by means of conserved quantity-transfer. Now, this move alone would not be sufficient in order to account for the supposed modal force of laws: transfer of energy-momentum, for example, is productive, but not *by itself directed* to some particular sort of product. There can be transfers of conserved quantities here and there, but this *by itself* does not explain particular sorts of stable connections in nature. Therefore, causality can merely lay the ground for an explanation of the modal force of laws. The very modal force of laws must be something operating on this ground. Now, the following look on Bird's objection against Armstrong's theory of laws will give us a clue to what this something might be.

Bird's (2005) *ultimate argument* claims that Armstrong's necessitation N is too soft in order to explain modal force. Since, according to Armstrong's approach, (second-order) necessitation N must itself be a genuine categorical universal, in the same way in which first-order properties F, G are, N cannot be endowed with lawmaking force *essentially*. Thus, N has to borrow its force from some further third-order property N*, to which then the same consideration would apply. Thus, we run into an infinite (vicious) regress, and have to conclude that the approach is unable to somehow *locate* the force according to which N supposedly glues together natural property tokens.

Bird's argument seems to depend on the tacit premise that only *essentially* possessed forces can explain lawfulness. Given this premise, he is correct in concluding that neither N nor any other higher-order categorical universal can guarantee lawfulness.

[6] Cf. Schrenk (2011), 580–581.

[7] See: Schrenk (2011), 588 f.

But do we really need *essentially possessed* forces? What, if we accepted that, not only, departing from the actual world, N (F, H) with some H different from G, is true in some possible world – this agrees with the standard reading of Armstrong – but also that there are possible worlds in which N (F, G) holds without N having any lawmaking force there that glues together F and G? N's supposed lawmaking force is not conceptually bound to be some *essential* characteristic of N. According to this reading, N would be a *quiddity* (a property that is not *individuated* by its actual lawmaking role), i.e., N would have its lawmaking force in the actual world, but not in all possible worlds.[8] Whereas according to the standard reading, it is contingent that N makes the connection between F and G a law, and not, for instance, the connection between F and H, this more radical reading would mean that it is also contingent that N is a lawmaking relation at all: In 'It is necessarily true [N (F, G) → Each F is a G]', the Necessity-operator would be cancelled. This would not in any way diminish the fact that there is a *productive* force exercised by N in the actual world, but it would terminate N's modal status as being essentially lawmaking.

3 Explaining the modal force of natural laws by non-modal facts

To conceive the productive force of laws as a quiddity means, from the perspective of physics, that it would depend on certain general physical conditions which are fulfilled in the actual world. Such a general condition is the world's time-asymmetric structure, needed for causal productivity in the sense of transfer of energy-momentum.[9]

[8] Regarding universals, Armstrong is a categoricalist/quidditist (cf. Armstrong 1997, Chapters 3–5), that is, just like Lewis, he believes that no property (universal) has its nomological or causal role attached essentially. In the above interpretation (his own!) Armstrong's quidditism holds only with the exception of the second-order universal N: N has its lawmaking role attached essentially (necessarily). "Yet, think now of N as being quidditistic, too. Then we do not only get the above contingency of laws, but also that, in some worlds, N ceases to be necessitation, i.e., that, there, it is no productive force. In such worlds, F's might well not be G's despite N (F, G) because, there, N (F, G) has no necessitating power. Under this interpretation, N would be, at least in our world, pure production, free of any modal connotations." (Schrenk unpublished).

[9] As is well-known, conservation of energy-momentum does not, in general, hold in General Relativity (cf. Wald 1984; Lam 2010). Now, the concept of causality entails 'balanced' change: no change can be causal, if it is not balanced by some equal change, where the measure of equality is, according to the transfer-theory of causation, energy-momentum. But then, according to my identification of laws with causal interactions, laws could only exist within general relativistic spacetimes, if those spacetimes have very special symmetry properties (existence of time-like Killing fields, e.g. in FRW-worlds). Now, the reason for the failure of energy-momentum conservation in a gravitational field is not that energy-momentum is in any sense lost or created ex nihilo (there exists an equation representing 'differential energy conservation' which guarantees that there is no mysterious local loss or creation of energy in the system (cf. Lam 2010, 65)). Instead, a material system moving in spacetime loses or gains energy-momentum "because the gravitational tidal forces can do work on the fluid and may increase or decrease its locally measured energy" (Wald 1984, 70). Thus, the non-conservation of energy-momentum of the material system is generically balanced by the energy-momentum of the gravitational field (whereas in flat spacetimes the energy-momentum of the material system remains constant for each spatio-temporal displacement). What is special about the case of General Relativity is that there is no invariant integral expression for the energy exchange between material system and the field; since gravitational energy can be 'transformed away' locally, the energy contained in a finite volume of spacetime, and thus the quantity of energy exchanged with a material system, depends on the coordinate system. In sum, I argue that processes in a gravitational field can be conceived as causal because no energy-momentum is lost or created – despite the fact that the amount of energy that is exchanged in the interaction with the field can only be determined relative to some coordinates.

Additionally, it is only by the peculiar property of types of elementary interactions to be mutually independent that this productivity is *stable*, i.e. acting irrespectively of the presence of other types of interactions. Stable productivity thus appears as a contingent trait of our world that occurs against the background of physical conditions which are fulfilled as a matter of fact. Mutual independence and thus stable productivity of interactions is not itself required by any law of nature. Rather, there is a successful practice of physics of using Lagrangians for elementary interactions as universal tools of description, even when a system undergoes more than one interaction. The success of this practice is evidence that elementary interactions are, as a matter of fact, mutually independent.

Mutual Independence and thus stable productivity of elementary interactions is the particular factor making natural laws special: It provides them with their supposed modal force, their characteristic ‘recalcitrance’, which, according to Hüttemann (2014), cannot be explained by (at least by open-future) regularity theories.[10] The notion of ‘recalcitrance’ stands for our experience that laws of nature dictate what we can and what we cannot achieve no matter how hard we try to overcome them. Now, mutual independence of interactions explains this experience: The nature of some elementary interaction, expressed by its corresponding Lagrangian,[11] sets restrictions which can neither be overcome by any intervention into accidental background conditions nor by adding further elementary interactions. For instance, how matter couples to gravity (in particular that it couples to all forms of energy in the same way) is determined by the corresponding Lagrangian. No matter how hard we try to overcome the restrictions set by the nature of the interaction, by bringing in some other sort of interaction, what we can achieve is influencing the resulting behavior of some physical system, but not cancelling the restrictions themselves. Thus, mutual independence of interactions explains the experience of recalcitrance and thus the supposed modal force of laws.

Since it is mutual independence (and thus stable productivity) of elementary interactions that grounds the supposed *modal force* of laws, MIA claims that *types of elementary interactions* shall be identified with laws of nature. By proposing that *types of elementary interactions* are the laws of nature, I drop the basic assumption shared both by proponents of the metaphysical necessity and the contingent necessitation view of laws, according to which the modal force of natural laws arises from necessary connections between natural properties. Such necessary connections would *over-explain* the empirical regularities. Since interferences always occur, there are no strict regularities in nature with respect to pairs of occurring property tokens (cf. Schrenk 2010, 2011). Neither causality nor any other natural relation could possibly yield such exceptionless connections. Thus, the modal force of natural laws should, pace Armstrong, *not* be associated with connecting pairs of properties (or states of affairs). MIA is ontologically sparse: it needs neither essentially possessed dispositions nor necessitating relations. Furthermore, whereas it can be doubted that necessitation relations à la Armstrong can be ‘read off’ from natural law equations in some non-arbitrary and unique way, it is a plain fact which type of interaction is represented by some particular law equations.

[10] Cf. Hüttemann (2014), 33 f.

[11] There are also Lagrangians describing ‘free particles’, i.e. the idealized interaction-free case.

Since the mutual independence of interaction types is supposed to be the decisive lawmaking property, further central characteristics of laws should also be reducible to this property. Perhaps the most important one for our scientific practice is that we can use laws to ‘support’ future-directed counterfactuals and thus justify predictions. Recourse to laws seems to legitimize inductive expectations of the future course of events: For example, there is reasonable expectation that if massive bodies A and B were (tomorrow) brought into some relative distance D, a gravitational attraction between them would occur the quantity of which would be proportional to the product of their masses and inversely proportional to D^2.

Now, no genuine modal factor (dispositions or other sorts of metaphysical necessity) is part of MIA that could ground the truth of those counterfactuals. Perhaps the mutual independence, and thus recalcitrance of the gravitational interaction would cease tomorrow – not to mention the possibility that this type of gravitational interaction as we know it would have ceased.[12] But whereas future directed counterfactuals cannot be reasonably supported, MIA allows to *explain the success of past counterfactual reasoning*. Our past evidence to the effect that instances of gravitational interaction have shown up to be ‘recalcitrant’ without exception can best be explained by assuming that gravitational interaction has been one of the mutually independent elementary interactions in nature up to now. Thus we are justified to infer from past evidence to the truth of the respective counterfactuals that have been expressed in the past.

It could be doubted that ‘mutual independence’ is really a *non-modal* property of interactions. Does not mutual independence mean that interactions are in some sense *robust*, and has not robustness to be understood as a counterfactually defined, and thus modal, property? I think that contrary to first impression, the sort of ‘robustness’ that is given by mutual independence can, but not necessarily has to be formulated in a counterfactual way. That a type of interaction, for instance, gravitational interaction has up to the present time behaved independently with respect to all other types of elementary interactions, can exhaustively be expressed by summarizing all past facts about instances of gravitational interaction. In other words: The truth conditions of ‘Gravitational interaction is a type of interaction that is mutually independent from other elementary interactions’ are determined by what was and is presently going on in the actual world. They do not include any counterfactual facts of the sort ‘If there had been an additional planet in the solar system at any past time, there would have been a gravitational interaction between the earth and this planet which …’. Justifiable as those counterfactuals are on the basis of our past experience, as I have claimed before, they do not contribute to the *truth conditions* of the plain claim ‘Gravitational interaction is a mutually independent type of interaction.’ Including counterfactuals in the truth conditions of this claim would amount to treat the property of mutual

[12] It should be noted that, according to Beebee (2011), even modal accounts of laws like essentialist or necessitarian accounts would be unable to overcome the inductive skeptic. A time-limited assumption of necessary connections (the necessary connections have hold *so far*) would provide as good an explanation for the *so far observed* regularities as the corresponding timeless assumption. But the time-limited assumption would then be compatible with the possibility that the necessary connections would cease tomorrow. Thus time-limited necessary connections cannot support inductive inferences to the future, but they can (at least) explain the success of our *past* inductive practice. Since I accept this point, I cannot require my own account, which includes not even any genuine modal factor, to do better than to explain the past inductive practice, i.e. to give a reason for the fact that former law-based counterfactuals had been justified.

independence as a *disposition* of this interaction-type. This would be a possible move, but it is not a necessary move and it will not be taken here.

Within physics, there exists a canonical characterization of elementary interactions (and thus laws of nature) by means of their corresponding Lagrangians. Each form of Lagrangian characterizes a unique type of physical interactions and informs about everything that makes up the nature of that interaction-type.

Electron-photon-interactions, for instance, are a type of interactions that have, according to Quantum Electrodynamics (QED), a unique (and therefore identifying) representation in form of the well-defined Lagrangian L_{QED}, including a Dirac-term for the electron, a Maxwell-term for the electromagnetic field, and a specific interaction term $L_{int} = -e\psi^*\gamma^\mu\psi A_\mu$ (e representing the charge of the electron, ψ the state of the electron, and A_μ the vector potential of the electromagnetic field). This type of interactions, as it appears e.g. in case of synchrotron radiation, is a law of nature as represented by L_{QED}.

Now, one may suspect that MIA turns out to provide just another label for a *sophisticated regularity theory*. Carving out instances of types of elementary interactions of the totality of physical events and identifying those types with the natural laws, may read like a manual for the construction of a 'best' systematization of our empirical evidence. Thus, my approach has something in common with a best system-analysis.[13] But unlike a best system-approach, the natural laws are not just conceived as a conceptual structure, a device to systematize our empirical knowledge. Rather, in line with Armstrong's approach, each law of nature is a first-order-universal, an abstraction from particular interactions which instantiate this universal. Since the law will be "fully present in each instantiation",[14] MIA proposes an ontic understanding of laws. Law-instantiations are concrete physical interactions that get their supposed modal force by means of their natural non-modal property of mutual independence.

4 Against the metaphysical necessity of laws

In Sections 2 and 3, I have argued that drawing the lessons of Armstrong's theory of natural laws paves the way for a new approach anchoring the modal force of laws in the physical nature of elementary interactions. Now, there is another option that has not come into play yet: Explaining the modal force of laws by essential dispositions of natural properties producing other properties with metaphysical necessity (cf. Bird 2007). In the following, I will shortly review some arguments telling against *metaphysical necessity*-approaches to the modal force of laws.

The *first* objection is that it seems to be implausible to assign metaphysical necessity to *all* sorts of laws. Some philosophers would take, for instance, *Electrons are negatively charged* as exemplifying metaphysical necessity: That electrons are negatively charged, follows, they would say, from their essential dispositional nature or from the nature of the natural kind they form. Plausible as this might seem, it remains to be shown that the proposition exemplifies a law of nature. Now, this seems to be much less plausible; instead we would rather intuitively classify it as a case of some factual

[13] Cf. Lewis (1973).
[14] Cf. Armstrong (1983), 89.

truth about certain kinds of particles, albeit some metaphysically necessary truth.[15] Such metaphysically necessary factual truths about certain kinds of objects are exactly *not* what we would intuitively like to call a law of nature.[16] On the other hand, *conservation of energy* would be a much more plausible candidate for being a law of nature (possibly even one with a very strong modal status, according to Lange!), but conservation of energy is *not* metaphysically necessary in the way that *Electrons are negatively charged* is: It does not follow from what energy *is* that it must be conserved (see more about that in Chapter 6).

A *second* objection has been raised by Tahko (2015) who claims that at least not all laws are metaphysically necessary. He argues that evidence from physics tells us that the values of certain natural constants may have changed over time in the history of our universe.[17] This weakens the claim of metaphysical necessity for fundamental laws which those natural constants are part of: If natural constants, and thus the content of fundamental laws, can change over time, this speaks in favor of their *contingency* rather than their metaphysical necessity. It seems conceivable then that at least in other (metaphysically) possible worlds the natural constants could appear with values different from those in the actual world:

> "[…] actual variation over time constitutes at least prima facie evidence for variation over metaphysically possible worlds. That is, given the actual variation of α [the *fine structure constant*] over time, it does not seem to be unreasonable to imagine, say, that α could've had a different initial value and perhaps also a different rate of change over time. If this is the case, then it would appear to be easy to imagine that the laws of nature that involve the fine structure constant could have been different […]."[18]

The inference from changeability to contingency is for sure not conclusive – there is always the way out to insist that possible 'changeable' laws could not be the *final* laws the latter being metaphysically necessary. But, nevertheless there seems to be at least some tension between metaphysically necessary laws and changeability of fundamental constants.

A *third* objection has been raised by Kit Fine (2002). He argues that claims for metaphysical necessity of laws are in danger of trivialization: If someone claims that, for example, Newton's law of gravitation is metaphysically necessary in virtue of the necessary connection of the property of mass with that form of gravitational law, then any claim to the contrary (e.g., the claim that mass could be well conceived as connected with an inverse r^3-law of gravitation) could be *too easily* dismissed by stipulating that 'mass' connected with inverse r^3-dependence would represent not *mass*, but some different property, say *schmass*. Assumptions of metaphysical necessity are thus too much of a free lunch: they can be restored against possible objections by mere stipulation.

[15] Wolff (2013), 901.
[16] The term ‚electron' has been coined by Stoney for the ‚atom of electricity', i.e. for the then hypothetical bearer of elementary (negative) electrical charge. Thus, literally understood, ‚Electrons are negatively charged'is an analytical truth.
[17] Tahko (2015), 520.
[18] Tahko (2015), 520.

This list of objections to claims of metaphysical necessity for laws, even if not complete, seems to disqualify metaphysical necessity as a general mark of lawfulness. This would let open the possibility of a *mixed (or: hybrid*[19]*) theory*, according to which *some* laws would be metaphysically necessary whereas others would not. But, this move would then require, first of all, some different demarcation criterion of lawfulness (with respect to empirical regularities) which would be independent from metaphysical necessity/contingency, i.e. we should be able to know, whether some empirical truth is a law of nature or not, independently of whether it holds by metaphysical necessity or not. This shows that a mixed theory would not really take us any step further in understanding what laws of nature are.

5 Constraint laws and compositional laws

What about *constraint laws* constraining how the values of different variables are related at some given instant of time (examples are the Boyle-Charles-law for ideal gases $pV = kT$ and the Maxwell-equation Div $E = \rho$)? Those laws apparently do not represent causal interactions. With respect to these possible counterexamples, the answer is that, for the representation of causal interactions, we need both, constraint laws and laws that govern the temporal evolution of systems. Thus the complete Maxwell-equations of classical electromagnetism as much as Einstein's field equations can be divided into constraint equations that "impose conditions on instantaneous initial data" and dynamical equations "governing the temporal evolution of the data".[20] No part can work without the other. Constraint laws do not determine any dynamics in isolation, but as a constitutive part of a complete set of field equations (or of the corresponding Lagrangian) they contribute to the equations of motions that can be derived from that field equations (or the Lagrangian, respectively). Modal force (in the sense of MIA), and thus lawful status, first of all belongs to types of *interactions* which are represented by specific Lagrangians and laws of motion derived from them, not by some isolated components thereof.

Another example of supposed non-causal laws are *composition laws*. Take, e.g., the superposition principle for forces in classical Newtonian Mechanics. This principle does not follow from Newton's axioms and has thus to be added as an independent requirement to the effect that the totality of Newtonian forces being present in some application must be represented by the vector sum of the single forces. What has been claimed for constraint laws is also true for compositional laws: they are a constitutive part of a comprehensive system of equations that as a whole can represent causal interactions. Neither can we derive anything informative about the dynamics of particle systems only by means of the superposition principle, nor can we get the dynamics without using the superposition principle. The principle belongs to the rules of application of Newtonian Mechanics. The same applies, for instance, to the superposition principle in Quantum Mechanics: It tells us how to apply the Hilbert space formalism to quantum mechanical states.

[19] Cf. Tahko (2015).
[20] Cf. Earman (1995), 125–126.

There are also ‘composition laws’ that do not tell us how to compose theoretical elements within *one* theory in order to construct a complete representation of certain interactions, but instead how to combine laws of *different* theories. What, for instance, is the combined representation of a process that is governed by both, electromagnetic and gravitational forces? Do we have, in those cases, independent composition laws that have to be added to the ‘pure’ laws of the separate theories?

Take for instance the case of gravitational interaction combined with electromagnetic interaction. What is searched for, in this case, is not any particular ‘law of composition’. Instead, the nature of gravitation, according to general relativity, dictates that the classical Maxwell-equations have to be written in some generally invariant form. There is a very elegant and simple way to do that, namely by replacing the Minkowski metric tensor $\eta_{\mu\nu}$ by the metric tensor of general relativity, $g_{\mu\nu}$, and the ordinary derivatives by covariant derivatives[21]; this procedure follows the ‘minimal coupling principle’, but the principle is unreliable and at most of some heuristic value. There are possible alternative formulations that cannot be excluded by means of general principles, but by empirical reasons only.

Thus, what we have is not really a ‘composition of laws’ from different theories, but the *extension* of a theory that holds in the case of vanishing gravitational influences to a more comprehensive theory representing full physical reality including the gravitational field. The assumption that there are ‘composition laws’ in those cases reveals a somewhat distorted picture of what happens when physical theories are extended. Extending a theory is a process of theory construction that may follow some more or less general recipes, but there are no laws that govern such processes. The supposed ‘composition laws’ are in a sense ‘included’ in the Lagrangians of the extended theories (as in our example, in the Lagrangian of QED) in form of *interaction terms*. Thus, no ‘laws’ have to be added to the ‘pure’ interaction-free laws, but the interactions are a constitutive part of the laws of those theories that cover more than one fundamental field.

6 Symmetries and conservation laws

There is another group of possible counterexamples usually classified as laws of nature to which, on the one hand, many would assign an even higher degree of ‘necessity’ as compared to causal laws (and thus would qualify them as laws even in some preeminent sense), whereas on the other hand, they seem to lack the sort of modal force required for laws according to my approach. These are *symmetry principles* and *conservation laws* for energy, momentum, charge etc., which derive from the fulfillment of symmetry principles.

According to Wigner (2003), laws of nature are related to events in a similar way as symmetries are related to laws of nature: “If we knew what the position of a planet will be at any given time, there would remain nothing for the laws of physics to tell us about the motion of that planet”.[22]

[21] Cf. Ohanian (1976), 259.
[22] Wigner (2003), 24.

Being not in the position of complete knowledge about the positions of the planet, the law tells us what future positions of the planet we have to expect, but the law does not add thereby anything to the totality of planet positions. In a similar way, symmetry or invariance principles do not add anything to the content of the equations fulfilling those principles:

> "It may be interesting to note that the correlations between events which the equations predict are the same no matter whether the events are viewed by an observer at rest, or an observer in uniform motion. However, all the correlations between events are already given by the equations themselves […]. More generally, if we knew all the laws of nature […] the invariance properties of these laws would not furnish us new information."[23]

If Wigner is right in stressing that symmetry or invariance principles do not contain any information that is not already contained in the laws, then it seems that these principles would have to be classified as *meta-laws* in the sense that they represent, first of all, properties of *laws,* not of physical *events*. This line of argument needs a bit of qualification. Since symmetry or invariance properties, like any other general properties of laws, do not only tell something about laws, but also constrain the sort of lawfully possible physical *interactions*, their being 'about laws' does not disqualify them per se from being laws themselves.

On the other hand, symmetry principles represent *general* constraints for physical interactions, not any *specific* dynamics; they cover whole classes of interaction-types with various dynamical properties. Since modal force is always connected to a *specific* type of physical interactions with its particular dynamics (encoded by its related Lagrangian), we cannot ascribe modal force to symmetry principles. Despite their imposing constraints on physical interactions, they disqualify as laws of nature because they do not contain any specific dynamical information.

What has been said so far is addressed in particular to global (in Wigner's terms 'geometrical') symmetries. But what about the *local* 'dynamical' symmetries of modern physics? They seem to be much more intimately connected to the dynamics than classical *global* 'geometrical' symmetries. Whereas classical global symmetry principles have been deduced from the laws of nature, as Wigner noticed, physicists today try to deduce the laws of nature from symmetry principles[24]: "Often symmetries found in experiments, together with other principles of theory construction […] determine the Lagrangian, i.e. the fundamental law of the theory."[25] […] "For example, the only Lorentz invariant and gauge invariant renormalizable Lagrangian for photons and electrons is precisely the original Dirac Lagrangian […] Gauge theories are good examples for deriving the dynamics of a theory with the help of symmetry principles".[26] While symmetry principles are strongly involved in the construction of Lagrangians, the dynamics cannot be completely deduced from those principles.[27] What has to be added is the background of forerunner theories (in case of quantum

[23] Wigner (2003), 25.
[24] Cf. Stöckler (1997), 346.
[25] Stöckler (1997), 347.
[26] Stöckler (1997), 346.
[27] Stöckler (1997), 347.

field theory this is classical mechanics as much as QED); the forerunner theories provide the general scheme that has to be fitted to the requirements of a theory extension by the help of symmetry principles (as, for instance, the principle of general invariance as a means of extending the equation of classical Maxwell-theory to the effects of gravitation on electromagnetic phenomena[28]). Thus, even if (local) dynamical symmetries are (partly) constitutive of the respective Lagrangians, they do not 'contain' complete information of a particular dynamics – even though being more specialized than global ones, they do not single out one particular type of physical interactions.

The conclusion is that neither global nor local (dynamical) symmetry principles determine any specific dynamics, and thus, according to our requirement that laws of nature be characterized by their modal force, symmetry principles cannot be laws of nature, without thereby disregarding their decisive role for the development of modern physics. This is true *a fortiori* for theorems that are consequences following from the validity of symmetry principles. A case is *Pauli's principle*, often cited as a case for the supposed existence of non-causal laws of nature. Pauli's principle follows directly from the permutation symmetry for many particle quantum states requiring an anti-symmetric state representation for fermion states.

The existence of conserved quantities is a further consequence of central importance in physics that follows from the fact that various symmetry principles apply to certain equations of motions. Noether's[29] first theorem says that for every continuous *global* symmetry (a symmetry depending on a constant parameter) of the Euler-Lagrange equations associated with a Lagrangian L one gets a continuity equation for a so called Noether current from which "integrating over an entire space-like surface we obtain [….] conservation of the associated Noether charge".[30] In such a way the spatial translation, spatial rotation and time translation symmetries in classical particle mechanics are connected to the conservation of linear momentum, angular momentum, and energy, respectively. Now, the existence of conserved quantities is thereby strongly dependent on the conditions required for the validity of the Noether relations, and these conditions are that all fields appearing in the theory, as represented by the respective Lagrangian, satisfy Euler-Lagrange equations of motions. Thus, the existence of conserved quantities is dependent on the particular *dynamics*: If, and only if, the dynamics of the physical systems involved is of Euler-Lagrange-type, then the invariance of the Lagrangian with respect to certain groups of symmetry transformations grounds the conservation of the respective quantities. Energy conservation, for instance, does not hold with metaphysical necessity, as long as we do not assume that particular Euler-Lagrange equations grounding it hold with metaphysical necessity. Nor do conservation laws contain any genuine dynamical information, they hold in virtue of the fact that the dynamics is of Euler-Lagrange–type and has particular symmetry properties.

Conservation laws thus provide a *weaker* sort of constraint for physical systems as compared to particular dynamical laws – they would remain valid, if the dynamical laws were different, as long as those different laws would be of Lagrange-Euler-type

[28] Ohanian (1976), 258.
[29] See: Noether (1918).
[30] Brading and Brown (2003), 97.

and the respective symmetry properties would apply; in this sense they are 'meta-laws'. Just as the symmetries from which they derive they classify dynamical laws under the heading of some general property; they are neither particular dynamical laws, nor do they embody some higher degree of necessity.

At first sight, the situation concerning metaphysical necessity of conservation laws might look somewhat different with respect to *local* symmetries and Noether's second law that applies to them. Conservation of electric charge in QED can be derived from a local gauge symmetry of the wave function (the respective Lagrangian is not invariant with respect to this local transformations, but, in order to restore invariance, has to be modified by an interaction term representing the interaction of charged matter with the electromagnetic field). Now, as Wolff (2013) has argued "in the case of theories with local symmetries […] we do not require the equations of motion in order for the conservation laws to be derived. Now it seems that the conservation laws hold just in virtue of mathematics […] If the conservation laws hold as a matter of mathematics, it […] seems that conservation laws might be metaphysically necessary after all".[31] Wolff is right about the fact that in the case of local symmetries the derivation of the Noether current leads to an expression including two terms, the second one of which vanishes identically (by mathematical reasons).[32] This term represents the connection of two physical fields – in the case of QED these are the current of the matter fields and the electromagnetic field. In this case, Noether's equation for the Noether current requires the electromagnetic field tensor to be a symmetric object. This might be a natural requirement, but nevertheless it is a requirement on physical fields and therefore has well-determined physical significance. In any case, it is not true that the conservation laws hold "just in virtue of mathematics". This becomes clear all the more by taking sight of the first term. This term vanishes if the Euler-Lagrange equations are satisfied. Thus, just as in the case of global symmetries, the respective conservation law holds only if the equations of motions are of Euler-Lagrange–type and are invariant with respect to particular symmetries. But the requirements are even stronger in this case, because of the condition for the interacting fields. All these requirements are physical in nature; they do not follow from pure mathematics. Therefore, Wolff's conclusion to the metaphysical necessity of conservation laws is unjustified.

7 Conclusion

As explained in Chapter 6, neither global nor local (dynamical) symmetry principles determine any *specific* dynamics. Thus, if we require that laws of nature be types of elementary interactions, demarcated from empirical regularities by their *modal force*, those principles cannot be conceived of as laws of nature. This does not amount to disregarding their decisive role for the development of modern physics. Nor would I deny that this conclusion is in tension with common linguistic convention. But my aim, in this paper, was not first of all to do justice to all of the sometimes controversial linguistic conventions concerning the notion of a natural law. My aim instead was to show that there is a possible explication of 'natural law' such that natural laws so

[31] cf. Wolff (2013), 904/05.
[32] Brading and Brown (2003), 102.

conceived can be demarcated from empirical regularities by their *modal force*. According to MIA, natural laws are identified with types of elementary interactions. The modal force of these types of interactions is grounded in the contingent fact that their causal productivity is stable on the basis of their mutual independence. As a result, the modal force of laws can be explained without any recourse to genuine metaphysical features like dispositions or necessitation, just by means of contingent facts of our world.

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