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The World as One of a Kind: Natural Necessity and Laws of Nature

JOHN BIGELOW, BRIAN ELLIS and CAROLINE LIERSE

1 INTRODUCTION

This world is one of a kind. Some philosophers have maintained that there are many other worlds which are spatially, temporally and causally unrelated to ours. We are not asserting that there are any such disconnected worlds. Nor do we assert that there are none. There is at least one world; and it is a member of a natural kind whether or not there are any others of its kind. If there were any other world, in addition to this one, or instead of this one, then there would be a nontrivial question whether that world was of the same natural kind as ours. We can imagine worlds which would be of the same natural kind as ours; but we can also imagine worlds which would not.

Recognition that this world is one of a kind offers a new approach to the question of what a law of nature is. We argue that in general laws of nature are concerned with natural kinds. In some cases laws simply describe the essential properties of natural kinds. Maxwell's equations, for example, describe the essential properties of the electromagnetic field. In the case of other laws, for instance where there are interactions between things of different kinds, the laws stating how they behave are derivable from their essential natures. We hold that this is true even of the most fundamental laws of nature, *e.g.* the conservation laws, the principles of relativity, and the symmetry principles: they too are concerned with the essential properties of a natural kind. Their concern is with the kind of world this is.

This theory of the nature of scientific laws derives from the basic idea that things behave as they do because of what they are made of, how they are made, and what their circumstances are. In so far as the behaviour of a thing depends on what it is made of, it depends on the essential natures of its constituents. In so far as its behaviour depends on how it is made, or on its circumstances, it depends on laws of interaction. The various laws of interaction, we suppose, depend on the essential natures of the things interacting with each other, and on the forces or fields which mediate these interactions. Thus we hold that laws of nature are grounded in the essential natures of things, not superimposed on them, as the term 'law of nature' seems to suggest.[1]

2 NATURAL KINDS AND ESSENCES

When we speak of natural kinds, we have in mind things like copper, gold, protons, or electromagnetic fields. They are kinds of things which exist in the world independently of human knowledge, language and understanding.

Not every class of things counts as a natural kind. For every objective property there is a class of things which have that property. But not every such class constitutes a natural kind.

Natural kinds of the sort we have in mind are characterized by *clusters* of properties which play an especially important *explanatory role* with relation to other properties and relations. They are what Mill called 'real kinds', and are to be contrasted with classes of things which just happen to share some number of properties, but which do not share any cluster of *explanatorily crucial* properties.

If we are to use natural kinds in the explication of laws of nature, then we must sooner or later give an analysis of natural kinds. We presuppose that some descent analysis of natural kinds can be given. We presuppose, furthermore, that natural kinds may be taken as *more basic*, in some sense, than laws of nature. If we are to use natural kinds to explain *laws*, then we should not use laws to explain *natural kinds*. To do so would be to move in a tight circle.

There are at least two ways of proceeding to construct such an explanation. The first is to develop an ontology in which natural kinds occur as primitives. For example, we might suppose natural kinds to be primitive substances which are distinguished from each other by their internal properties and structures, and whose dispositions to act or react are determined by these internal properties and structures. These substances may be supposed to exist no less primitively than the things which instantiate them. The essential properties of a natural kind might then be identified with those properties which belong strictly to the natural kind itself, while its so-called accidental properties might be supposed to be just those properties which happen to be instantiated by all or some of the individuals which are its instances. In this way, we may be able to provide an ontological foundation for the essence–accident distinction.

[1] Our theory is not entirely unanticipated by the work of others. Harré and Madden [1975] have advanced a perspective on laws of nature akin to ours.

The second approach is to develop a theory of essences as primitive, and seek to define natural kinds in terms of essences. Essential properties can be defined in terms of necessity, quantification, and identity. An essential property of a given individual is one which is such that, *necessarily*, if *anything* lacks that property, then that thing is not numerically *identical* with the given individual. Essential properties, thus defined, could then be used to define natural kinds. Membership in a natural kind is, arguably, an essential property for each of the members of that kind. Consequently natural kinds could be construed, for instance, as classes of individuals which share an explanatorily significant cluster of essential properties.

However, it is beyond the scope of this paper to develop a theory of natural kinds sufficient to support the theory of laws which is being proposed. Here we merely aim to show what consequences would follow concerning laws of nature, given that we are right about the ontological priority of natural kinds and essences over laws of nature.

If this world is granted to be one of a natural kind, then natural necessities will emerge in the following way. Natural kinds are always associated with *essential properties*. If something is of a natural kind, then there will be properties which this thing must have to be a thing of that kind, and which it could not cease to have without ceasing to be a thing of that kind. We think this applies to the actual world: there are properties which this world could not lack without ceasing to be the kind of world it is. Other properties of this world are *accidental properties*. A world of the same kind as ours could exist which lacked these properties. Worlds which lacked the essential properties of our kind of world could also exist. They are not *logically* impossible. But they would be different kinds of worlds from ours, and so not other ways *this* world could have been.

Laws of nature, we claim, derive from the attribution of essential properties to things. A special case will be that of the attribution of an essential property to the actual world. Such an attribution will be a posteriori, since we do not know a priori which possible world we are in. Yet if it is a correct attribution, it will not be on the same footing as a sheer contingent truth about the actual world. It will have a modal status intermediate between sheer contingency on the one hand, and logical necessity on the other. It is not like logical necessities, which are true of any world whatever. Yet it is not like a sheer contingency, which could have either held or not held of the world we are in. It has a degree of necessity, which we may aptly call *natural* necessity, since it depends on the nature of the world which we happen to be in. A law of nature is not just something which is true of the actual world but which could have been otherwise *in this very world*; rather, it is something which could not have failed to hold *of this world* without this world ceasing to be, and another world altogether existing instead—another world of a different natural kind with a different nature from the one we are in. Thus, there is an immediate advantage to a theory which construes laws as attributions of essential properties: it automatically bestows upon laws the kind of necessity which they manifestly do have, something intermediate between mere contingency and logical necessity.

On traditional Humean conceptions laws are privileged correlations. Yet there are many laws, we shall argue, which are not easily construed as asserting correlation of one thing with another. Various laws, such as the fundamental conservation laws, symmetry laws, and a variety of other laws must be laboriously kneaded into shape before they can be fitted into the traditional Humean conception of laws as privileged correlations. On our theory no such kneading is needed: laws may often be correlational, but they need not be, as we shall show in Section 4.

According to Aristotle, the essential properties of a thing are those on which its identity depends. They are the properties of a thing which it could never have lacked, and which it could not lose without ceasing to exist or to be what it is. Accidental properties of a thing are properties which that thing could either have had or lacked. For example, you could be sick, or you could be healthy, so your state of health is not one of your essential properties. An essential property of you, if you have any, would be a property which you could not lack without ceasing to be who and what you are. If Aristotle was right, then being human is one of your essential properties, for the property of being human is not something you could lose without thereby ceasing to exist, *i.e.* without ceasing to be who and what you are.

However, when we speak of laws as attributions of essential properties we are not thinking of such properties in the Aristotelian sense; that is, we do not construe essential properties just in terms of the conditions deemed necessary and sufficient for the application of some particular concept. Rather, what we have in mind are *real* essences in Locke's sense. According to the Lockean conception, real essences are properties which play a central role in the scientific explanation of a thing's other properties and relations—they are the characteristics which make a thing the kind of thing it is. For example, consider the case of water being essentially H_2O. According to the Lockean conception, being H_2O is an essential property of water, for its being H_2O is what makes water the kind of substance it is. Nothing could come to have the structure H_2O without water thereby coming into existence. Likewise, some water could not cease to have the structure H_2O without that water ceasing to exist.

It is worth noting that our paradigms for essences come from physics and chemistry rather than, as for Aristotle, from biology. Essences are easier to grasp for relatively simple substances like water; they are harder to grasp for complex, self-replicating and evolving substances like cows or grass. Ultimately, the causally explanatory Lockean essence for an organism could arguably be taken as its genotype, and this is a chemical structure like H_2O, only much more complicated. Yet the genotype for Socrates is not strictly identical with that of Callias or of anyone else. So genotype seems not to be quite the same as the supposed Aristotelian essence of humanity. Aristotle held that all humans have exactly the same essence. One way of understanding that idea is by comparing it with the now unacceptable hypothesis that all humans have exactly the same genotype, and that all differentiation within the species is phenotypic. What has been discovered in biology, however, is that all that holds a species together as a single natural kind is a sufficient *degree of similarity* among genotypes.

When we turn our attention to something even more complex than cows and grass, namely to *the whole world*, essences and natural kinds will probably be even more a matter of degree than they are for cows and grass. But this will not empty the idea of all content. Just as for each cow there will be its own fully determinate individual bovine genotype, so too for the world we inhabit there will be its own fully determinate set of essential properties—the complete catalogue of all its natural laws. Just as a cow's genetically identical twin, if it has one, will have exactly the same Lockean essence, so too another possible world with all the very same laws as ours will be unambiguously another way this very world could have been—a physically possible world with respect to our world. As we turn our attention to worlds whose laws resemble ours less and less completely, we shade off by degrees into worlds which are less and less of a kind with our world. Eventually we reach worlds which are as undeniably of a different kind from our world as cows are of a different biological kind from the grass they eat.

Thus, the Lockean conception of essences and natural kinds can be applied, without absurdity, to complex as well as to simple individuals. There is no reason in principle why it could not be applied to as big an individual as the whole world. The Lockean real essence of the world itself would have to consist of the properties and structures which make this world the kind of world it is. They would have to be those which have a fundamental role in explaining the patterns of events observed in the world.

The thesis to be defended here is that the fundamental laws of nature derive from the Lockean essential properties and structures of the world. If our analysis is sound, then laws of nature must be supposed to exist, and to hold *necessarily*, whether or not anybody knows that they exist, or has any idea of what they are. Hence, our theory of laws is an *ontological* one. It grounds laws in something which is postulated to exist independently of human expectations or conventions. Not all philosophers agree that laws need any such ontological grounding. Humean theories explain why laws *seem* to be necessary even though there is nothing in the world which grounds this necessity. Some philosophers have tried to explain why it is desirable to hold on to some generalizations more firmly than others, making them effectively true by convention, thus giving them the status of provisional conceptual truths. Theories of this sort make no postulation of any *ontological* grounds for laws.

However, in this paper, we make no attempt to refute any of the non-ontological theories. Nevertheless, it is important to contrast our theory of laws of nature with other ontological theories which purport to explain their nomic necessity, and to show that our theory has many advantages over them.

3 THE DIRECTION OF EXPLANATION

The best-known and best-developed of the current ontological theories are those of F. I. Dretske, M. Tooley, and D. M. Armstrong (DTA).[2] While these three accounts are distinct, they are sufficiently similar for us to be able to treat them together.[3] For the purposes of this paper we shall focus mainly on Armstrong's theory of laws.

Armstrong claims that laws of nature are irreducible dyadic relations of necessitation (or probabilification) holding between universals. It is this relation between two universals (itself a universal), which is supposed to endow certain regularities with their nomic status.

Although Armstrong's approach has some plausibility, we do not think that this account of nomic necessity is successful. Nor do we believe that this theory of laws is tenable in the light of current scientific theory. But our purpose here is not to offer a refutation,[4] but rather to propose an alternative ontological theory of the nature and necessity of laws, and to clarify our theory by contrasting it with its current rivals.

The most striking difference between our account of the necessity of laws and the accounts offered by DTA concerns the *direction of explanation*. On our account, laws express, or are derivable from statements expressing, the essential nature of the world and the kinds of things it contains. The direction of explanation is from the bottom up, so to speak, *from things* with their necessary properties *to laws*.[5] On the DTA account, laws are viewed as correlations between the properties or behaviour patterns of various kinds of things in the world, and their necessity is explained by the existence of certain

[2] Dretske [1977]; Tooley [1977], [1987]; Armstrong [1978], [1983].

[3] They are from the same genre in so far as all three accounts describe laws in terms of necessary connections between universals, but they differ from one another in the way each theory is formulated. For instance, one important difference between Tooley's and Armstrong's accounts concerns the ontology of universals. Armstrong, unlike Tooley, does not allow uninstantiated universals. While such differences may be significant when comparing the three theories with each other, these nuances need not concern us here.

[4] Critical discussions of Armstrong's, Dretske's and Tooley's accounts can be found in Carroll [1987]; Earman [1984]; Forge [1986]; Hetherington [1983]; Lewis [1983]; Niiniluoto [1978]; and van Fraassen [1987]. For some replies see Armstrong [1988]; Dretske [1978]; and Tooley [1987].

[5] Shoemaker [1980] and Swoyer [1982] defend similar versions of a 'bottom-up' approach.

'necessary' second-order relations between the universals that are correlated. Thus, the direction of explanation is from the top down, so to speak, from the second-order relations to the first-order correlations.

While Armstrong's account circumvents some of the more damaging objections to the traditional reductionalist accounts, we argue that its main weakness lies in the difficulty it has in explaining the necessity of the relations between universals. Laws of nature, Armstrong states, are *contingent* relations of necessitation. That is, even when such a relation does tie one universal to another, it is not *logically* necessary that this relation should hold between these two universals—the holding of this relation is a contingent matter.

At first blush the contingent status of Armstrong's necessitation relation seems to have definite merit. Not only does it guarantee the a posteriori character of laws, it also fits well with our belief that such relations (laws) could have been otherwise. But why should it be that some sets of relations are more special than others, thereby constituting 'necessitation' relations between universals? One answer requires us to take this relation of necessitation as primitive, and to say that it is just a basic fact that certain relations are necessitation relations. This is Armstrong's position. To illustrate, consider the law that all metals are electrical conductors. According to Armstrong's theory, the necessity of this law derives from the fact that there is a relation of nomic necessitation holding between the properties of being a metal and that of being an electrical conductor, so that anything which has the first property must necessarily have the second. But what makes the relation between these properties one of nomic necessitation? According to Armstrong's theory, nothing does; its status as a necessitation relation is primitive and unanalysable. It is simply one of a class of necessitation relations which are to be found in nature.

However, this response fails to provide an illuminating explanation of the nomic necessity of laws of nature. On this model, laws or law statements are just *descriptions* of 'necessary' relations between universals, but why these relations hold is left unanswered, and, even granted that they do hold, the question remains why the holding of these relations is appropriately described as constituting a 'necessitation' relation. Given that the holding of the relation is contingent, what does its holding between two universals have to do with 'necessity'? As Lewis points out, *labelling* the relevant relation a 'necessitation relation' cannot by itself create a *necessary* link between the related things, any more than calling someone 'Armstrong' can give them mighty biceps![6]

One alternative approach to the explanation of nomic necessity is by appeal to higher-order universals.[7] The alleged 'necessitation' relation R_1, which

[6] Lewis [1983], p. 366.

[7] John Carroll raises this possible approach and following objection in his [1987], p. 265.

purportedly joins properties p and q, must hold of p and q in virtue of something. Suppose it holds in virtue of some further relation R_2 in which R_1 stands to p and q. We might then attempt to explain the 'necessity' in the relation R_1 by claiming that it holds in virtue of R_2. However, this line of reasoning immediately threatens a regress. We suppose $\langle p, q\rangle$ to stand in relation R_1, and we explain that this is a necessitation relation because it involves a distinctive relation R_2. We may then ask why R_2 is distinctive in a way which warrants the title 'necessitation'. It is, of course, possible to terminate the regress at any time, but this can only be achieved by claiming that the necessity of a particular relation R_n must be taken as primitive. Hence, this approach fails to give an enlightening exposition of the nature of laws.

Like Armstrong, Dretske and Tooley, we believe that certain relations between universals are in some sense 'special'. We agree with them, for example, that there is a relation of necessitation holding between the properties of being a metal and being an electrical conductor. But on our view, this relation derives from the essential nature of metals, as well as the essential natures of their elementary constituents and the electromagnetic fields which may act on them. That is, we think that the relation of necessitation between these universals is ontologically grounded in the essential natures of the various kind of things involved.

Laws often entail the presence of relations between universals. These relations are special because they are *necessary* relations. Yet unlike Armstrong *et al.* we do not believe that their necessity stems from an intrinsic (or primitive) feature of the relation itself. Rather, it is to be explained at a more fundamental level. Laws of nature, we argue, are truths whose necessity is grounded in the essential properties of this world and the things in it. Hence, it is not the relation between universals that constitutes the necessity of laws, but rather, their necessity results from the essential natures of the properties on which the nomological relation supervenes. Thus, laws of nature are not just mysterious relations that preside over an unsuspecting world, but relations which bear an essential connection to the world and its content, in that their nature, existence, and necessity derives from the essences of the things they govern.

How is it possible for the laws of nature to arise from essential properties? This can be explained by direct appeal to the nature of a property itself. We argue that included among the essential properties *of a property* is the *propensity* or disposition of whatever possesses it to display a particular kind of behaviour in a specific kind of context. What science observes and codifies are the manifestations of these dispositions. Hence (statements of) laws which describe how properties behave will at the same time tell us what things which have these properties *must* do, in virtue of being the kinds of things they are. The necessity of laws is not a primordial feature of necessitation between properties, but rather is 'inherited' from the underlying essences of those properties. The necessitation relation between properties is, we argue, *supervenient* on the essences of the properties which stand in that relation.

One important feature to be made clear is that the kind of supervenience we are postulating of laws on essences, is *broad* supervenience:[8] *i.e.* given a particular set of base properties (the subvenient class), the ensuing supervenient properties or relations are the same in all possible worlds which feature the subvenient properties. This means that, given the essential natures of the kinds of things said to be nomically connected, the supervenient relation (law) must *necessarily* follow. Hence, there is no possible world where things of these kinds exist, but the supervening (nomic) relation fails to hold.

It has been objected that our analysis of natural necessity makes laws logically necessary where clearly they are not.[9] This objection stems from the fact that we explain the necessity of laws in terms of the essential properties of natural kinds. And yet it is not logically possible for a natural kind to have different essential properties from those it does in fact possess—if one of its properties could be absent, it would not be an essential property. Hence, anything which is true in virtue of the essential properties of a natural kind will have to be true in all possible circumstances in which that natural kind exists.

Nevertheless, this fact does not imply that the laws of nature are logically necessary. For it is a contingent matter what natural kinds there are. There was a time when chlorine was thought to have atomic weight 35·5 approximately, and at that time this would have been thought to be an essential property of chlorine. When isotypes were discovered it was found that nothing had atomic weight 35·5; but it was not concluded by anyone that chlorine did not exist. This shows the revisability of our statements about essential properties—they are conjectures about Lockean real essences rather than stipulative definitions of concepts. Hence laws are *epistemically* contingent. This accounts for the a posteriori character of laws. It is consistent with this, however, that laws are true in virtue of the essential properties of natural kinds. *Given* that the natural kinds referred to in the statements of a law are what they are, *then* the truth of the law is determined by the essential properties of those natural kinds. Fix the natural kinds referred to, and you determine the truth value of the statement of the law. So a natural law, unlike a logical truth, would not be true *in all worlds*, but would be true in all worlds which contain the natural kinds mentioned in the law. Hence, a law possesses a kind of conditional necessity: necessity relative to the natural kinds to which it actually refers.

To highlight an important contrast between the rival ontological theories and ours, imagine the world, and the laws within it, as represented by the game of chess. In this analogy, take the board to represent the basic structure

[8] As defined by Peter Forrest [1988], p. 5.

[9] This objection was brought to our attention by Freya Mathews, John Bacon and John Fox.

of the universe (including its space-time structure, its symmetries, and the conservation laws), the pieces to represent physical entities, and the rules of the game to represent the laws governing the relations between these entities. One salient feature of this picture is that there does not appear to be any *logical* connection between the matter in the world and the laws that govern its behaviour. It is possible that the rules for chess could have been formulated so that the legal moves for the rook, for instance, required that it moved only in a diagonal direction. The fact that it is the bishop which moves in this particular way is just a contingent fact about the game—it is *logically* possible that the rules could have been otherwise. In fact, if the rules are imposed on the pieces from above (as by irreducible, necessary relations), it can be seen that the way the rook moves has nothing to do with its essential nature. It is not difficult to imagine dozens of different ways the rule book for chess could have been written, or alternatively, the possibility of the pieces and the board existing without a rule book to govern the movements of the pieces (*i.e.* an anarchic, Hume world). This image portrays the creator of the game as carving the pieces, forging the board, and then sitting down to formulate the legal movements for each piece. This is like an image of God calling forth the subatomic zoo, letting there be a space-time to house it, and then sitting down to formulate the laws governing their interactions.

In contrast with the DTA account, we urge that there is no need for a chess manual to dictate the rules of movement for the chess pieces. There is no need for a rule book because there is no freedom to choose the rules of movement for the pieces. By embedding laws in essential natures, the legal moves for a given piece are determined by the nature of the piece itself. Thus, by construing rules (laws) as consequences of essential properties, the rules were created simultaneously with, and exist in virtue of, the pieces which they govern.

According to the analogy, the bishop can only move (and thus instantiate a rule) in virtue of its essential nature. The way it interacts with the board and other pieces is what makes it a bishop. If we were to modify the game in such a way that the piece which we previously referred to as the 'bishop' now moved according to a different set of rules, then the piece would no longer be a bishop. Hence, by changing the rules for moving a particular piece, we are changing its essential nature, and so changing its identity. For this reason, we argue, it makes no sense to talk about the other ways *the bishop* could have moved.

Consequently, it makes no sense to talk about a piece independently of the rules which govern its moves. Analogously, it makes no sense to speak of a natural kind, *e.g.* being an electron, independently of the laws which govern its behaviour. An electron is an electron precisely because it exhibits a specific set of interactions under various conditions: this is what makes it an electron. If something failed to exhibit these qualities it would not be an electron; there would exist, instead, something other than an electron. Therefore, to speak of a possible world with a different set of laws to ours necessarily entails speaking of a world containing different natural kinds. Hence, 'Disney' worlds, in which things defy our law of gravity and so fourth, are by logical necessity ruled impossible as ways in which the things in *this* world could have behaved. And if we did, by chance, happen to come across a world which appeared to resemble ours in all respects except for the laws governing the behaviour of its inhabitants, its similarity to ours would be illusory. Prima facie, it may appear to contain entities belonging to the same natural kinds as ours, but it could not in fact be an authentic copy of our world.

Thus, our theory of laws differs from its main ontological rival in the following way. In the DTA theory, laws rest on necessitation relations between universals; and the holding of these relations between universals is a *contingent* matter. Properties which stand in a necessitation relation *could have* failed to stand in that relation, *without* thereby ceasing to be the properties that they are. According to our theory, in contrast, such necessitation relations are grounded in the essential properties of the natural kinds which stand in these relations.

It remains to be shown that our conception of laws of nature is a viable one, in that it stands up well as an account of the currently accepted laws of nature. This is the task to which we now turn.

4 ESSENCES AND LAWS OF NATURE

Laws of nature all have the kind of necessity which we call 'natural necessity'. For every action, there *must* be an equal and opposite reaction. If the potential difference along a wire is V, and its electrical resistance is R, then a current $I = V/R$ *must* flow along the wire in the direction of decreasing potential. For a black body radiator, the radiation *must* have a frequency distribution in accordance with Planck's radiation law. In any closed and isolated system total momentum *would have to be* conserved. No two electrons *can* be in the same mechanical state. It is *impossible* for there to be a perpetual motion machine. It is *impossible*, by any finite process, to reduce the temperature of an object to absolute zero. It is *impossible* to accelerate an object of non-zero mass to the speed of light. The question is, 'What is the source of this kind of necessity?'

The simplest examples of this kind of necessity are the 'laws' of chemistry which concern the basic properties of the various elements and compounds, their atomic and molecular structures, the kinds of bonding which are to be found in them, how they may be ionized, what kinds of salts may be formed from them, and so on. For example, it is essential to the nature of copper that it is a metal with atomic number 29 and electron structure 2.8.18.1; that it forms two series of salts, cuprous and cupric, the cuprous ions being monovalent and having unit charge $+1$, the cupric ions being bivalent and having charge $+2$. Similarly, it is essential to the nature of common salt that it is sodium chloride, its molecular formula is NaCl, the bonding is electrovalent; and it is essential to the nature of methane that it has the molecular formula CH_4, molecular structure:

H
. .
30H : C : H
. .
H

and that the bonding in this structure is covalent. Clearly, chemistry textbooks are full of 'laws' like these.

But are these really laws of nature? Armstrong, for example, claims that these 'composition laws', as they are sometimes called, are not genuine laws of nature, because they fail the test of relating distinct, non-overlapping universals.[10] Moreover, they are seldom called 'laws' by textbook writers, and most scientists would probably agree with Armstrong that they are just some of the basic facts of chemistry. The laws of chemistry, they are likely to say, are the principles governing chemical interactions, and not descriptions of the fundamental properties of elements and compounds. From our point of view, it does not matter whether we call these descriptions 'laws' or not. They are all necessary statements attributing essential properties to natural kinds, and clearly they are an important part of the theoretical basis for determining what chemical reactions are possible or impossible, or in what circumstances they will occur. Therefore, even if they are not themselves laws, it is plausible to suppose that the necessity of the laws governing chemical reactions derives, at least in part, from the essential natures of the chemical elements and compounds involved in these reactions.

Consider, for example, the law that when hydrochloric acid is electrolysed, hydrogen is liberated at the cathode and chlorine at the anode. The necessity of this law derives from the nature of the bonding between hydrogen and chlorine in hydrochloric acid, the fact that hydrogen ions are positively charged, while those of chlorine are negatively charged, and the fact that opposite charges attract each other.

In particle physics, the equivalents of the chemical elements are the various fundamental particles. Like the elements, they are natural kinds, and we are

[10] Armstrong is careful to make a distinction between the task of discovering what sorts of things or properties there are in the universe and how they are constituted, and the separate exercise of finding what laws link these properties together. In this framework, the discovery that copper has the atomic number 29 is classed as belonging to the first enterprise, as it is a truth about the internal structure or 'geography' of a universal. While Armstrong states that each enquiry is inextricably bound up with each other, he nevertheless argues that they are distinguishable (see Armstrong [1983], pp. 3 and 139).

now able to say quite a lot about their essential natures. For example, the electron is a stable lepton, with unit negative charge and spin 1/2; the proton is a stable baryon, with unit positive charge, spin 1/2; and so on. If you wish to say that these are not laws of nature, just basic facts about the fundamental particles, we do not mind. You may prefer to reserve the title 'law' for the principles which determine what particle interactions are possible or impossible, or in what circumstances they may occur. If so, we are willing to go along with this suggestion, for these principles would appear to have a similar status to the laws of chemical interactions, except that they are non-classical probabilistic laws. The same point may therefore be made with respect to the principles of particle interaction: we should expect the detailed explanations of these laws to depend on the essential properties of the fundamental particles. It is plausible, therefore, to suppose that the laws governing these interactions have to hold because it is essential to the natures of the particles involved that they should have the dispositions to interact with each other in the kinds of ways they do.

What goes for particles also goes for fields. Consider Maxwell's equations. It is our view that Maxwell's equations describe the essential properties of the electromagnetic field. To simplify the case, consider Maxwell's equations for otherwise empty space (*i.e.* where there are no charges or currents). These equations tell us: (a) how the rate of change of the electric field depends on the gradients in the magnetic field; (b) how the rate of change of the magnetic field depends on the gradients in the electric field; and (c) that neither the magnetic nor the electric field is divergent in these circumstances (*i.e.* there are always as many lines of force entering a region as leaving it).[11]

It is our contention that these equations describe the essential properties of the electromagnetic field. Such a field is necessarily a field which has electric and magnetic components which are interdependent in these ways. If a region of space contains no electric or magnetic field components which are so related, then it does not contain an electromagnetic field.[12] We hold that these equations represent the essential nature of the electromagnetic field for two reasons. First, the equations are evidently quite fundamental to the whole theory of electromagnetism. A very wide range of electromagnetic phenomena may be represented as solutions to these equations. Second, there is no rival conception of the essence of the electromagnetic field which would allow us to view the field equations as anything other than essential. If they are not essential, what is the nature of the entity which bears the varying properties of electric and magnetic field strength which happen to be related by these equations? The ether? No. There is no ether, there is nothing but the field.

[11] The magnetic field is in fact always non-divergent; the electric field is non-divergent in every region except where there are electric charges.

[12] The electrostatic and magnetostatic fields are the special cases where the magnetic and the electric field gradients respectively are zero.

If we are right about Maxwell's equations, then this supports an analogous way of regarding other kinds of field equations in fundamental physics. If Maxwell's equations describe the essence of the electromagnetic field, the equations of quantum field theory might plausibly be supposed to describe the essential natures of the fields which are or carry material particles. Thus the scientific endeavour to discover the essences of things is not clearly distinguishable from the quest for the most basic laws of nature. For at least some principles which nearly everyone would describe as 'laws of nature', *e.g.* Maxwell's equations, are directly concerned with essences. The question is whether all genuine laws of nature are descriptive of the essences of natural kinds in the same sort of way, or are derivable from laws which are. We think they probably are, and that this is the explanation of their distinctive kind of necessity.

However, to explain the necessity of the most fundamental laws of nature, *e.g.* the conservation laws, the principles of relativity, and the symmetry principles, it does not ring true to suppose that they are characterizing one specific kind of thing within the world. On the face of it, such laws neither ascribe properties to things within the world, nor describe correlations between things in the world. It is natural to construe them, rather, as characterizing not natural kinds *within* the world, but the world *as a whole*—as describing the kind of world in which we live.

Consider the conservation laws. These laws say what sorts of events and processes are possible. Basically, what these laws tell us is that in all self-contained events and processes certain quantities must be conserved. The quantities that must be conserved include energy, momentum, angular momentum, charge, lepton number, baryon number, and one or two other quantities. The conservation laws apply directly only to events and processes occurring in closed and isolated systems, *i.e.* systems where there is no inflow or outflow of matter or energy, and which are not being affected by any external forces. But all systems, other than the universe itself, are acted upon by external forces, *e.g.* gravitiation forces; and, in all macroscopic systems, except for the universe as a whole, there are inflows and outflows of matter or energy. So, strictly speaking, the universe is the only system which is perfectly closed and isolated. However, the external gravitational forces acting on a system are often so many orders of magnitude smaller than the internal forces involved (*e.g.* in particle interactions) that the external forces may simply be ignored. In cases where the external forces may not be ignored, or where there are substantial inflows or outflows of matter or energy, due allowance must be made for these influences when drawing up the conservation balance sheets. When all such allowances have been made, the conservation laws apply to all events and processes occurring in the universe.

Thus, the conservation laws have a special kind of universality. They are universal in the sense that the antecedent or reference class is a broad ontological category. They do not apply just to particular kinds of events or processes, but (when compensation is made for external influences) to *all* events and processes. The conservation laws thus have a scope which is wider than that of most other laws of nature. If we think of 'All As are Bs' as the assertion that everything whatever in the world is either 'not an A' or is 'both an A and a B', then there is a sense in which this claim is a universal one. But it is not universal *in scope* in the kind of way the conservation laws are. For if something is not an event or process, it could hardly be an energy-conserving, or momentum-conserving, or lepton-number-conserving event or process. Hence the conservation laws are not like ordinary laws or generalizations. The form of a conservation law is 'Every event or process which can occur is X-conservative', or equivalently, 'Events and processes which are not X-conservative are impossible'.

If this is the general form of a conservation law, then it is evident that it presents a serious difficulty for the DTA account of laws. The claim that events and proceses which are not X-conservative are impossible is not naturally construed as an assertion of a relation between universals. For what are the universals which must be said to be related? Are energies at times, momenta at times, etc., to be counted as primitive universals? It is, surely, an advantage of our theory that it does not require the introduction of any such dubious relational properties to stand in the required necessitation relation.

It is not essential to the category of events that they should be energy-conservative, or angular-momentum-conservative, or conservative in any other respect. Changes which were not in accordance with these conservation principles would still be events. But it seems to be of the nature of the universe we live in that such events should never, or at least very rarely, occur. A universe in which the forbidden changes did occur sufficiently often would not be our kind of universe. If, for example, lepton and baryon number were not at least very nearly conserved, then electrons and protons (if they could exist at all) would not be sufficiently stable particles for matter, as we know it, to exist. Therefore, if the reason for the necessity of the conservation laws is like the reason for the necessity of other less general laws, we must suppose it to be essential to the nature of the universe that it should be one in which these quantities are at least very nearly conserved. Without the assumption that the universe is one of a kind in which certain basic quantities are conserved in this way, we do not see any satisfactory way of giving an ontological explanation of their necessity. There is no equally plausible rival bearer of essential properties which could explain the necessity of the conservation laws. Therefore, we conclude, conservation laws are best understood as ascribing properties to the world *as a whole*, properties which are essential to the natural kind to which our world belongs.

We do not claim to know for sure what the conservation laws are. But we do say that when we get them right, they will describe essential properties of the kind of world we live in. Sometimes, of course, we posit conservation laws which fail to fit the facts in the actual world. Such misdescriptions of the world are not called 'laws of nature'; but they are 'law-like'. They are the kinds of things which would be laws, if only they were ture. They describe laws which could have held, but which do not actually hold. They describe a kind of world which, if it existed, would be distinct from the one which actually exists. There are many kinds of worlds which it is logically possible for there to have been; and that is why conservation laws are contingent. But what we are seeking, when we make conjectures about the conservation laws, are truths about the essential properties of this kind of world. It is to be hoped that the logically possible kinds of worlds we are describing will be getting closer and closer to the kind to which this world does in fact belong.

Conservation laws are especially instructive, because they lend themselves exceedingly eagerly to our general analysis of laws. Conservation laws do look, on the face of things, like descriptions of essential properties of the world as a whole. It takes an effort to rewrite them in such a way that they sound as though they are describing correlations of some parts of the world with others. It takes somewhat less effort, but some effort nevertheless, to rewrite conservation laws in such a way that they sound as though they are describing essential properties of mere proper parts of the world. Yet if you take conservation laws to assign essential properties to the kind of world we live in, then they can be taken more or less at face value. They fall into place without rewriting. Conservation laws are not, however, the only laws which fall into place neatly, if construed as describing the natural kind to which the whole world belongs. We urge, in fact, that *all* laws of nature are best understood in this way.

On present evidence, it seems that the kind of world we live in is a Minkowskian world with a four-dimensional, space–time structure. The laws of relativity and gravitation are of the essence of this structure. Worlds like ours are ones which display certain global symmetries. The symmetry principles derive from this. The world is one of a kind which consists basically of a relatively small number of kinds of fundamental particles or fields. The fundamental particles are known to occur in families, and the different kinds of fields are thought to be related. It is implausible that their nature should turn out to be independent of each other. We speculate, therefore, that when the fundamental nature of the world is better understood, it will be predictable what kinds of fundamental particles and fields there are, and what their essences must be. The particles or fields which exist in the world change and interact with each other in all of the ways permitted by the conservation laws. The interactions that can occur must do so with probabilities determined by the appropriate solutions to the field equations for the kinds of fields involved. This is the source, we suppose, of the probablistic laws of quantum mechanics. This is the kind of way we think the various laws of nature are to be understood as arising out of essences. They all derive ultimately from the nature of the world we inhabit.

Our theory of laws gives laws a kind of necessity which is quite distinct from logical necessity. It permits laws to be logically contingent, and yet also necessarily true—necessarily true of any world of the same natural kind as our world. It also grants laws of nature the right kind of universality. Essences of things in the world, and correlations which depend on the essences of such things may both contribute to the essence of the world as a whole. For the world may be such that it necessarily contains things of these kinds, which consequently must be correlated in these ways. That is why some truths about essences of parts of the world, such as the laws of electromagnetism, may properly be regarded as laws of nature. They contribute to the essence of the world as a whole. Essential properties of parts of the world, and correlations among parts of the world, constitute laws of nature just when they give us general information about the essential properties of the kind of world we live in.

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