6. "There sweep great general principles which all the laws seem to follow"

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My title is taken from a passage in Richard Feynman's classic book, *The Character of Physical Law*:

> When learning about the laws of physics you find that there are a large number of complicated and detailed laws, laws of gravitation, of electricity and magnetism, nuclear interactions, and so on, but across the variety of these detailed laws there sweep great general principles which all the laws seem to follow. Examples of these are the principles of conservation . . . (Feynman 1967, 59)

My aim in this paper is to understand this conception of the conservation laws and to examine what it reveals about the character of physical law generally—in particular, about the laws' modality, their explanatory role, and the adequacy of the dispositional essentialist conception of laws as metaphysical necessities arising from the causal powers essential to the sparse fundamental properties of physics.

My main positive result is that science recognizes an important distinction: between conservation laws as *constraints* on the fundamental forces there could be, on the one hand, and conservation laws as *coincidences* of the fundamental forces there happen to be, on the other hand. In the above passage, Feynman characterizes conservation laws as constraints. I do not argue that they are constraints; on my view, this is a matter for science, not metaphysics, to decide. However, I argue that some conservation laws have sometimes been taken (with good reason) to be constraints, that their status as constraints would make an important difference to their role in scientific explanations, and that the distinction between constraints and coincidences applies to other laws besides the conservation laws. I ultimately cash out the distinction between constraints and coincidences in terms of the truth of various counterfactual conditionals, and I briefly sketch how this way of elaborating the distinction relates to my broader account of natural law (Lange 2009).

My main negative result is that metaphysical pictures along the lines defended recently by Alexander Bird (2007), Brian Ellis (2001, 2002), and Stephen Mumford (2004)—for which, despite some disagreements among these authors, I will use the catch-all term "dispositional essentialism"—cannot accommodate the distinction between constraints and coincidences. Such a picture must portray all conservation laws as coincidences. It thus forecloses options that science has (with good reason) taken seriously. This failure is a weighty count against dispositional essentialism.

1. CONSTRAINTS VERSUS COINCIDENCES

Consider the law of energy conservation. (I could just as well have chosen any of the other conservation laws that have been proposed in the history of physics, such as the conservation of linear momentum, angular momentum, electric charge, mass, parity, baryon number, or lepton number.) As Feynman emphasizes, though the various kinds of fundamental interaction differ in a host of ways (in their range, their strength, the kinds of bodies that participate in them, and so forth), they are all alike in conserving energy. As convenient examples of kinds of fundamental interactions, I shall follow Feynman and take gravitational and electric interactions as described in classical physics by Newton's gravitational-force law and (in the static case) Coulomb's law, respectively. Despite their differences, these two types of interactions are alike in both conserving energy. Of course, gravity is not in fact a force at all according to general relativity, and electric and magnetic forces are not actually distinct kinds of force according to special relativity. But none of this matters to my argument. I shall be appealing to these two forces only to illustrate my claim that physical theory recognizes an important distinction between two different ways in which a law like energy conservation could hold: as a constraint or as a coincidence. I contend that any metaphysical account of natural law should leave room for both of these possibilities. The same distinction must be drawn whatever the fundamental forces actually are—indeed, even if there is in fact only a single kind of fundamental force (a “grand unified field”).

Why are gravitational and electric interactions alike in conserving energy? Here are two possible explanations.

1. Gravitational interactions conserve energy because the gravitational force law requires them to. Electric interactions conserve energy because the electric force law requires them to.[1] The two interactions are therefore alike in conserving energy—but for separate reasons.
2. Both kinds of interaction conserve energy for the same reason: because the law of energy conservation requires them to.

On the first option, it is just a *coincidence* that these two different forces conserve energy, since there is no common explanation of their doing so. Just as it would be a coincidence for two friends both to be in Chicago on the same day if there was no important common reason for their both being there then (e.g., they had made no plans to meet there, they were not both attending the same convention), so likewise it is a coincidence for various distinct forces all to conserve energy if there is no important common “cause”, but rather each does so for a substantially separate reason.[2] On the second option, in contrast, the law of energy conservation is not a coincidence. Rather, the various fundamental kinds of interaction all have a common reason for conserving energy: the conservation law.

[1] The force law alone is not enough to entail that the interaction will conserve energy. The explanation must also appeal to the fundamental dynamical law: the law relating forces to the motions they cause (in classical physics: Newton’s second law of motion).

[2] I say “important” and “substantially” in order to acknowledge that two components of a coincidence may have some explainers in common—as long as they are beside the point in the context in which an explanation of the two components is being demanded. For instance, suppose that the two friends both happened to travel to Chicago on the same airplane flight. Then there would be some common explainers of their both being there (e.g., the flight, the natural laws governing jet engines). But these are not the sorts of explainers that we would (ordinarily) be asking for in asking “What brings you to Chicago?” Likewise, although the fundamental dynamical law (see note 1) is common to the explanation that gravitational interactions conserve energy and to the explanation that electric interactions conserve energy, it is incidental; the force laws involved would (typically) be the focus of our explanatory demand. Hence, it is a coincidence that both forces conserve energy.

It is a *constraint* on the forces. That is, the law of energy conservation limits the kinds of forces there could have been. The only kinds of force there could have been are forces that conserve energy, and that is why every kind of force there actually is conserves energy.

The difference between constraint and coincidence is a difference in what is explanatorily prior to what. If energy conservation is a coincidence, then the various force laws are explanatorily prior to the law of energy conservation. On the other hand, if energy conservation constrains the force laws, then the conservation law is explanatorily prior to them. It does not entail the particular force laws there are, but it explains why they each exhibit a certain feature. These two options (constraint or coincidence), then, are mutually exclusive.[3]

However, these two options are alike in one important respect: whichever option holds, the law of energy conservation is physically necessary—a law rather than an accident. As a coincidence, the conservation law is physically necessary in virtue of following exclusively from laws, such as the gravitational-force law, the electric-force law, and the law that all fundamental forces are gravitational or electric or . . . (a "closure law"). As a constraint on the force laws, the conservation law transcends the grubby, pedestrian details of the various particular force laws. It is a higher-order law, as Feynman suggests. It does not depend on the kinds of forces there actually happen to be. It limits the possible kinds of forces.

Since the difference between constraint and coincidence is a difference in explanatory priority, the conservation law's status as con-

[3] They are not collectively exhaustive. Rather, they are the extremes; there are intermediate cases. For instance, suppose that some fundamental kinds of interactions have a certain feature (e.g., are capable of both attraction and repulsion) whereas others (namely, interactions A, B, and C) do not have this feature. Suppose it is a law that every kind of interaction with that feature conserves energy, and suppose that law is a constraint. Then the fact that every kind of interaction conserves energy might be explained by this constraint together with A's force law, B's force law, and C's force law (along with the fundamental dynamical law). In that case, energy conservation is neither a complete coincidence nor a constraint. As another kind of intermediate case, the law of energy conservation might follow from exactly two separate constraints (e.g., that all of the forces capable of both attraction and repulsion must conserve energy, and that all of the forces capable only of attraction or only of repulsion must conserve energy). For the sake of simplicity, I shall not return to these intermediate possibilities, but I believe that it is clear how my remarks apply to them.

straint or coincidence makes a difference to whether certain arguments carry explanatory power. It makes a difference to the success of many putative explanations well beyond whether the conservation law explains why gravitational and electric interactions both conserve energy. Consider the fact that an ideally incompressible, nonviscous fluid in a container at rest in a uniform downward gravitational field is not undergoing any circulation; none of its parcels at the top feels an unbalanced force pulling it downward, nor do any bottom parcels feel unbalanced forces pushing them upward. Why is that?[4] If energy conservation is a constraint, then it explains why. A force arising from no outside agency that would make the fluid parcels begin to circulate from rest would violate energy conservation: in beginning to circulate, the parcels' kinetic energy would increase but their total potential energy would be unchanged. (As ascending parcels gain gravitational potential energy, descending parcels lose an equal quantity of it.) Energy conservation as a constraint rules out any circulation-inducing force.

However, as a coincidence, energy conservation cannot supply this explanation. If energy conservation is a coincidence, then the reason why the fluid undergoes no circulation is that electric forces fail to induce circulation (because of the electric-force law), gravitational forces fail to induce circulation (because of the gravitational-force law), and so forth for all of the actual kinds of forces experienced by the fluid parcels. This is a "bottom-up", causal/mechanical explanation. As a coincidence, the general principle of energy conservation cannot figure in such an explanation. It cannot explain why various kinds of fundamental force are alike in failing to induce fluid circulation, since as a coincidence rather than a constraint, it is not explanatorily prior to the force laws. The reason why electric forces fail to induce circulation (and the reason why they conserve energy) is not the coincidence that all forces conserve energy; it is the electric-force law.

Suppose that, instead of trying to take the comprehensive conservation law and slot it into the explanation somewhere explanatorily prior to the force laws, we try to place it somewhere explanatorily

[4] The explanandum is a scientifically significant fact; it is not a fact that only a philosopher would inquire into. (Don't pretend that you don't know what I mean!) For example, it is central to the reason why Archimedes' Principle holds.

posterior to the force laws. Then we encounter a different problem. The fluid parcels feel gravitational forces, so the fact that gravitational forces conserve energy may help to explain why there are no circulation-inducing forces. But if the fluid parcels feel no magnetic forces, then the fact that magnetic forces conserve energy does not help to explain why there are no circulation-inducing forces. If the conservation law is just a coincidence, then it is effectively the fact that gravitational forces conserve energy, magnetic forces conserve energy, and so forth for all of the actual kinds of forces. But if some of these forces are not experienced by the fluid parcels, then the fact that they conserve energy is not explanatorily relevant, and so neither is the general principle of energy conservation. For a coincidence to be explanatorily relevant to an outcome, all of its components must be relevant. For instance, the reason why you and I ran into each other at the mall this afternoon might be the coincidence that you and I both chose this day to go shopping there—but the coincidence that you, I, and Frank all chose this day to shop there does not explain why you and I encountered each other there. As a coincidence of the various kinds of fundamental forces, the conservation law explains only if all of those forces are explanatorily relevant.

Suppose, then, that the fluid parcels feel every species of fundamental force so that every component of the energy-conservation coincidence is explanatorily relevant. Then the resulting explanation from energy conservation would still not be a top-down explanation. Rather, it would have to include the fact that each of these forces is actually felt by the fluid parcels. The top-down explanation does not specify which kinds of fundamental force the fluid parcels experience. Its point is that the outcome does not depend on what possible forces are actually at work; no matter which possible forces were operating on the fluid parcels, the fluid would inevitably still fail to circulate.

If energy conservation is a coincidence, then the reason why the fluid undergoes no circulation is that electric forces fail to induce circulation (because of the electric-force law), gravitational forces fail to induce circulation (because of the gravitational-force law), and so forth for all of the kinds of forces actually experienced by the fluid parcels. In contrast, if energy conservation is a constraint, then this bottom-up argument (though, of course, still sound) does not explain why the fluid is not circulating because it would then inaccurately depict the explanandum as depending on the particular kinds of forces that happen to be acting on fluid parcels. The only explanation is a top-down explanation: that any circulation-inducing force would violate energy conservation, which is impossible. Here is an analogy. Consider Jones and Smith, each convicted in separate trials before separate judges of possessing (independently) 100 kilograms of marijuana. Why did each of them receive a sentence exceeding five years? The reason is not that Smith's judge passed this sentence because he believed that Smith's crime rose to a certain level of seriousness because of various factors including . . . and Jones's judge passed this sentence because he believed that Jones's crime rose to a certain level of seriousness because . . . *if* the two judges were constrained by a mandatory minimum sentencing law to pass sentences of at least five years for the possession of 100 kilograms of marijuana. If there is such a law, then it is no coincidence that the two judges handed down sentences that are alike in this respect. Rather, the law is a common explainer—and any account is mistaken if it depicts the two sentences as the products of independent judicial decisions that weighed the particulars of the individual cases.

The success of various proposed top-down scientific explanations, then, depends upon the status of energy conservation as a constraint. Even if energy conservation is a coincidence, the law that gravitational forces conserve energy could still be used to help explain why the fluid does not circulate. But this explanation would simply be a bottom-up account that portrays the fact that the fluid does not circulate as arising from the coincidence that each of the particular kinds of forces acting on the fluid conserves energy. In contrast, if energy conservation is a constraint, then the fact that the fluid fails to circulate does not depend on the particular kinds of forces at work on it.

Here is another way to bring out this contrast. Consider a wooden block (of any shape) sitting on top of a post, and suppose that across the upper surface of the block is laid part of a uniform loop of rope (or chain), while the rest of the loop hangs below the block, experiencing uniform downward gravity. Why does the rope loop, having been laid across the block, not spontaneously begin to turn round and round the block?[5] If energy conservation is a constraint, then it explains why no force puts the rope loop into circulation: any such force is ruled out by energy conservation for exactly the same reason as it precludes a force inducing spontaneous fluid circulation. However, if energy conservation is a coincidence, then this explanation is unavailable. Energy conservation does not help to explain features of the force laws. Instead, the explanation is that one kind of force felt by the rope fails to induce circulation, another also (for independent reasons) fails to do so, and so forth for all of the kinds of forces at work on the rope. This explanation may involve different kinds of fundamental forces from the corresponding explanation of the fluid's behavior; different forces may be at work on ropes and fluids. Therefore, the bottom-up explanations do not unify these two cases. In contrast, the top-down explanations not only unify these two phenomena under the same explainer (the law of energy conservation), but also unify them further by giving them explanations of the very same form.

My point is that whether energy conservation is a constraint or a coincidence makes a big difference to features of the world that science cares greatly about: to the kinds of explanations that there are and to the unifications that those explanations bring.[6] These are matters for empirical work to discover. I am not arguing that if every single fundamental kind of force conserves energy, then this "conspiracy" is unlikely to be a coincidence – that it probably has a

[5] The explanandum is a very important fact. For example, it is central to Simon Stevin's 1586 *clootcrans* explanation of the law of the inclined plane (Stevin, 1955, Vol. 1, 178).

[6] If we believe that energy conservation is a constraint if it is true, then we are prepared to confirm the hypothesis that energy is conserved very differently than if we believe it is a coincidence if it is true. Roughly speaking, if we believe that energy conservation is a coincidence if it is true, then we regard the fact that one fundamental kind of interaction conserves energy as no evidence that another kind does (just as we take my being in Chicago as no evidence that you are there, too, if we believe that our both being there would be coincidental). However, if we believe that energy conservation might be a constraint, then we may take the fact that one fundamental kind of interaction conserves energy as some evidence that another kind also does. Feynman (1967, 76) says that we are "confident that, because we have checked the energy conservation here, when we get a new phenomenon we can say it has to satisfy the law of conservation of energy." A good example of such a new phenomenon was radioactive decay which physicists believed to conserve energy before they had any significant confidence in any theories regarding the particular force(s) involved.

common "cause". I insist only that the hypothesis positing such a constraint is sometimes a reasonable one to entertain, that science has frequently taken such hypotheses seriously, and that therefore metaphysics should not foreclose such hypotheses.

A conservation law need not be a brute fact in order for it to be a constraint. It may have an explanation. In fact, one way for a conservation law to be a constraint is for it to arise from a symmetry principle, since if it so arises, then each of the actual forces conserves the relevant quantity for the same reason: because of the symmetry principle. As is well known, various classical conservation laws follow from various space-time symmetries within a Hamiltonian dynamical framework: energy conservation follows from the laws' invariance under arbitrary temporal displacement, linear momentum conservation from their invariance under arbitrary spatial displacement, and so forth. If these derivations explain why the conservation laws hold (as they are often said to do), then the conservation laws are constraints, not coincidences. As Eugene Wigner says:

> [F]or those [conservation laws] which derive from the geometrical principles of invariance it is clear that their validity transcends that of any special theory—gravitational, electromagnetic, etc.—which are only loosely connected. (Wigner 1972, 13)

In other words, Wigner contends that those symmetries are not coincidences of the particular kinds of forces there happen to be, and so the associated conservation laws transcend the idiosyncrasies of the force laws figuring in bottom-up explanations.

2. OTHER POSSIBLE KINDS OF CONSTRAINTS BESIDES CONSERVATION LAWS

Conservation laws are not the only "great general principles" that have sometimes been reasonably thought to "sweep" across the various force laws, explaining why all of those laws share certain features. One candidate proposed by Heinrich Hertz may not turn out to succeed. But an adequate metaphysical account of natural law must at least leave room for explanations of the kind Hertz proposed.

Newton's gravitational-force law is an inverse-square law. So is Coulomb's law for the electric force between two point charges at rest. So is Ampere's law for the magnetic force between two electric-current elements. In his 1884 lectures delivered at Kiel, Hertz said that (as far as science has been able to discover) all fundamental force laws are inverse-square—and that this regularity has never been thought coincidental [zufällig] (Hertz 1999, 68).

What could Hertz have meant by this? Presumably, he did not mean that no one has thought this regularity to be physically unnecessary—since although this is true, it is a trivial remark: obviously, no regularity among the force laws could be accidental. The laws alone must suffice to logically entail any such regularity. Rather, I suggest, Hertz meant that the inverse-square character of all of the fundamental forces has always been considered to be a *constraint*, not a *coincidence*. In other words, Hertz meant that there is (according to widespread consensus) a common explanation for each force's being inverse-square; they are not independently inverse-square.

This interpretation of Hertz's remark is confirmed by his characterizing this regularity among the various fundamental forces as too remarkable for its instances not to have a common explainer: "Is it not marvelous [wunderbar] that all long-range forces follow [an inverse-square] law?" (Hertz 1999, 68). Indeed, Hertz immediately suggests one possible common explainer: "Kant and many others before and after him have tried to relate this feature [the inverse-square character of the force laws] to the three-dimensional nature of space." But whereas Kant offers the inverse-square character of forces as explaining why space is three-dimensional (see Callendar 2005), Hertz proposes that explanatory priority runs in the opposite direction.

Hertz's proposed explanation begins with another regularity among the fundamental forces that he takes to be a constraint on any force there might have been rather than a coincidence of the various forces there actually are: that every fundamental force acts by contact—that is, by a field acting at the same point in spacetime as the force that it causes, so that the field causally mediates between the two, perhaps spatiotemporally widely separated bodies thereby interacting (see Lange 2002). In other words, Hertz's explanation begins with the premise that none of the fundamental kinds of interaction constitutes action at a spatiotemporal distance. In fact, Hertz presents himself as arguing for this premise by inference to the best explanation: the most plausible explanation of the "marvelous" fact that all fundamental forces are inverse-square is that all fundamental forces must operate by contact action.

In his Kiel lectures, Hertz does not say anything about why, in turn, all fundamental forces must operate by contact action. But to fund his explanation of the inverse-square character of all fundamental forces, this contact-action regularity must also be a constraint rather than a coincidence. For if it were a coincidence, then it could not be a *common* reason why every force is inverse-square. At best, the electric-force law would be inverse-square because electric charges interact by contact (i.e., through the electric field at each charge's location), the gravitational-force law would be inverse-square because gravity acts by contact, and so forth. In that case, it would be a *coincidence* that all of the fundamental forces are inverse-square, contrary to Hertz's view (following a broad consensus, Hertz says) that this regularity is no coincidence.

How is the constraint that all forces be inverse-square supposed to be explained by the constraint that all forces act by contact (in three-dimensional space)? Consider a configuration of bodies and any imaginary surface enclosing them. If a given sort of influence operates by contact action, then the influence of those bodies on any body outside of the surface must pass through the intervening surface (rather than hop "over" it). Therefore, the field at all points on the surface must fix the influence of the enclosed bodies on any body outside of the surface. Hence, any two configurations with the same field at all points on the surface must have the same field everywhere outside of the surface. The existence of such a "uniqueness theorem" (as it is commonly called today) imposes strict limits on the form that the force law can take. As Hertz (1999, 68) rightly notes, the requirement that there be a uniqueness theorem rules out a force that declines linearly with distance or with the cube of the distance. Indeed, though Hertz does not mention this result explicitly, it is a mathematical theorem that for a $1/r^n$ force, a uniqueness theorem is possible (in three-dimensional space) only for $n = 2$ (Bartlett and Su 1994). That is why (according to Hertz) all of the various fundamental forces are inverse-square forces.

On Hertz's view, at least two constraints are not conservation laws: that all fundamental forces are inverse-square and that all fundamental forces act by contact. Notice once again that a constraint need not be a brute fact; on Hertz's view, the inverse-square constraint is explained by the contact-action constraint. It seems to me that Hertz's explanation cannot be correct as it stands since an inverse-square force is not quite the only kind of central force (with a force law consisting of an analytic function that is real-valued except, perhaps, at isolated singularities) that permits a uniqueness theorem.[7] Rather, a uniqueness theorem holds for such a force if and only if it is proportional to $1/(e^{kr}\, r^2)$ for some real k. This is called a "Yukawa force law" (or a force with a "Yukawa potential"). An inverse-square force is the special case where $k = 0$.

More about the various types of forces is known today than in Hertz's day. Not all of the forces that physicists today look upon as perhaps fundamental are inverse-square. However, if all actual fundamental forces are Yukawa forces, then perhaps an argument like Hertz's explains why this is so. A Yukawa force was famously posited by (can you guess?) Yukawa in 1935 as the strong nuclear force (i.e., the force holding protons and neutrons together in atomic nuclei). However, even if Hertz's proposed explanation fails because not all actual fundamental forces are governed by Yukawa force laws, my point still stands. An adequate metaphysics must not foreclose explanations of the sort Hertz proposes on pain of failing to do justice to the fact that science has rightly taken such proposals seriously. Many sorts of regularities among the various forces could be constraints rather than coincidences.

3. CONSTRAINTS AS MODALLY MORE EXALTED THAN THE FORCE LAWS THEY CONSTRAIN

I have suggested if top-down explanations appealing to conservation laws succeed, then they work because those laws constrain the lower-level laws figuring in bottom-up explanations—namely, by limiting the kinds of forces and force laws there could possibly be.

[7] A "central force" is a force directed along the line joining the body exerting it and the body feeling it.

In that case, the kinds of forces and force laws there could have been go beyond the kinds there actually are. For gravitational forces to exist and to diminish with the inverse-cube of the distance, for example, is *physically* impossible (i.e., is logically inconsistent with some laws of nature—in this case, the gravitational-force law) but nevertheless possesses some broader species of possibility in being logically consistent with the various constraints on the force laws. In contrast, if energy conservation is a constraint, then energy's conservation is not just physically necessary, but also possesses an even stronger kind of necessity (that is, one that applies to some but not all of the physical necessities).

On this view, a top-down explanation may proceed by expressly considering hypothetical states of affairs that the lower-level laws rule out (and that are not even approximations to or idealizations of some physical possibility). A top-down explanation may succeed even if it appeals to a physical impossibility, as long as that hypothetical state of affairs is not ruled out by the constraints on the lower-level laws. The top-down explanation exploits this broader species of possibility since it works by showing the explanandum to possess the corresponding species of necessity (stronger than physical necessity).

Here is an example of such an explanation: the standard textbook explanation (originating with J. Willard Gibbs) of the entropy of a mixture of two non-interacting ideal gases. The explanation uses energy conservation to account for the expression for ΔS: the difference between the mixture's entropy and the entropy of the gases when separated. Suppose N_A molecules of gas A occupy volume V_A (the left side of a container) and N_B molecules of gas B occupy volume V_B (the right side); the container is isolated and the two gases have the same pressure P and temperature T. Suppose gas A is confined behind a freely moveable membrane permeable to B but not to A, and gas B is similarly confined behind a membrane permeable to A but not to B. Initially, the two membranes divide the container along the same plane, so the gases are entirely separated. Then the membranes are allowed to move slowly, each gas expanding quasi-statically, so that ultimately the two membranes reach opposite ends of the container and both gases fill the entire container (volume $V_A + V_B$). Each gas's expansion is a reversible isothermal process. Let W be the total work done on the system:

$$W = -\int_{V_A}^{V_A+V_B} PdV - \int_{V_B}^{V_A+V_B} P\,dV = -\int_{V_A}^{V_A+V_B} N_A kT \frac{dV}{V}$$
$$-\int_{V_{BA}}^{V_A+V_B} N_B kT \frac{dV}{V} = N_A kT \ln \frac{V_A}{V_A+V_B} + N_B kT \ln \frac{V_B}{V_A+V_B}$$

By energy conservation (i.e., the first law of thermodynamics), the change ΔU in internal energy and the heat Q absorbed are related by

$$\Delta U = Q + W$$

Since the gases expand isothermically, $\Delta U = 0$, so $Q = -W$. Thus

$$Q = N_A kT \ln \frac{V_A+V_B}{V_A} + N_B kT \ln \frac{V_A+V_B}{V_B}$$

Then since ΔS = Q/T,

$$\Delta S = N_A k \,\mathrm{In} \frac{V_A+V_B}{V_A} + N_B k \,\mathrm{In} \frac{V_A+V_B}{V_B}$$

which is the explanandum: the formula for the entropy of a mixture of two non-interacting ideal gases.

Crucially, this explanation does not presuppose that the lower-level laws make it possible for there to exist a pair of membranes, one permeable to A but not to B, the other permeable to B but not to A. Whether there are any possible materials that could constitute such membranes depends on the particular gases involved. Generally, such membranes are impossible. For instance, if molecules of A are small and uncharged whereas molecules of B are large and charged, then typically there is nothing that could form a membrane permeable to B but not to A according to the lower-level laws (which specify the molecular constitution of A and B, as well as the behavior of physically possible membrane materials).

But remarkably, the thermodynamic explanation is not thereby undermined. That is because it proceeds entirely from *constraints* on possible lower-level laws. As far as those constraints are concerned, such membranes are possible for any molecular species. As Max Planck said in 1891 in commenting on Gibbs' derivation of this equation:

The enormous generalization that Gibbs has given to this tenet and which must, in and of itself, appear irresponsibly daring, rests clearly on the self-evident thought that the validity of so fundamental a tenet as that of the entropy of a mixed ideal gas, cannot depend on the arbitrary circumstance of whether we really have available in each individual case a suitable semi-permeable membrane. (translated in Seth 2010, 108)

It is not entirely an "arbitrary circumstance" since, after all, it is a matter of physical necessity. Yet it is "arbitrary" as far as the constraints are concerned, since whether any such membranes are possible for a particular pair of gases is a matter of what the fundamental force laws *happen to be*. Because the top-down explanation shows the explanandum to depend on thermodynamics alone, the explanation can afford to posit membranes that are impossible according to lower-level laws.[8] The laws of thermodynamics transcend the laws concerning various particular physically possible kinds of gas and kinds of materials out of which membranes could be constructed. That is because the laws of thermodynamics (and any explanandum they entail) would still have held, whether or not the lower-level laws allow a suitable pair of membranes for a particular pair of gases—an "arbitrary circumstance", as Planck says.

Similarly, to explain various laws concerning dilute solutions, Planck in 1887 (cf. Fermi 1956, 115) considered what would happen were the temperature so high and the pressure so slight that the solute and solvent vaporized into a mixture of ideal gases. After explaining the equations in this way, Planck wrote:

[I]ncidentally, it is completely inconsequential [gleichgultig] if the given state can really be arrived at experimentally, and certainly whether it represents a stable state of equilibrium or not; because these expressions [the explanandum] are completely independent of this [question]. (translated in Seth 2010, 102)

Later he elaborated:

[8] Many textbooks dance lightly over the fact that these membranes are generally physically impossible, characterizing the two gases as separated "conceptually" (Yourgrau, Van der Merwe, and Raw 2002, 235) or "hypothetically" (Annamalai and Puri 2002, 145) without elaborating any further. Fermi (1956, 101) is admirably forthright: "We should notice . . . that in reality no ideal semipermeable membranes exist. The best approximation of such a membrane is a hot palladium foil, which behaves like a semipermeable membrane for hydrogen."

> In reality, such a process [vaporizing a dilute solution into a mixture of ideal gases] will admittedly often not be realizable, because in many cases, at high temperatures, as are necessary here, chemical transformations occur, and the molecules are thereby altered. (translated in Seth 2010, 108)

Seth (2010, 102) comments:

> [Planck's point], introduced so casually, was, in fact, anything but incidental. Planck had clearly seen an apparent objection, and an obvious one at that. If one considers the case described (a dilute solution, say, of NaCl in water), lowering the pressure and increasing the temperature does not automatically produce the result required [a mixture of ideal gases, one of the solute and one of the solvent]. In most common cases, the water will vaporize, leaving a solid salt. For Planck's process, however, one requires both the salt and the water to vaporize *and* to maintain their molecular integrity as compounds. Whether it was at all possible to carry out such a procedure cannot have been clear to Planck.... The argument, however, was a thermodynamic one and the details of the process, including the very possibility of its experimental realization, did not matter for Planck. It was thermodynamically possible and hence the result followed.

"Thermodynamic possibility", as Seth nicely terms it, is broader than "physical possibility" because the laws of thermodynamics constrain the lower-level laws; like logical possibility, thermodynamic possibility includes more than just the physical possibilities. Planck's explanation succeeds, despite trafficking in physical impossibilities, because it works by showing the explanandum to be thermodynamically necessary, not merely physically necessary. No bottom-up explanation could explain the explanandum by showing it to be inevitable in just this respect because no bottom-up explanation, rooted in the various particular lower-level laws, could show that the explanandum would still have held, had the lower-level laws been different. The lower-level laws do not entail what the lower-level laws would have been like, had they been different. I shall now focus on such subjunctive conditionals.

4. MY ACCOUNT OF THE DIFFERENCE BETWEEN CONSTRAINTS AND COINCIDENCES

Let's now try to be more precise about what it would take to make a conservation law into a constraint rather than a coincidence. As

I hinted at the close of the previous section, I suggest that this distinction be elaborated in terms of subjunctive conditionals. Energy conservation constrains the possible force laws exactly when energy would still have been conserved even if there had been an additional kind of force (that is, a force that is not electric or gravitational or any of the other actual kinds) acting together with the various actual kinds—that is, even if there had been an additional kind of interaction experienced by some of the same entities undergoing some of the actual kinds of interaction. (If the additional kinds of force were uninstantiated, then they would obviously pose no threat to energy conservation. If forces of the additional kinds were not influencing any of the actual sorts of entities, then they would pose no threat to the conservation of quantities possessed exclusively by those entities.) The subjunctive fact associated with energy conservation as a constraint is supposed to be roughly that energy's conservation is resilient: that energy would still have been conserved even if there had been additional kinds of force threatening to undermine its conservation. On the other hand, to say that energy conservation is a coincidence of the actual force laws is to say that it is *not* the case that energy would still have been conserved, had there been additional kinds of force. Rather, energy is conserved because as it happens, each of the actual kinds of force conserves energy as a result of its own particular force law. So had there been additional kinds of force, energy might still have been conserved, but then again, it might not have been, depending upon the force laws of the additional forces.

This means of distinguishing constraints from coincidences portrays constraints as like "higher-order" laws. The lawhood of Coulomb's law is traditionally thought to be associated with the fact that Coulomb's law would still have held, had there been additional charged bodies. Similarly, the accidental character of the fact that each of the families on my block has exactly two children is associated with the fact that it is not the case that had there been an additional family on my block, it would still have been true that each of the families on my block has exactly two children. My account draws the same sort of distinction at a "higher order": energy conservation is a constraint exactly when energy would still have been conserved, had there been additional kinds of forces.

This means of distinguishing constraints from coincidences fits nicely into my more general account of natural law. I have presented this account in detail elsewhere (Lange 2009). Within the confines of this paper, I am obviously not able to offer much in the way of argument for my general account. Rather, my main aim is to argue that any account of natural law must recognize the distinction between constraints and coincidences. This cannot easily be done by the accounts of natural law currently on the market (as I will illustrate in the following section on dispositional essentialism). Here I offer my account simply as an example of how it is possible for an analysis of lawhood to leave a natural place for the distinction between constraints and coincidences (as I have just drawn it) and thereby to recognize the important role that this distinction plays in science (as I have suggested in the preceding sections).

As I just mentioned, laws of nature have traditionally been thought to differ from accidents in having greater perseverance under counterfactual suppositions. For instance, since it is a law that no body is accelerated from rest to beyond the speed of light, this cosmic speed-limit would not have been broken even if the Stanford Linear Accelerator had now been cranked up to full power. On the other hand, if it is just an accident that all gold cubes are smaller than a cubic meter, then had Bill Gates wanted a gold cube larger than a cubic meter, I dare say there would have been one.

Of course, laws are unable to persist under counterfactual suppositions with which they are logically inconsistent. This suggests the following proposal:

> m is a law if and only if in any conversational context, under any counterfactual supposition p that is logically consistent with all of the laws, m would still have held (i.e., $p \,\Box\!\!\rightarrow m$).

In this proposal and until further notice, I reserve letters like "*m*" for "sub-nomic" claims, i.e., for claims such as "The emerald at spatiotemporal location . . . is 5 grams" or "All emeralds are green" as contrasted with "nomic" claims such as "It is an accident that the emerald at spatiotemporal location . . . is 5 grams" or "It is a law that all emeralds are green". (On my view, a claim is "sub-nomic" exactly when in any possible world, what makes the claim hold (or fail to hold) is not that a given fact in that world is a law or that a given fact in that world is an accident.) Let me also note that the account of laws I am sketching here presupposes that every logical consequence of laws qualifies as a law and that every broadly logical truth (e.g., every truth holding with narrowly logical necessity, metaphysical necessity, mathematical necessity, moral necessity, etc.) is by courtesy a natural law. (These convenient simplifications could be dropped, however.)

Although the above proposal captures an important difference between laws and accidents in their behavior in counterfactuals, this proposal uses the laws themselves to pick out the relevant range of counterfactual suppositions. This is problematic since if there is no prior, independent reason why this particular range of counterfactual suppositions is special, then the laws' invariance under these particular suppositions fails to make the laws special. They merely have a certain range of invariance (just as a given accident has some range of invariance).

This problem can be avoided. Let's start by characterizing what I shall call "sub-nomic stability":

> Consider a non-empty set Γ of sub-nomic truths containing every sub-nomic logical consequence of its members. Γ possesses *sub-nomic stability* if and only if for each member *m* of Γ and for any *p* where $\Gamma \cup \{p\}$ is logically consistent (and in every conversational context), it is not the case that ~*m* might have held, had *p* held (i.e., $\sim(p \Diamond\!\!\rightarrow \sim m)$).[9]

Notice that $\sim(p \Diamond\!\!\rightarrow \sim m)$ logically entails $p \Box\!\!\rightarrow m$. Therefore, a set of truths is sub-nomically stable exactly when its members would all still have held (indeed, not one of their negations might have held) under any counterfactual supposition with which they are all logically consistent. So in contrast to the earlier proposal, stability does not use the laws to pick out the relevant range of counterfactual suppositions. Rather, each set picks out for itself the range under which it must be invariant in order for it to be stable.

This suggests my proposal for distinguishing laws from accidents: that the set Λ of all sub-nomic truths *m* where it is a law that *m* is sub-nomically stable, whereas no set containing an accident is sub-nomically stable (except perhaps for the set of all sub-nomic truths, considering that the range of counterfactual suppositions under which this "maximal" set must be preserved in order to qualify as stable does not include any false suppositions since no falsehood is logically

[9] For the sake of simplicity, this definition of "sub-nomic stability" omits some details from my (2009) that will not make any difference here.

consistent with all of this set's members). For instance, the set spanned by the fact that all gold cubes are smaller than a cubic meter is unstable because this set's members are all logically consistent with Bill Gates wanting a gold cube larger than a cubic meter, yet the set's members are not all invariant under this counterfactual supposition.

It is a law that *m*, then, exactly when *m* belongs to a (non-maximal) sub-nomically stable set. Now let's show that this account leaves a natural place for the distinction between constraints and coincidences. Are there any other non-maximal sub-nomically stable sets besides Λ? The sub-nomic broadly logical truths form a sub-nomically stable set. I'll now show that for any two sub-nomically stable sets, one must be a proper subset of the other:

1. Suppose (for *reductio*) that Γ and Σ are sub-nomically stable, *t* is a member of Γ but not of Σ, and *s* is a member of Σ but not of Γ.
2. Then (~*s* or ~*t*) is logically consistent with Γ.
3. Since Γ is sub-nomically stable, every member of Γ would still have been true, had (~*s* or ~*t*) been the case.
4. In particular, *t* would still have been true, had (~*s* or ~*t*) been the case. That is, (~*s* or ~*t*) □→ *t*.
5. So *t* & (~*s* or ~*t*) would have held, had (~*s* or ~*t*). Hence, (~*s* or ~*t*) □→ ~*s*.
6. Since (~*s* or ~*t*) is logically consistent with Σ, and Σ is sub-nomically stable, no member of Σ would have been false had (~*s* or ~*t*) been the case.
7. In particular, *s* would not have been false, had (~*s* or ~*t*) been the case. That is, ~((~*s* or ~*t*) □→ ~*s*).
8. Contradiction from 5 and 7.

Thus, the sub-nomically stable sets must form a nested hierarchy.

Since no non-maximal superset of Λ is stable (since it would include an accident), any other stable sets must be among Λ's proper subsets. Many of them are clearly unstable. For instance, the set spanned by a restriction of Coulomb's law to the past is unstable since had Coulomb's law been violated sometime in the future, then (with Coulomb's law "out of the way") it might have been violated sometime in the past.

However, some of Λ's proper subsets may be stable, and I suggest that any constraint must belong to at least one such set. Other members of such a set plausibly include the fundamental dynamical law, the law of the parallelogram of forces, the space-time transformations, and other laws that "transcend" the particular kinds of forces there happen to be; the various force laws and the "closure law" specifying the actual kinds of forces are excluded from such a set. In other words, if a conservation law belongs to no non-maximal stable set besides Λ, then it is a coincidence. If energy conservation belongs to a stable proper subset of Λ that omits the various force laws and the closure law, then the set's stability requires the subjunctive fact that (I proposed) distinguishes constraints from coincidences (that energy would still have been conserved, had there been additional kinds of forces) since the supposition that there are additional kinds of forces is logically consistent with each of the set's members. Energy conservation's status as a constraint is then associated with its invariance under a certain range of counterfactual antecedents, and that range consists of those antecedents that are logically consistent with every member of a stable subset of Λ to which energy conservation belongs. For instance, if the various particular force laws are all omitted from that set, then in connection with its status as a constraint, energy conservation would still have held, had gravity not been an inverse-square force.

This approach leaves room for multiple levels of constraints on the force laws, each one associated with a stable set that occupies a spot in the nested hierarchy of stable sets somewhere between the set of broadly logical truths and Λ. Moreover, this approach accounts for the role of constraints as higher-order laws—that is, laws that are modally more exalted than the force laws they constrain, and so able to explain why all of the forces share certain features. It accounts for the way in which the constraints carve out a species of possibility that is more inclusive than physical possibility (as we saw in connection with "thermodynamic possibility", which embraces some physical impossibilities). The members of a stable set would all still have held under any counterfactual supposition with which they are all logically consistent—that is, under which they could (i.e., without contradiction) all still have held. In other words, a stable set's members are collectively as resilient under counterfactual suppositions as they could collectively be. They are maximally resilient—that is to say, necessary. Accordingly, I suggest that a sub-nomic truth has a species of necessity exactly when it belongs to a non-maximal sub-nomically stable set, and that for each of these sets, there is a distinct species of necessity that is possessed by exactly its members. On this view, then, whereas constraints and coincidences are both physically necessary, a constraint also possesses a species of necessity (a stronger cousin of physical necessity) that the coincidences and force laws lack. Thus, we are entitled to say that a constraint limits the kinds of forces *there could have been*, whereas a coincidence merely reflects the kinds of forces *there happen to be*. The actual inventory of forces is a matter of physical necessity and yet also a matter of happenstance in that it lacks the stronger necessity possessed by a constraint.

Finally, this view explains why any conservation law that follows from a symmetry principle within a Hamiltonian dynamical framework constitutes a constraint rather than a coincidence and so (as Wigner says) "transcends" the various force laws. A symmetry principle, such as the fact that *the laws* are invariant under arbitrary temporal displacement, is not expressed by a *sub-nomic* claim. Rather, a symmetry principle is made true by which facts *are laws*. It is expressed by a "nomic" claim, i.e., a claim that purports to describe which truths expressed by sub-nomic claims are (or are not) matters of law. So to characterize the invariance that is characteristic of symmetry principles as "meta-laws", we need an analogue of sub-nomic stability that applies to sets of claims that are either sub-nomic or nomic. Here it is (now allowing letters like "*p*" to stand for claims that are either sub-nomic or nomic):

Consider a non-empty set Γ of truths that are nomic or sub-nomic containing every nomic or sub-nomic logical consequence of its members. Γ possesses *nomic stability* if and only if for each member *m* of Γ (and in every conversational context), ~ (*p* ◇→ ~*m*) for any *p* where Γ∪{*p*} is logically consistent.

The symmetry principles are meta-laws in that they form a nomically stable set more exclusive than the set spanned by all truths about which sub-nomic claims are laws and which are not. Moreover, if the conservation laws are logically entailed by symmetry meta-laws within a Hamiltonian dynamical framework, then they belong to a sub-nomically stable set that is more exclusive than Λ and therefore are constraints. That is because for any nomically stable set, its sub-nomic members must form a sub-nomically stable set. Here is the proof:

1. If *p* (a sub-nomic claim) is logically inconsistent with a nomically stable set Γ, then Γ must entail ~*p* (also sub-nomic), and so *p* is logically inconsistent with the set Σ containing exactly Γ's sub-nomic logical consequences.
2. Conversely, if *p* is logically inconsistent with Σ, then obviously *p* is logically inconsistent with Γ.
3. By Γ's nomic stability, Σ is preserved under every sub-nomic antecedent *p* that is logically consistent with Γ—which (we have just shown) are exactly those sub-nomic antecedents that are logically consistent with Σ. Hence, Σ is sub-nomically stable.

Therefore, if the symmetry meta-laws (forming a nomically stable set) entail that a given conservation law holds under the Hamiltonian dynamical framework, then the conservation law's holding if the Hamiltonian dynamical law holds belongs to a sub-nomically stable set that is more exclusive than Λ (since presumably, not all of Λ's members follow from the symmetry meta-laws' nomically stable set). Hence, if the Hamiltonian dynamical law is not a member of that set but (in transcending the various particular force laws) belongs to another sub-nomically stable set that does not include the force laws, then (since the sub-nomically stable sets form a nested hierarchy) the fact that the conservation law holds under the Hamiltonian framework must also belong to that set, and hence (by the set's logical closure) the conservation law must belong, too. So it constitutes a constraint. In other words, that the conservation law would still have held, even if the force laws had been different, follows from the fact that not only the fundamental dynamical law, but also the symmetry meta-law would still have held had the force laws been different.

Of course, I cannot do more here than sketch the relevant parts of this conception of natural law. But it is worth seeing how an account of lawhood can incorporate the constraint/coincidence distinction in a natural way. Now I shall conclude by turning to an approach to natural law that is ill-equipped to have the same success.

5. DISPOSITIONAL ESSENTIALISM RULES OUT CONSTRAINTS

According to Alexander Bird (2007), every sparse fundamental property of physics is constituted by one or more dispositions. On Bird's view, the association between a fundamental property of physics and some disposition is a matter of metaphysical necessity; moreover, the identity of a given fundamental property of physics is exhausted by its dispositional character. Therefore, it is metaphysically necessary that any entity possessing a certain sparse fundamental property of physics exhibit certain further properties if suitably stimulated. These regularities, or the corresponding relations among properties, are the laws of nature. Although metaphysically necessary, the laws do not perform the explanatory heavy-lifting. The motor and cement of the universe are the dispositional essences of the fundamental properties of physics. Views along roughly similar lines have been proposed by Brian Ellis (2001; 2002) and Stephen Mumford (2004), among others. These views differ in some details from Bird's: for example, Ellis takes the dispositional essences responsible for laws to be the essences of the natural kinds rather than of the sparse fundamental properties of physics, whereas Mumford holds that since any fundamental property of physics is constituted by a cluster of causal roles and other connections to other properties (such as its excluding certain properties and being compatible with certain others), there are no laws because nothing governs property instances in the manner traditionally ascribed to laws. However, these differences will make little difference here.

A conservation law does not say that any entity possessing a certain sparse fundamental property of physics exhibits certain further properties if suitably stimulated. Unlike (for instance) the occurrence of a certain force, energy's remaining conserved is not the manifestation of a particular disposition. Therefore, it is difficult for views like Bird's to accommodate conservation laws, as Bird (2007, 211) himself notes.

It is worth distinguishing three forms that this objection can take. The first form is that energy's remaining conserved under any interaction of a given kind is simply not the manifestation of any disposition constituting any of the sparse fundamental properties of physics manifested in such interactions. The dispositions associated with electric charge, for instance, may manifest themselves in various accelerations or various contributions to the electric field. Thus, the laws specifying that charges manifest themselves in certain ways under certain conditions do not include among these manifestations anything about energy being conserved. The law that electric interactions conserve energy therefore seems to have been left out of the account. However, it seems to me that the law has not been neglected. From the laws concerning electric interactions, it follows logically that such interactions conserve energy. So on this account, energy's conservation in electric interactions is a metaphysical necessity arising from the dispositions essential to various fundamental properties of physics, including charge. There is no problem yet for Bird's view.

The second form of the objection is that the law of energy conservation does not follow simply from the law that energy is conserved in electric interactions, the law that energy is conserved in gravitational interactions, and so forth. There must be a further premise, since these force laws taken together do not preclude the existence of another kind of process that fails to conserve energy. One premise that would close the gap is a "closure law": that electric interactions, gravitational interactions, and so forth are all of the kinds of interactions there are, i.e., that every fundamental natural process belongs to one of these kinds. The objection, then, is that this "closure law" does not reflect any property's dispositional essence. Hence, the overall conservation law is not the reflection of the dispositional essences of the fundamental properties of physics.

Ellis's view purports to be invulnerable to this form of the objection. Ellis takes the laws to be grounded not in the dispositional essences of various properties, but rather in the essences of the various natural kinds. He suggests (following Bigelow, Ellis, and Lierse 1992) that the world is the only member of a certain natural kind and that the essence of this kind includes various quantities being conserved (Ellis 2001, 205 and 250). Its essence also includes its being populated by exactly certain sorts of particles and fields undergoing exactly certain sorts of interactions, thereby accounting for the "closure laws". I have replied elsewhere that this move "seems like a desperate attempt to find *something* the essence of which could be responsible for various laws. Even if gravity and the electron have essences, it is not obvious that 'the world'—reality—does" (Lange 2009, 83). Bird also finds this move "somewhat *ad hoc*" (2007, 213). However, I shall not pursue this concern here.

This form of the objection may turn out not to pose a terribly severe challenge for Bird's view. One option that Bird might explore is to say simply that although the conservation "law" is not a metaphysical necessity, the fact that energy is conserved is no accident either. Rather, it is grounded in the sparse fundamental properties of physics, i.e., in the world's repertoire of fundamental causal powers. But this option would require Bird to allow different repertoires in different possible worlds, which Bird is reluctant to do (since in that case the actual laws, though still true in all worlds, are not laws in some of them). Another option for elaborating Bird's view accords metaphysical necessity to the conservation law and allows every world to have exactly the same laws. As I just explained, energy's conservation in electric interactions is a metaphysical necessity arising from the dispositions essential to various fundamental properties of physics. So likewise is energy's conservation in gravitational interactions, and similarly for any other actual type of interaction. On Bird's view, the various fundamental properties of physics would be different properties if they bestowed additional powers and susceptibilities—for instance, the power to exert and the susceptibility to feel some alien force that fails to conserve energy. Presumably, no metaphysical necessity precludes the instantiation of alien fundamental properties of physics. But "electric charge" (or any other non-alien property) would be a different property if it bestowed susceptibility not just to the influence of other electric charges, but also to some other alien influence. What if we go further and suppose that all of the non-alien properties (or at least enough of them that all non-alien kinds of entities must possess one) have as part of their essences that they bestow immunity to being influenced by any alien property (and so their possession by an entity precludes its also possessing any alien property that would bestow susceptibility to being so influenced)? Then the possession of any alien properties (by entities not possessing any of the non-alien properties) could not influence the behavior of any entities possessing non-alien properties and so could not disturb the conservation of the quantities that are in fact conserved under each of the various actual types of interaction, as long as those quantities are possessed only by entities possessing the non-alien properties. This is obviously the case for electric charge and, by the dispositional essentialist's lights, arguably the case for energy and momentum, since these properties (the essentialist might say) are constituted by various combinations of non-alien fundamental properties such as mass, velocity, charge, separation, and so forth. In that case, although these quantities are not instantiated in every possible world, they are conserved in any world where they are instantiated, since the non-alien properties constituting these quantities bestow immunity to any other influences besides the various actual types of forces. Energy conservation is then metaphysically necessary even if the "closure law" is not and even though the conservation law is not the manifestation of any single fundamental property's dispositional essence.

However, let's now consider a third form of the original objection that views like Bird's cannot properly accommodate conservation laws. This form of the objection will prove more difficult for views like Bird's to answer. On Bird's picture, even if energy conservation is metaphysically necessary, it is the product of the various particular types of interactions there are: that gravitational forces conserve energy, electric forces conserve energy, and so forth. The various dispositions essential to various fundamental natural properties are responsible for energy's conservation. So although energy conservation is metaphysically necessary, it is a coincidence rather than a constraint.

To appreciate this, recall the subjunctive fact that (I have suggested) is what it is for energy conservation to be a constraint: that energy would still have been conserved even if there had been an additional kind of interaction experienced by some of the entities undergoing some of the actual kinds of interaction. This conditional's antecedent is a countermetaphysical according to the view I have just offered Bird in response to the previous form of the objection. Even without that response, on Bird's view there is no disposition (or collection of dispositions) essential to some sparse fundamental property of physics (or collection of such properties) that is available to underwrite this conditional's truth. On Bird's view, the causal powers constituting those properties do the metaphysical heavy lifting, but these causal powers cannot underwrite this conditional's truth; none of them has as its manifestation that certain alien fundamental natural properties are instantiated or has as its manifestation-eliciting stimulus that some alien kind of interaction occurs. The conditional associated with being a constraint does not concern what the actual causal powers would produce under suitable stimulation, but rather concerns what causal powers there would be if there were more besides the actual ones—so the actual causal powers do not sustain this conditional's truth. (The same applies to other subjunctive conditionals whose truth would reflect a conservation law's status as a constraint, on my view of constraints as belonging to stable proper subsets of Λ. For example, the fact that energy would still have been conserved, had gravity not been an inverse-square force, posits a countermetaphysical and is underwritten by no causal powers, on Bird's view.) Ellis's view faces a similar problem: there is no natural kind whose essence can step in to sustain the conditional needed to make energy conservation a constraint. Even the world's essence cannot do the job since the conditional's antecedent is inconsistent with that essence. On Ellis's view, had there been additional kinds of interactions, there would have been a different kind of world; it might have been a world where energy is conserved, but then again, it might not. Energy conservation is therefore a coincidence, not a constraint.

On a view like Bird's, a conservation law cannot be a constraint because a conservation law cannot be explanatorily prior to the force laws—or, rather, to the various dispositions responsible for the force laws and essential to the various sparse fundamental properties of physics. Gravitational interactions conserve energy not because the law of energy conservation requires them to, but because of the causal powers involved in gravitational interactions (which the gravitational-force law reflects). The conservation laws cannot explain why (e.g.) no fluid circulates; rather, the explainers must be the particular powers involved. Even if a given power's conserving energy when it is manifested suffices to entail the explanandum, energy conservation as a comprehensive law covering all of the actual powers is explanatorily irrelevant; all that matters to the outcome is the fact that the particular power at work in this case conserves energy. This is how all scientific explanations must work, according to Ellis—from the bottom up:

> Essentialists seek to expose the underlying causes of things, and to explain why things are as they are, or behave as they do, by reference to these underlying causal factors. Consequently, explanations of the sort that essentialists are seeking must always have two parts. They must contain hypotheses about the underlying structures or causal powers of things, and hypotheses about how things having these structures and powers must behave in the specific circumstances in which they exist. (Ellis 2002, 159–60)

This approach to scientific explanation leaves no room for the top-down explanations that constraints supply. Why are two forces alike in conserving energy? Why do no kinds of interaction put fluids spontaneously into circulation? That energy conservation constrains the kinds of forces there could have been is not the kind of explanation Ellis allows. On Ellis's picture, the explananda are merely upshots of the various particular kinds of interaction built into the world's essence, all of which conserve energy.

Bird likewise seems to find top-down explanations from conservation laws problematic:

> [T]here is something mysterious about conservation laws. They seem to require explanation . . . How does a system know that energy should be conserved? . . . It is not clear how these could be fundamental laws—they seem to stand in need of a deeper explanation. (2007, 213)

The deeper explanation Bird has in mind would be in terms of the particular causal powers at work in the system. It is these powers that allow a system to "know that energy should be conserved". This is the order of explanatory priority that is characteristic of conservation laws as coincidences: the various force laws (or, for the essentialist, the various particular causal powers responsible for the force laws) come before the conservation law. But as we saw earlier in this paper, conservation laws as constraints provide explanations that are in some respects "deeper" than any explanations appealing to the particular powers involved. By constituting common explainers, conservation laws as constraints unify the non-circulation of ropes and fluids, for example, and likewise unify various otherwise unrelated forces as all inverse-square (or all subject to uniqueness theorems) or all conserving energy for the same reason. These explanations reveal that the fact to be explained would still have held even if different fundamental forces had been at work.

That conservation laws must be coincidences rather than constraints on his account seems to be roughly what Bird has in mind when he acknowledges that his account cannot accommodate conservation laws:

> Conservation and symmetry laws tell us that interactions are constrained by the requirement of preserving, e.g., mass-energy or momentum . . . [T]he dispositional essentialist holds that the laws are necessary. If that is correct there is no room for further constraints. Properties are already constrained by their own essences and so there is neither need nor opportunity for higher-order properties to direct which relations they can engage in. (Bird 2007, 211 and 214)

Bird's thought seems to be that as constraints on (the causal powers responsible for) the various force laws, conservation laws would have to impose limitations on the possible manifestations of the powers associated with electric charge, mass, and so forth, limiting the interaction laws to those that conserve energy. But these interaction laws are already fully determined by the properties involved in the interactions since those properties are essentially constituted by various causal powers, which fix their own possible manifestations. So there is no further constraining for a conservation law to do. It seems to me that there is more that the conservation law could constrain: what powers there would be, if additional fundamental natural properties were instantiated. But this would require that the conservation law do some metaphysical heavy lifting—a job that, on Bird's picture, is reserved for the causal powers.

In short, a conservation law as a constraint is a higher-order law; it has greater necessity than any of the motley collection of various particular force laws and thus explains why those laws are all alike in exhibiting certain features. But on views like Bird's and Ellis's, the particular force laws hold as matters of metaphysical necessity. No greater necessity is left for a constraint to possess; necessity has already been maxed out in the force laws. So there is no genuine "thermodynamic possibility"—no sense in which various actual properties could have been associated with certain alien powers but not with others (namely, with only those alien powers that, in being manifested, would conserve energy, momentum, and so forth). Therefore, conservation laws cannot be constraints; they can only be coincidences.

Bird seems content with this result:

> The dispositional essentialist ought to regard symmetry principles as pseudo-laws. . . . So it may be that symmetry principles and conservation laws will be eliminated as being features of our form of representation rather than features of the world requiring to be accommodated within our metaphysics. (Bird 2007, 214)

But I have argued (in the opening sections of this paper) that the price of adopting this view is too high. It precludes top-down explanations of a kind that science has reasonably taken seriously—indeed, on which science has often placed great importance. Views like Bird's rule out scientifically respectable theories. Perhaps Bird's prognostication regarding future science will be proved right; perhaps symmetry principles and conservation laws, along with the alleged top-down explanations they supply, will ultimately be eliminated from physics—and their place not be taken by other top-down explanations (like Hertz's) employing other sorts of constraints. Personally, I doubt it. But more importantly, a metaphysics that cannot do justice to top-down explanations and the constraints they require is at a serious disadvantage even if as a matter of fact, there turn out to be no such explanations. Room should still be left for them; it should be up to science rather than metaphysics to foreclose them.

Consider, for instance, the conservation of baryon number in contemporary physics. By energy conservation, an isolated proton can decay only into particles that have less rest-mass than it does, and the proton is the lightest baryon (i.e., the lightest particle with non-zero baryon number). The conservation of baryon number thus entails that the proton is stable (radioactively, I mean—not "subnomically!). Does baryon-number conservation explain why the proton is stable? This remains controversial.

It is no explanation if the conservation of baryon number is a so-called "accidental symmetry" (a term that was introduced by Steven Weinberg; see Weinberg 1995, 529). An accidental symmetry reflects merely the particular forces in action at lower-energy regimes rather than some deeper "symmetry of the underlying theory" (Weinberg 1995, 529). Accordingly, if baryon-number conservation is an accidental symmetry, then it may not even hold at higher energies (and so the proton may turn out not to be stable, but rather to have an extremely long half-life). But even if an accidental symmetry is unbroken, it would still be a coincidence of the particular kinds of interactions written "by hand" into the underlying theory, and so it would fail to explain. (The stability of the lightest baryon would then help to explain why the baryon number turns out to be conserved, not vice versa.)

On the other hand, baryon-number conservation may turn out to be a consequence of a more fundamental symmetry, in which case it would help to explain the proton's stability. Thus, whereas some physicists cite baryon-number conservation as explaining why the proton is stable (e.g., Davies 1986, 159; Duffin 1980, 82), other physicists put scare-quotes around "explain" (Lederman and Teresi 1993, 303) or say that the jury is still out (Ne'eman and Kirsh 1996, 150–1). The uncertainty regarding the conservation law's explanatory power is matched by the uncertainty regarding the law's status as constraint or coincidence. But this live scientific controversy would be settled outright by views like Bird's. I do not think that metaphysics should prejudge the outcome.

If the laws are the upshot of the inventory of powers, and hence (according to dispositional essentialism) of the sparse fundamental properties of physics, then any regularity in those powers (even if metaphysically necessary) is coincidental; no law transcends the various powers, constraining those there could have been. However, an adequate metaphysics should allow the "great general principles which all the laws seem to follow" to be constraints; it should not require them to be coincidences.

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