Philosophy of Science: Laws

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Part I: Introduction[1]

For a long time the analytic tradition in philosophy of science focused on two main questions about laws: 'Can one reasonably take a realist stand about the laws of science?' and 'What distinguishes a law from other kinds of truths, especially from universal and statistical truths that are not laws?' For a discussion of the first question, look to the entry on 'realism'. The second was taken to be important because laws were thought to be ontologically fundamental – the basis responsible for all other natural facts – and to be the source of scientific prediction, explanation and technology. Nowadays these assumptions are under attack from a variety of vantage points and the second question is overshadowed by a prior one: 'Of what use are laws to begin with?' In Part III we shall discuss five overlapping positions that downplay the role of laws in science and nature. The slogan of all of these could be Ronald Giere's "Science without laws!" Before that in Part II we describe more traditional views that take laws as central, either as the repository of scientific knowledge (laws of science) or as the basic sources or governors for what happens (laws of nature).

Part II: Traditional views

What we call the *traditional view* takes laws to be a fundamental aim and a crowning achievement of modern science. The problem is only to find an adequate definition of them. What does it mean to be a law of nature? This question dominated metaphysics and philosophy of science in the second half of 20th century. Among the accounts of laws the most notable competitors are the *necessitarian theory* and the *systems view*. However, both of these accounts can be viewed as reactions to an older, Humean, view of laws. Hence we begin with a description of the Humean regularity account.

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1. The regularity account and its critique

David Hume's empiricist treatment of causality is usually credited as an inspiration for this view. [2] Hume took causal relations to be nothing but relations of constant conjunction between a cause and its effect, plus spatio-temporal contiguity. He granted that we feel a certain necessity in the causal connection between, say, kicking a ball and the ball moving, so that we are able to say that if the ball was not kicked it would not have moved. However, he claimed that the observed constancy of the connection between the kick and the movement of the ball is all that accounts for our feeling that there is a necessary connection between a cause and its effect. The feeling of determination is, for Hume, an addition of the mind, not an indication that there is necessity in the world.

By reducing causation to constant conjunction, Hume opened the possibility for a similar understanding of laws of nature. Laws, for a Humean, are just expressions of universal regularities of occurrent properties, propositions that say, as A.J. Ayer puts it, "what invariably happens".[3] Expressed in the language of first-order logic, laws are just the conditions in the world that make expressions like the following true: for all x, if x has a property F then x has a property G.

The account is attractive to empiricists who seek to emphasise the inductive and the a posteriori element in science, as opposed to the deductive and a priori nature of logical knowledge. Empiricists are also keen to economise on their ontology by eschewing all modal notions such as necessity. However, it is not hard to realise that this simple account fails. Two problems are most commonly cited.

First is the problem with *noninstantial* and *vacuous* laws. Vacuous regularities are those whose antecedent is always false, thereby making the universal implication true. Ayer's famous example of such a regularity is "All winged horses are spirited". Obviously, we would like to exclude vacuous generalisations by stipulating that the antecedent of a law has to be realizable. But that would in turn exclude noninstantial laws, such as Newton's law that a body on which no forces act will move inertially.

This problem gets more serious when we consider the implications of the fact that a law, for a regularity theorist, cannot refer to any unrealised possibility. The difficulty was pointed out by, among others, William Kneale[4] and George Molnar.[5] The latter reconstructed the argument as follows:

If "Something is F" is a statement of unrealised possibility then it is false. If it is false, then by the regularity view "Nothing is F" is a law of nature. So "Something is F" is inconsistent with a law of nature and hence is not a statement of unrealised possibility.

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[2] Hume 1946.
[3] Ayer 1998, p. 815.
[4] 1950, 1961.
[5] 1969.

Molnar concludes: "[F]or any contingent unrestricted existential proposition containing only empirical predicates, it logically cannot be the case that the proposition is false and that it is consistent with every law of nature".[6] This is very counter-intuitive, for we are asked to choose either truth or impossibility. This means that if there never was a chain reaction of plutonium within a strong steel shell containing heavy hydrogen, then there is a law of nature preventing it from happening. It also implies that there is a law of nature that there cannot be a river of Coca Cola.

The second obstacle is known as the problem of accidental generalisations. "All golden spheres are less than a mile in diameter" is true accidentally, whereas "All uranium spheres are less than a mile in diameter" is true in virtue of a law of nature.[7] The regularity account can make no sense of this obvious and important distinction.

What is known as the *epistemic* version of the regularity account attempts to address these problems by supplementing the occurrent regularity requirement with a proviso that laws are those universal generalisations towards which scientists have a special *attitude*. This special attitude can be readiness to use a generalisation as a tool for prediction, acceptance of the law on the basis of examining only few instances, treating the generalisation as a part of a deductive theory, etc.[8] (More on this later.)

The other philosophical accounts of law can be viewed as reactions to the regularity view, because they seek either to incorporate or to exorcise its empiricist intuitions, and to overcome its obvious failings.

2. The necessitarian view: motivation, theory and problems

One attempt to overcome the problems associated with the regularity view is to admit that laws of nature are not contingent, but necessary (in some non-logical sense of necessity). Indeed, regularity theorists often slide necessity or other modal notions through the back door when answering the standard objections. Consider Karl Popper's attempt to rescue the Humean theory. To accommodate Kneale's objections Popper proposed that a law of nature is a statement deducible from a statement function which is satisfied in all worlds that differ from ours at most in their initial conditions.[9] This, however, is no longer a purely Humean view since it makes use of the modal notion of possible worlds. Many philosophers conclude that we cannot after all make sense of laws of nature without some notion of necessity. But a positive account of this view was not articulated until David Armstrong, Fred Dretske and Michael Tooley pioneered their versions of a necessitarian view of laws in the 70s.[10]

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[6] p.81.
[7] van Fraassen 1989, p. 27.
[8] Ayer 1998.
[9] Popper 1959.
[10] Tooley 1977, Dretske 1977, Armstrong 1983.

The necessitarians reject the possibility of making sense of laws on any version of the Humean model, epistemic or otherwise. Dretske, for example, argues against all variants of these accounts.[11] He summarises the attempts to preserve a Humean element by the following formulae:

Law = universal regularity + X, where X can be a) high degree of confirmation, b) wide acceptance within the relevant community, c) readiness to use this regularity for explanation, d) deductive relations with a larger theoretical framework and e) predictive use. Nowadays we should also add explanatory power and ability to unify to this list. (See discussion below.)

The first two attempts to supplement the universal regularity are epistemic, and hence, as Dretske points out, are unable to clarify the ontological status of a law of nature. High degree of confirmation and a wide acceptance are characteristics of a *statement* expressing a law of nature, it is not an intrinsic characterisation of the law itself. If we take it to be the latter, then we are left with the uncomfortable conclusion that universal truths *become* laws of nature once we begin to treat them as such and that there are no unknown laws.

Being deducible from higher level statements cannot be definitive of a law either, for this requirement could not be satisfied by the most fundamental laws of a theory. We could, however, postulate that the genuine laws are 'nomologically ultimate', or not deducible from other universal generalisations plus some singular statements of initial conditions.[12] So if a universal generalisation can be shown to be a special case of another such generalisation, then it is not a basic law. On this view only basic laws have to be realised, and we thus reduce the problem of noninstantial laws (though we do not solve it). However, this modification won't eliminate the difficulty with accidental generalisations. Molnar asks us to imagine an accidental and an unexplainable (i.e. non-deducible from laws) event such as the death of a lone moa before reaching fifty. It is most counter-intuitive that this should be considered a basic law.

In response to these objections, it is often claimed that the main characteristic of a law is its explanatory power with respect to instances as well as lower-level generalisations. Yet, necessitarians claim, a universal regularity cannot suddenly acquire explanatory power, since many universal generalisations patently lack such power. The addition of this condition is ad hoc because we do not know how these generalisations can serve as explanations.

A better theory of laws, necessitarians propose, can be obtained if we postulate properties and connections between them. Since properties are universals, laws of nature are constituted by relations between universals, of the form 'F-ness yields G-ness'[13], so that "something's being F necessitates that same something's being G in virtue of the

[11] Dretske 1977.
[12] Molnar 1969.
[13] Dretske 1977.

universals F and G".[14] For example, the correct way to read Newton's 'F=ma' is as follows: the properties of being subject to a force *f* and having a mass *m* necessitate the property of accelerating in the direction of this force at *f/m* meters/second^2 *(N(F,G))*. The relation N(F,G) implies and explains a universal association between Fs and Gs, but is not in turn implied by it.

Modern necessitarians take necessitation to be a non-logical relation holding between the universals, but not between the particulars which may have the properties described by those universals. Hence, there is no strong necessitation relation between physical objects in the world, rather the relation holds only between properties and the 'mustness' is then 'passed on' to the particulars. Necessitarians such as Armstrong also espouse the Principle of Instantiation, which requires that universals be instantiated by real particulars in the world.

The view has some intuitive plausibility. Postulating universals can explain how laws but not accidental generalisations support counterfactuals: laws do so in virtue of an existing relation between the universals which accidental generalisations lack. Nevertheless, many philosophers find the account controversial. Bas van Fraassen's critique of the necessitarian conception of laws is perhaps the most widely cited.[15] He raises a dilemma. Its two horns are known as the *problem of identification* and the *problem of inference*.

The inference problem is an invitation to explain how the 'mustness' at the level of particulars is implied by the relation between the universals whose properties these particulars have. If it is a law that all As are Bs, how do we infer that an A *must* be a B? The inference is not logically straightforward. One could just postulate that lawhood *is* necessity and that all that is necessary is actual. However, then necessity cannot be a *ground* for lawhood, in which case we face the identification problem. What is the nature of the relation between universals such that it yields necessitation at the level of particulars? Just calling the relation necessity does not seem to help. This is the problem that led David Lewis to conclude that 'necessitation' cannot just be postulated. "It [necessitation] cannot enter into them [necessary connections between particulars] just by bearing a name, any more that one can have mighty biceps just by being called 'Armstrong'".[16]

3. Laws as best systems

Some necessitarians sought to justify their postulation of universals and relations between them by pointing out the advantages of this view over the regularity theory and claiming that universals are the best explanation for lawhood. However, such metaphysical extravagance did not suit the tastes of more traditional empiricists. The account of laws as best systems can be seen as an empiricist response to necessitarians, motivated to maintain an austere ontology of occurrent facts.

[14] Armstrong 1983, p.96.
[15] van Fraassen 1989.
[16] Lewis 1983, p.366.

a. The best balance of strength and simplicity

One such view is known as the Mill-Ramsey-Lewis account. It proposes that laws of nature be regarded as axioms or theorems that appear in those deductive systems that strike the best balance between strength of description and simplicity. The strength of a deductive system is usually defined by the amount of information it carries about the world, while simplicity is measured by how efficiently the system organises the disparate facts that describe the universe. Its proponents claim that it passes "the empiricist loyalty test"[17] or satisfies *Humean supervenience*, which requires that metaphysical and epistemological priority be granted to occurrent properties and regularities.[18] It is also argued that the systems account avoids the problems of noninstantiated laws and accidental generalisations. Admitting vacuous laws and accidental generalisations jeopardises a deductive system's simplicity, while eschewing noninstantiated laws can hurt its strength. Finally, systems theorists contend that the account explains why scientific theories aim at universality, coherence and parsimony.

Most critics of this account point out that strength and simplicity are far from unproblematic as criteria for lawhood. Both are highly dependent on the language used for theory formulation and lack an objective definition. Could they be more than slogans? Van Fraassen argues that in fact the Mill-Ramsey-Lewis account requires five criteria: theories have to be formulated in 'natural predicates', be true, simple, strong, and balanced between strength and simplicity. Can these criteria be maintained in the face of evidence from the history of science? For van Fraassen these criteria are too general for actual use in science, easily defeasible by other criteria and highly dependent on the starting point of an investigation.[19]

John Earman, a prominent systems theorist, argues that this account can and should be modified by replacing its highly general criteria for lawhood with more pragmatic principles: simplicity and information content can be maximised relative to a certain application of a theory. He also doubts that simplicity and strength as applied to deductive systems can by themselves secure lawhood.[20] It is possible though not obvious, he argues, that considerations of simplicity will necessarily exclude accidental generalisations. Earman thus suggests further constraints based on Mill's notion of indefeasibility.[21] Mill introduced the notion to distinguish between defeasible (or nonlawful) generalisations and the indefeasible (or genuinely lawful) ones. However, most philosophers agree that he failed to secure such a distinction.[22] Earman sees the distinction between fundamental laws and generalisations of fact as one of degree rather than of kind, where the former are set apart from the latter by the fact that their conditions

[17] Earman 1984.
[18] Lewis 1986, p.ix.
[19] 1989, p.56.
[20] Earman 1984.
[21] Mill referred to indefeasibility as *unconditionality* (see Mill 1947, Book III, chapter 5).
[22] For an argument to this effect see Mackie 1974.

of defeasibility are exceptional rather than generic. The methodology is as follows: take any generalisation of fact, partition its realisation conditions into *defeasors* (the states of affairs that guarantee the failure of this generalisation) and *enablers* (those that guarantee its success). If the enablers are exceptional, the generalisation is accidental, otherwise, it approaches lawhood.

Earman's addendum requires a better articulation. How are we to measure genericness and exceptionality? Simple statistical head counting seems to be too crude and sample-dependent. The condition is also very demanding and it is unclear that it can be applied to much of contemporary science. Take, for instance, the poor cousins of physics – the special sciences. There we have very little reason to expect a complete theory. As things stand now, the few laws that biologists and social scientists claim to have discovered rely on very specific *ceteris paribus* assumptions and hence, in Earman's language, have rather exceptional enablers. Lawhood in special sciences, on his account, should be characterised by generic defeasors and exceptional enablers! Many would argue that this is not a good reason to deny some principles the status of a law.

b. Explanatory power and unificationism

An alternative systems view to taking laws as those generalisations that balance strength with simplicity is to associate lawhood with explanatory power and to see that in turn as a matter of unification.

On this view, perhaps first articulated in contemporary work by Michael Friedman, the growth of understanding and, consequently of science, proceeds by formulating fewer and fewer laws as ultimate and reducing the number of independent phenomena we need to accept as basic.[23] To explain a phenomenon or a law is to show how it follows from more basic laws that also explain very different phenomena and laws. The role of laws on this account is to contain as much information as possible so as to serve as the deductive basis for the rest of our knowledge. For the deduction to count as a genuine unification (i.e. to avoid the reduction of the number of laws just by treating them as conjunctions), the deduced laws have each to be independently acceptable.

Another major proponent of the unificationist view of scientific progress and explanation is Philip Kitcher.[24] Kitcher criticises Friedman's account because it seeks to construct unification as a progressive reduction of the *number* of laws and insists that what really counts is "a reserve of explanatory arguments" that best unifies the statements accepted as true by a scientific community. According to Kitcher, the history of science shows that successful theories offered general patterns of argument that could be applied to many new phenomena. A Newtonian pattern, for example, requires us to specify a force function, mass of the bodies, distance, time, etc. If much of our presently accepted knowledge can be derived using the same argumentative pattern, then the argumentative

[23] Friedman 1974.
[24] 1976, 1981.

pattern with the strongest unifying power is the one that should and generally does get accepted.

Although rarely made explicit, the assumption that true laws of nature are few and unifying, has been the driving force behind this view. It motivates the claim that unification is the essential feature of explanation. This claim has recently come under fire.[25] But a more direct challenge to this account, both as a prescriptive and a descriptive ideal, comes from two directions. On the one hand, the unificationists have been attacked by students of modelling in science. Notice how Friedman uses 'laws' and 'phenomena' interchangeably. Since he wrote, many detailed case studies of the practice of application of theories in natural science have exposed the very tenuous relationship between fundamental laws and the actual phenomena.[26] According to this literature laws are, at best, only one element in explanation, an element whose relation to reality is neither deductive nor simple. (More on this later.)

A different challenge to the unificationist program can be posed by the special sciences, where explanation and modeling is achieved on a much more local and piecemeal basis than the unificationist view allows. Take, for instance, rational choice theory, hailed by its proponents to be the next grand theory of the social world. Unification of all, or almost all, human behaviour under the paradigm of rational choice is seen by many to be the main virtue of this research program.[27] However, when we inspect the few examples of the actual successful application of rational choice theory, the locality and fragility of the conditions under which the theory applies become evident.[28] The unifying power of this theory thus only conceals its real problems. We will return to these concerns below. Now we proceed to two of the most recent accounts within the traditional approach and a final challenge to the traditional view of laws.

4. Recent revivals of laws

Two recent approaches that continue to set laws centre-stage in science are Marc Lange's[31] and Michael Friedman's.[32] The former takes laws to be empirical though necessary principles, while the latter formulates a Kantian view of laws.

a. Lange: laws in terms of stability

Marc Lange aims to make his account "fit the facts of scientific practice".[33] If his account lives up to his claims, he will be able to avoid both importing necessity from outside, as

[25] Dupré 1993, Cartwright 1999.
[26] Cartwright 1983, Morgan and Morrison 1999.
[27] Ferejohn and Satz 1994.
[28] Guala 2001.
[29] 1995.
[30] p.224.
[31] 1997, 2000.
[32] 1999.

do accounts that ground lawhood in relations between universals, and distinguishing law-truths from others by prior metaphysical appeals, such as the assumption that the laws that science discovers must be simple and unifying. The account Lange offers also promises to provide degrees of necessity, which will allow, for instance, that the laws of biology and of the social sciences will be laws, like the laws of physics, but with a lower degree of necessity, as well as the possibility that there are distinct sets of truths that count equally as laws. The trick is in Lange's use of counterfactuals. He takes these for granted and does not suppose they are reducible to or supervene on facts about what actually occurs – thus diverging from all "Humean supervenience" accounts that take what is and is not a law to be fixed by the non-nomic, non-modal facts.

i. Laws and counterfactuals

Although Lange's account of lawhood relies on a close connection between laws and counterfactuals, it does not suppose, as traditional accounts do, that what picks out laws from other truths is the distinctive capacity of natural laws to support counterfactuals. Lange argues, instead, with those who hold a pragmatic view of laws (see below, section III.3), that accidental generalisations, just like laws, can support counterfactuals. His work begins rather from the idea central to current invariance accounts of laws (see section III.4b) that what is distinctive about laws is that they would continue to be true under the widest possible variety of circumstances: that is in some sense laws "collectively possess a maximal range of invariance".[34] He concludes that any non-nomic claim is a physically necessary non-nomic claim exactly when it is preserved under every counterfactual supposition consistent with the physically necessary non-nomic claims.

However, Lange's ultimate aim is to specify the relation between counterfactuals and laws "without using the concept of a law".[35] Saying that no accidental truth is preserved under every counterfactual consistent with the laws is simply trivial and question begging. The problem is not that the relationship between laws and counterfactuals is stated in terms of laws. The problem is that the relationship between laws and counterfactuals is explained in terms of laws, giving no indication as to why such a relation is special.

The key is the notion of stability. This is a relation to the non-nomic facts borne uniquely by the laws, whose scientific importance can be appreciated without presupposing that the laws are special in the first place. Such a relation, claims Lange, has "never before been identified".[36] Lange defines a set S to be *non-nomically stable* if and only if it is a logically closed set of true non-nomic claims that is preserved whenever it *could* be preserved without any logical inconsistencies; in other words, a *non-nomically stable* set is *maximally* invariant. In this parlance, Lange concludes that the set of all physically necessary non-nomic claims is non-nomically stable, i.e. maximally invariant.

[33] Lange 2000, p.6.
[34] Lange 1997, p.246.
[35] Lange 2000, p.10.
[36] Lange 2000, p.99.

Why though, is the range of invariance of non-nomically stable sets important? Lange shows that besides the trivially non-nomically stable sets of all logically true non-nomic claims and all true non-nomic claims, the set of all physically necessary non-nomic claims is most plausibly the only non-trivially non-nomically stable set. Scientific practice seems to suggest that we accept this set to be *uniquely* non-trivially non-nomically stable as a consequence of a root commitment we make in believing that some hypothesis states a law, that is, that it results from our best set of inductive strategies. Inductive confirmation is simply unavailable to claims that we do not regard as physically necessary. Since we cannot perceive what we believe to be an accident as having been inductively confirmed, no accident could be preserved along with the set of physically necessary non-nomic claims. Consequently, there can be no non-trivially, non-nomically stable set that contains an accidental truth. So, finally, the special and exclusive relation of laws to counterfactuals is this: *the set of physically necessary non-nomic claims is non-nomically stable (maximally invariant) and non-trivially stable (exclusive to accidents).*

ii. Multiple grades of physical necessity (lawhood)

Under Lange's scheme it is logically possible that there be more than one nontrivially, non-nomically stable set and, he claims, it is up to science to discover whether this is the case. This logical possibility incites Lange to introduce the notion of multiple grades of physical necessity.[37] Physically necessary non-nomic claims are preserved under the range of counterfactuals that they themselves pick out and this preservation must itself not be accidental. In this sense "there is a grade of necessity corresponding to a set (of non-nomic claims) if and only if that set is non-nomically stable, i.e. is *maximally* invariant" (preserved whenever it logically could be).[38] Associated with the set of all physically necessary non-nomic claims is a grade of physical necessity, which lies between the logical necessity associated with the set of all non-nomic logical truths and zero necessity associated with the set of all non-nomic truths. Since there could logically be non-nomically stable subsets of physically necessary non-nomic claims, there could also logically be multiple grades of physical necessity, the respective grades of necessity increasing when we move closer towards a 'kernel' of 'most' physically necessary laws.

b. A Kantian view of laws

Michael Friedmanhas recently proposed a vision of laws (especially those in mathematical physics) that combines and builds on insights from Immanuel Kant, Rudolph Carnap and Thomas Kuhn. This account is supposed to fulfil two tasks: to

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[37] Lange 1997, pp.260-261.
[38] Lange 1997, p.260.
[39] Lange 1997, pp.261-262.
[40] Friedman 1999.

describe both the structure of theories and the rationality of their development. We will concentrate on the first aspect.

The core of a physical theory, according to Friedman, is its constitutive principles. Friedman's examples of these principles include principles of geometry (Euclidian and Riemannian), calculus (including tensor calculus), Newton's laws of motion and Einstein's principle of equivalence. What unifies these statements is their special status with respect to the rest of our physical knowledge. They are, it is claimed, necessary conditions for the possibility of formulation of empirical problems and their treatment within this theory. The constitutive principles also explain the phenomenon of 'conceptual shift', which characterises scientific revolutions. To explain how Friedman appeals to a Kantian notion of the 'synthetic a priori'. In its original formulation, the notion encompassed, on the one hand, the necessary preconditions for doing the science of nature, and, on the other, eternal, unrevisable truths. Friedman suggests that we need to reject the second element of the Kantian notion in order to accommodate the possibility of radical revision of the basic principles of mathematical physics, which characterises the history of science. We are then left with a "relativized and dynamical conception" of the constitutive a priori: it makes natural knowledge possible but at the same time can change with the development of new physical theories.

On Friedman's theory, the basic laws of physical theories are not empirical principles. Rather they are a priori rules for studying nature. They supply elements of both Carnapian linguistic conventions and Kuhnian conceptual paradigms. The revision of these constitutive principles is not only an empirical but also a philosophical matter (see, for example, Descartes's justification of Galilean physics and Kant's treatment of Euclidian geometry and Newton's laws of motion). The progress of physics, Friedman concludes, is a progressive movement towards more and more general constitutive principles.

5. Generality and connectedness

The traditional empiricist view in almost all its forms supposes that laws must be *general* or *repeatable* in the sense of having a large and varied stock of instances. They must not in general be true of just a handful of objects (as in the non-lawful claim "All the coins in my pocket are copper") and in particular there are no laws of nature about single specific individuals but only about kinds of individuals. Constancy of conjunction between two features (like 'being a coin in my pocket' and 'being copper') will admit too many claims as laws if there are too few objects displaying these features. As we have seen the insistence on wide scope of instances is central to both main versions of the systems view. Erhard Scheibe argues that this assumption must be a mistake because it rules out as laws the esteemed laws of fundamental physics.[41] That is because of the total interconnection (what Scheibe calls 'coherence') of physical systems, an interconnection dictated by the laws of physics themselves.

[41] 1995.

Our world, Scheibe points out, is composed of a vast number of physical systems that are always interacting and modern physics shows us how to treat their composition and interaction. Our best theories, such as classical mechanics and quantum mechanics, contain dynamical laws that imply that there are *no* completely independent systems. For example, only perfectly isolated planets would actually orbit in a Newtonian ellipse; real planets' orbits are disturbed by the interfering influences of other planets, comets and so forth. Are these interfering influences not themselves covered by the inverse square law? Yes indeed, but the point is that Newtonian theory does not describe accurately until *all* influences are taken into account, which means not until the whole universe is taken into account. Hence "no subsystem of a Newtonian system is itself a Newtonian system".[42] Strictly speaking, only one solution to the gravitational equations can be realised in one spacetime. Similar remarks apply to quantum mechanics, where the inseparability of quantum mechanical states is the general rule.

The implication of these observations is that to require that laws have a large number of instances – indeed more than one – is wrong in principle. In practice we may very well discover systems that are independent or separable enough, and hence the universal quantifier in front of our laws will be a decent approximation. But, as Scheibe points out, it is still important to understand that multiplicity of instances, as far as our best physics is concerned, fails in principle. An implication of Scheibe's argument is that neither constant conjunction nor descriptive strength nor the power to unify, can be a characterizing feature of a genuine law wherever the kind of interconnectedness prescribed by basic physics theories obtains. On Scheibe's account, *no* law is non-trivially of the form 'All As are Bs'; a true law can only be of the form 'The whole universe is C'.

If correct Scheibe's argument undermines the strategy of the various systems views for substituting some kind or another of generality for necessity in distinguishing laws claims from other true claims about the world.

Part III: Science without laws

Those who attack laws, develop substitutes or ignore them altogether do so from a great variety of distinct points of view.

1. Models

One reason that models play a central role in philosophy of science nowadays is the *semantic view of theories*: the doctrine, popular throughout Anglophone philosophy of science but most articulated and well illustrated by the German structuralists, that a theory is not a set of claims as the Logical Positivists maintained but rather a set of

[42] p.224.

models.[43] The semantic view is not, however, in itself opposed to laws. The models that constitute a theory must be specified in some way; the standard way is to list the laws. The models that constitute the theory are the ones that satisfy those laws. Focussing on the models rather than the laws that they satisfy is thought to have a number of advantages, however. For instance the language and logic used to express the laws becomes unimportant and the relations between theory and the world can be thought of in terms of isomorphism of structure rather than the truth of a proposition.

In opposition to laws some authors are explicit in arguing that the models that constitute theory and that satisfy its laws are not the models that provide our best descriptions of the world.[44] The theory is at best a foundation from which more accurate models are built, by improvement and correction, models that in the end no longer satisfy the laws.

The arguments for this view are of two different kinds. The first involves a detailed investigation of the practice of the sciences themselves, which now occupies a great deal of attention in the philosophy of science.[45] The second focuses on the abstract and often mathematical nature of laws; the classical source for this kind of view is Pierre Duhem, a historian of science who wrote at the beginning of the 20th century.[46] If what happens is to be seen as a special case, or an instance, of the laws then it must be possible to describe – correctly – what happens as a literal *concretisation* for the circumstances at hand of the abstract description prescribed by the laws. 'Traversing an elliptical orbit' is for instance what in more concrete terms constitutes obeying Newton's abstractly stated laws for a system moving subject to the gravitational attraction of another body.

But the *concretisations* of abstract and mathematical vocabulary do not fit properly to the world, Duhem maintains. Our most accurate models are presented in a mix of material and theoretical descriptions, where the theoretical descriptions themselves come from a mix of theories at a mix of levels; and these cannot be squeezed back into the vocabulary that literally concretises the abstract descriptions from our laws, at least not from our fundamental mathematical laws. At best the theory concretisations form a core that with addition and correction can approximate the accuracy achieved with this more open mix of description. This is why Duhem claims that the laws of mathematical physics provide a mere *symbolic representation* of the facts of our world rather than an accurate abstract description.

More dramatic, though usually less explicit, opposition to laws comes from those who focus on the vast variety of different kinds of models used in science other than models that constitute theory – prototypes, blue prints, animal models of human behaviour, computer simulations, thought experiments, models of toy economies, idealisations, etc.[47] These are opposed to laws in the sense that they take away their business, the central functions that laws were thought to serve, or at least most of them: explanation,

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[43] Balzer, Moulines and Sneed 1987, see also Suppes 1977.
[44] Giere 1999, Cartwright 1983, Cartwright, Shomar and Suarez 1995, Suarez 1999.
[45] Morgan and Morrisson 1999, Giere 1999, Humphreys 2004.
[46] 1954.
[47] Morgan and Morrison 1999, Morgan 2001, Guala 2001, Humphreys 2004.

prediction, accurate and precise description and the provision of epistemic warrant for technological advance. In constructing and manipulating models we also learn new things not recognised before about the systems modelled, so they are the source of new knowledge of nature as well – yet another job previously assigned to laws. They do not however provide unification. Nor can models govern nature in the way that many take laws to do: models may describe, explain and predict what happens but no one thinks they can necessitate it.

2. Symmetries

Symmetries, especially those in contemporary physics, have also recently received attention previously reserved for laws. Symmetries of entities, equations, processes, etc. pick out their *invariances* under certain *groups of transformations*. Basically a symmetry is an operation that leaves some properties of an object unchanged. For example, in the case of a snowflake the unchanged property is the geometrical form. Some of the operations that preserve the geometrical form are rotation of 60 degrees, rotation by a full turn and reflection through an axis along any spoke. In physics, symmetry principles such as Galilean relativity (roughly, everything is the same if all systems in the universe are represented as if they had moved, say, three feet to the left) and Einstein's more complicated principles of relativity and general covariance (connected respectively with the special and the general theories of relativity), the symmetries in quantum theory, the gauge symmetry, etc. have been widely discussed by philosophers of physics as both sources and consequences of fundamental laws. Some philosophers invoke various symmetries as replacements for laws, others take symmetries to be a way of investigating the status of laws.

Van Fraassen belongs to the first group, arguing that the metaphysical notion of a law of nature should be rejected because all its definitions fail.[48] In its place, he invites us to accept the central role of symmetry arguments and principles, which are neutral between a realist interpretation as fundamental features of nature discoverable through science and a heuristic understanding on which symmetries are a guide to theorizing. (Van Fraassen himself prefers the latter as a part of his instrumentalism about science.) He argues that "at the most basic level of theorizing, *sive* model construction, lies the pursuit of symmetry."[49] Symmetry thus is a general ideal to which scientific theories aspire, and different sorts of symmetries can serve as particular clues to the building of models that are supposed to represent phenomena. For example, Galileo's principle that laws of physics are symmetrical between rest and motion with uniform velocity puts constraints on the form of these laws and hence is 'deeper' than these laws.[50]

Symmetries replace laws in van Fraassen's scheme not only in the sense that they constrain laws but also that they take on a number of the central virtues normally attributed to laws, especially *generality*. When a scientist analyzes a problem with the

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[48] van Fraassen 1989.
[49] p.233.
[50] p.223.

aim of giving it a theoretical treatment, she seeks to isolate the 'essential aspects' of the situation at hand. What counts as essential is theory-laden. She can apply existing theory to solve this problem if she establishes that this problem is 'essentially the same' as the one she already knows how to solve within her theory, or 'essentially the same' in all 'relevant aspects'.[51] Once this is done, the problem can be thought to be understood *generally*, which means "we know exactly which transformations do and which do not change the situation in relevant aspects".[52] Thus establishing all the symmetries of a situation leads to abstraction of its essential features and hence to its theory.

Postulations of symmetries is, of course, empirically fallible. We learn as we go which features of the situation are invariant under which transformations, and this, it is claimed, is what model-building is about. 'Laws' which are 'discovered' in its course are a function of the symmetries, or the generalities we require our theories to obey. For example, the principle of covariance in mechanics serves as a check on the law of conservation of momentum, so that the latter's logical status relative to this symmetry decides whether or not the law can be a basic principle of mechanics.

John Earman pursues a different direction.[53] He takes symmetries to be important for physical theory, but not in a way that dispenses with laws. For Earman pure philosophical analysis is incapable of providing results relevant to current scientific practice. His arguments start rather from fundamental issues in the foundations of physics. Laws of physics are, for Earman, the "sets of true principles that form a strong but simple unified system that can be used to predict and explain".[54] But which these are will depend on the symmetries they display, i.e. on their invariance under various transformations. Symmetries thus function at a meta level, helping to pick out the set of truths we should count as laws.

3. The special sciences, ceteris paribus principles and pragmatic laws

The traditional empiricist definition of law takes it to be an exceptionless generalisation with sufficiently general predicates. Perhaps the most noticeable feature of special sciences is the dearth or sometimes even the lack of such principles. What conclusions should we draw from this fact?

a. Biology

In biology the discussion among philosophers has been less about why laws are laws than about *whether* there are biological laws. Broadly speaking, the discussion has issued in four basic positions. First, some argue that at least some biological generalisations count as laws in the standard sense, for example Dollo's 'law', the Hardy-Weinberg 'law' and

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[51] p.235.
[52] p.236.
[53] 2002, 1993.
[54] 2002, p.3.

Mendel's 'laws'.[55] In direct contrast, others argue that there are no laws of biology.[56] A third position is that there are laws of biology, but that they are difficult or impossible for us to uncover due to biology's complexity. Charles Darwin offers a weak version of this position.[57] Stronger versions can be found in Alexander Rosenberg[58] and Barbara Horan.[59] Finally, others claim that there are laws of biology but want to widen the notion of what laws are.[60]

Elliot Sober's argument for laws of biology turns on a distinction between empirical laws and *a priori* laws. While he grants, with John Beatty and Alex Rosenberg, that biology has no empirical laws, he argues that "evolution is governed by models that can be known to be true *a priori*".[61] A simple, crude example of the kind of models he has in mind can be found in Malthus's claim about the relationship between resources and populations: other things being equal, the latter increases geometrically while the former increases arithmetically. A shortage of resources follows *a priori*, and this shortage (indirectly) governs certain evolutionary processes. For Sober, evolution – and so at least some of biology – is lawful in the sense that aspects of its path are completely constrained by *a priori* considerations.

Sandra Mitchell argues that most of the foregoing discussion is wrongheaded because it preserves a Logical Empiricist notion of law that is no longer defensible. In contrast to the metaphysical view that nature is simple and regular, Mitchell directs our attention to what she takes to be the contingency and complexity of the biological world and argues that our conception of what laws are (or should be) should shift to match this reality. On her view, it is a mistake to ask whether biology has any laws that resemble those of physics, since to do so is to ignore that in practice, generalisations across science differ in kind, and that the generalisations biologists use are often contingent in nature. Mitchell argues that we should replace the old view of laws as necessary and universal with one that stresses pragmatic virtues like cognitive manageability, degree of accuracy, and simplicity. When we do, she says, we will find that there a variety of 'pragmatic laws' of biology that operate in the explanations biology offers.

b. The social sciences

In philosophy of the social sciences the situation is similar: the traditional analyses of laws and their role in explanation have little to say about the successes and failures of economics, political science, sociology, etc. Some have argued that social science is forever doomed to produce only instrumentally justifiable knowledge.[62] Mitchell, as we

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[55] Sober 1993, 1997.
[56] Beatty 1995, Gould 1989.
[57] 1859.
[58] 1995.
[59] 1994.
[60] Mitchell 1997 and forthcoming.
[61] 1997, S548.
[62] Rosenberg 1994.

have seen, urges a more inclusive and pragmatic notion of lawhood. Still others seek to reject laws in favour of generalisations whose explanatory power derives from more methodologically feasible elements, such as invariance under intervention. (More on this later.)

The notion of a *ceteris paribus* law is well-known in philosophy of economics.[64] It is perhaps the most common way to cash out the conclusions derived from economic models. However, it is not unproblematic since we rarely know what the ceteris paribus clause stands for.[65] 'Other things' are never equal in real economies, so the condition carries little information. A more fitting notion is, perhaps, that of a causal tendency originated by J.S.Mill.[66] If Millian tendencies are to replace laws in social science, then we need to understand how they can, are and should be studied. Most models in economics derive tendencies a priori, using highly abstract concepts and very restrictive assumptions. Given how sensitive these derivations are to the exact conditions of the model it is hard to defend their empirical status. However, if we look at the practices of applied economists, we can discover some methods for identifying empirically robust tendencies and measuring their stability.[67]

It is clear that if philosophy of science is to make sense of the practices of the biological and social sciences, it needs to move beyond the traditional view of laws. Social scientists developed methodologies for evaluating different explanations of phenomena and for identifying robust processes on the basis of which we can build institutions and construct policy. Lumping all these practices under the heading of instrumental knowledge or immature science seems unilluminating. What is required instead is a critical analysis of the diverse methods for inferring explanatory principles in social science.

4. Causal principles

A few authors maintain explicitly that explanation, prediction, epistemic warrant for technology and necessitation all require causal principles rather than laws in any more traditional sense. Others, as with those who work on models, vote with their feet: they spend their time and effort not talking about laws but rather explicating what causal principles are, investigating how they can be confirmed and showing how they serve the bulk of functions laws are supposed to perform.

Causal principles differ from laws in at least three ways: i) Causes make their effects happen. So the idea of necessitation is built right into the relation between the antecedent and the consequent in a causal principle; it is not added on as in empiricist-based notions of law. ii) Causal principles can express themselves in regularities, but these regularities need not be universal – they can be probabilistic, and they need not be exceptionless –

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[63] Mitchell 1997.
[64] Hausman 1992.
[65] For an up-to-date discussion on ceteris paribus laws see Earman, Glymour and Mitchell 2002.
[66] Mill 1846.
[67] Guala 2001, Cartwright 1989.

they can have a *ceteris paribus* character. iii) Causal principles need not be eternal nor hold everywhere. This may be because they arise from more 'fundamental' eternal unchanging laws which lead to different derivative principles in different contexts or it may be just the way things are; authors writing on causation tend to remain silent on this.

The best attempts to provide a Humean analysis of causal principles that reduces them to facts about conjunctions all fail, even if purely probabilistic conjunctions are admitted. It seems that at some point some causal notion is needed in the analysis itself. So most authors currently restrict themselves to trying to provide an 'informative theory' of causation. The idea seems to be that there is some central fact about causal principles that marks them out from other kinds of principles. Interestingly, none of the central works attempt to explain what causal principles claim about the world, but rather just tell us some important characteristics they have.[68] The dominant current views include counterfactual accounts, manipulation accounts and causal process accounts, all of which are frequently on offer as theories of singular causation as well (read about them under 'causation'). There are two central accounts now popular specifically directed at generic causal claims, that is, at the causal principles that stand to replace laws:

a. Probabilistic theories of causality and Bayes nets

Causes make their effects happen. So if there are more cases of a cause occurring, there should be more instances of the effect (or higher levels of the effect) – unless something offsets this expected increase. So causes should increase the probability of their effects, *ceteris paribus*. Can we make this *ceteris paribus* clause explicit?

Standard social science techniques control for the effects of off-setting or confounding factors by looking for increase in probabilities of effects on causes in populations that are homogeneous with respect to the confounding factors. Overweight people tend to smoke and tend to have heart trouble. To study the effects of weight on heart conditions, we look to see if the two are correlated among those who do not smoke at all, or among those who all smoke the same amount. Probabilistic theories of causality, which originated in the work of Patrick Suppes, do the same.[69] "C causes E" is true iff the probability of E given C is greater than probability of E given ¬C, conditioning on any specific fixed arrangement of all the other causal factors for E. This formula of course is not a reduction of causality to probability because it relies on a causal notion to pick out the conditioning population. There is also considerable difficulty explicating what is meant by 'all' the other causes of E.

[68] Though see Cartwright (1989), who maintains that causal principles make claims about singular causal facts: "C's cause E's" claims that "In the long run, some C's, by virtue of being C's, do cause E's". See also Cartwright (forthcoming) and Christopher Hitchcock (2003) for an attack on the idea that there is any single central feature characteristic of causation.

[69] 1970.

Even supposing we know what we mean, we usually do not know all the other causes for a given effect. *Bayes-nets methods* can finesse this lack of knowledge.[70] They suppose essentially what Suppes supposed, that causes always increase the probability of their effect (which may not be true, for instance, if a cause and a countercause are correlated) and that this increase persists when we condition on fixed arrangements of the other causes, plus the assumption that the minimal causal structure obtains that is necessary for these other two conditions to hold. The computer programmes built using these methods can then generate for a given set of variables every set of causal hypotheses consistent with any given probabilistic information. All three of the assumptions about the relations between causes and probabilities are highly controversial, however, when taken as universally true.[71]

b. Invariance

Causal principles give rise to regular associations between the cause and its effect, either a 100% association or a merely probabilistic one. On the basis of such a regular association between two factors, C and E , we can hypothesise the principle that C causes E. On invariance accounts, like that championed by James Woodward, this hypothesis is true just in case the regular association persists when we intervene to change C.[72] This kind of invariance of the related association under intervention is thought to be characteristic of causal principles.

Two lines of thought motivate this claim. The first is close to the pragmatic view of laws described above. Causal principles are supposed to tell us what will happen as we change the cause; if the related regularity breaks down as we do so, we will not be able to predict what happens. The wider the range of interventions across which the regular association remains invariant, the more useful the causal principle is. The second generalises from features of common cause situations. Consider the regular association between the barometer dropping and storms, which arises because of a common cause, low pressure. If we manipulate the barometer this association breaks down, whereas we do not expect the association between low pressure and storms to break down were we able to manipulate the low pressure.

Several problems beset this view. If we *define* 'intervene' so that in intervening on C by definition we do not change the related association, the invariance account offers only a trivial necessary condition for causal principles. Can we offer a definition of 'intervention' that does not trivialise the result but under which causal principles really will be universally invariant under intervention? On the other hand, to defend it as a sufficient condition, we need to assure that associations will never remain invariant (in the right ways across all the right kinds of intervention) unless they express a causal principle. Showing that is a tall order, not yet filled.

[70] Pearl 2000, Spirtes, Glymour and Scheines 2000.
[71] Hoover 2001 (especially chapter 7.2), Cartwright 2001, for criticisms and answers see Spirtes forthcoming.
[72] Forthcoming.

5. Powers, capacities and mechanisms

For Aristotle the regularities of the world do not result from the governance of law but rather on account of substances acting according to their natures, which are constituted by their distinctive powers and dispositions.[73] As Eric Watkins reads him, for Kant too powers are absolutely central: Kant "holds that there are permanent substances along with changes of state in these substances and argues that such changes of state are possible only if substances exercise their causal powers in accordance with their natures. By thus accepting substances endowed with causal powers, Kant can grant that they stand in real relations to each other, relations that do not require (or even permit) further analysis, since it is built into the very nature of substances exercising their causal powers that they can determine the state of another substance in this way."[74]

Rom Harré and E.H. Madden were early advocates of powers in the post-war analytic tradition. For them "'X has the power to A' means 'X (will)/(can) do A, in the appropriate conditions, *in virtue of its intrinsic character*'".[75] A number of more recent authors similarly eschew laws, setting powers in their place, or something very similar such as capacities, mechanisms or dispositions.[76] There are a number of different kinds of advantages powers are supposed to have over laws:

a. Necessitation

Why are some features regularly associated with each other – say, an object's having a negative charge and any other object that is positively charged being attracted towards it? On a Humean view of law where laws are just, as Dretske says, universal regularities plus some add-on, laws just describe this association; they do not explain why it holds; nor do they necessitate it; nor do they provide any way in which the first feature necessitates the second.

Powers are supposed to do better on all three fronts. The regular association holds because negatively charged objects have the power to attract those that are positively charged, which they exercise continuously (other powers may be exercised spasmodically or only when triggered). The exercise of the power creates the second feature and in that sense necessitates it. This in turn also shows that the regular association of negative charge in one object with the attraction of a positive object is necessitated – so long as the connection between being negatively charged and having the power to attract a positively charged object is itself necessary.

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[73] Aristotle 1935.
[74] Watkins, *Kant and the Metaphysics of Causality,* Chapter 6, p.3.
[75] Harré and Madden, p. 86.
[76] Mumford forthcoming, Ellis 2001, Cartwright 1989 and 1999, Machamer, Darden and Craver 2000, Bechtel 1993.

This last is the reason that accounts in terms of powers tend to include something akin to Aristotle's natures, or Harré and Madden's stricture that the object that has the power – in our case the negatively charged object – has that specific power only if in attracting the positively charged object it is acting "in accordance with its intrinsic character". This is the source of the necessity in the connection between being a negatively charged object and the attractive force on a positive charge. An object with a negative charge must, because of its character or nature *as* a negative charge, have a very specific power to act in a very specific way – to create an attractive force on a positive charge.

The 'necessitarian view' that laws are necessary relations between universals also claims to be able to do these three jobs that the regularity view cannot. A powers view, though, is supposed to be better because it evades the inference problem (recall section II.2). The necessary relation between particulars is direct and does not need to be inherited from a necessary relation between universals: it follows from the concept of 'power' that the power to X cannot be exercised in the right circumstances without X obtaining. Still, matters are not so clear because of the connection between powers and natures. The power to attract positive charges is part of the nature of, or intrinsic to, negatively charged bodies. What account of necessitation is to be given that makes this relation a necessary one and will it fare better in being able to meet the challenges raised by law-endorsing empiricists than does the account that takes laws to be relations between universals? That question is still open.

b. Exercise vs achievement

As John Stuart Mill pointed out, much of modern science – both social science and natural science – operates by the analytic method. The overall cause acting at any time is analyzed into components, each of which has its own stable law of action – what Mill call a 'tendency law'. A tendency law dictates what a particular cause contributes on each occasion it is exercised and when we are lucky we will also have a law of combination that describes what results when a number of causes all operate at once. Classical mechanics with its separate force laws (the tendency laws) and its law of vector addition (the law of combination) is the paradigm.

How shall we understand these tendency laws? A traditional regularity view will not do since the effect is *not* regularly associated with its cause. One proposal to save the regularity account is to insert between the cause and the result actually achieved a new kind of item, a kind of shadow effect, that occurs each time the cause operates. For instance, a negative charge will not always produce a motion towards itself. So we posit that the charge always produces an *attractive force*, where that force itself, though it exists, has no effects on motion; only the total force, calculated by vector addition, can move an object.

The separate forces, it seems are idle. They do nothing. Or do they cause the total force? If so, the problem repeats itself. Mill's solution is to suppose that the separate forces *compose* the total force, as parts to the whole. This eliminates the need for a further causal story to explain what produces the total force and also shows how the separate forces themselves can play a causal role in the final result. Whether or not this proposal is reasonable for forces, it does not work where very different kinds of laws of combination are employed. For instance, the total current of a circuit is calculated from the tendency laws about the behaviour of resistors, capacitors and inductors by 'reducing' the actual circuits in which they sit to simple circuits, equivalent in their effect on the current, and even for the simple circuits it is farfetched to insist that the resulting current is *made up of* separate components, each contributed by one of the elements of the simple circuit.

Here again the ontology of powers and their exercise seems to have an advantage. A system may exercise its power and yet fail to produce the related effect if conditions are not right, for instance if it is interfered with or some other power operates in an opposed way. This is just what happens with causes where the analytic method is in play. If powers are admitted, tendency laws can be read as laws about the powers that a cause has and not about the results that are actually achieved whenever the cause is exercised.

c. Practices in specific sciences

Besides general reasons relevant across the sciences, powers or similar non-Humean items have been thought to be necessary to understand the practices and claims in specific sciences, most notably quantum physics, biology and the social sciences.

i. Quantum mechanics

It is well-known that in quantum mechanics we cannot ascribe to a system all the properties we would like to at once. For instance, if a system has a well-defined position, it cannot simultaneously possess a momentum. Nevertheless, were we to measure momentum we would find a definite result and in a long series of such measurements a clear probability distribution across the results will emerge. Karl Popper postulated that the system has a certain probabilistic *propensity* to produce momentum results, and in the observed distributions.[77] Propensities are like powers, in this case powers that need to be triggered by measurement: the effect (in our case the momentum) is not there all along; still, *something* – i.e. the propensity – is what explains how this kind of outcome results after a measurement and not something totally arbitrary and unsystematic.[78]

ii. Biological sciences

Recent work on the explanatory practices in the biological sciences emphasises notions other than law. The most prominent among them is *mechanism*, usually defined as a material system consisting of components with stable properties that produce stable behaviours.[79] A typical example of a mechanism in neurobiology is the phenomenon of

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[77] 1957.
[78] For discussion see Suarez 2003.
[79] Machamer, Darden and Craver 2000, Bechtel and Richardson 1993.

action potential, which involves a rapid surge and fall in the electric potential of a cell membrane and is responsible for firing of neurons in the central nervous system. Some mechanism theorists claim that laws necessarily underlie mechanisms, so that it is still laws that are ontologically fundamental.[80] Others, like Machamer, Darden and Craver take mechanisms (identified with particular entities and its activities) to be the proper ontic commitment for anyone who wants to make sense of neurobiology and molecular biology. Although laws sometimes enter into the description of the mechanism's activities, there are times when the regularities produced by mechanisms are not described by any laws. One could just call these regularities 'laws', but, according to Machamer, Darden and Craver, in the face of the immense explanatory potential of the notion of mechanism, this postulation has no philosophical advantages. In social sciences too, mechanism are invoked as the appropriate notion to understand the models that are supposed to represent and explain social phenomena.[81]

iii. Game theory and the social sciences

The dominant way of theorizing in economics nowadays is to offer game-theory models to represent or explain economic phenomena, from auctions to labour relations to the formation of industries. This mode of theorizing is sweeping through the rest of the social sciences as well, especially political science, where game theory is used to study, for instance, bargaining at the international level, formation of political parties, voting and legislation. For a game model one needs to specify the permitted moves for each player (in the famous Prisoners' Dilemma, for example, these are 'remain silent' or 'confess' for both players), the structure of the game (do the players move simultaneously or successively, are the moves 'one shot' or reiterated, etc.), the characteristics of the players (for instance that they are perfect calculators) and the pay-offs that the players receive for any combination of moves they are permitted.

The nearest thing to a law anywhere in the offing appears only when we turn to what might be called the *criterion for successful explanation.* A particular kind of behaviour is successfully explained by a game model when the behaviour can be modelled as that set of moves that secures the best payoffs for a player in light of what the other players do. If we are casting around for laws, it seems then as if the best candidate would be something like this: 'In the domain of behaviours to be explained, people always (predominantly?) behave in ways that maximises their gains.' That is not, however, how game models are presented. Rather the modellers talk about the *characteristics* of the agents – e.g. that they are perfect calculators, have full information and aim to maximise their pay-offs. This is language for which the ontology of powers and capacities is ideally suited. The agents have the *power* to do any calculation and they are *disposed* to maximise their own payoffs. The behaviour to be explained is the appropriate manifestation of these powers and dispositions in the game with the structure and rules on offer.

[80] Glennan 1996.
[81] Elster 1993.

As we have seen, throughout the philosophical discussion of laws and powers, the question always arises, “Which is ‘more fundamental’? Which explains which?”. In game models the answer seems transparent. The powers are fundamental and the laws are derivative. Why (if it is true) is it that people in the situations under consideration behave in ways that maximise their gains? Because they are disposed to maximise their gains and have the power to calculate how to do so. The maximising behaviour is the natural consequence when these dispositions and powers act unimpeded. Moreover, when we look at claims derived from these models (for example, in international diplomatic bargaining, democracies tend to threat less but more effectively), they too are not adequately viewed as laws. This is because derivations require a vast number of restrictive theoretical assumptions and hence we very rarely know what conditions in the world make these claims true. In these cases we may have evidence for a power or a disposition, but not for a law. The widespread use of game models suggests then that much of social science has abandoned laws in favour of powers and dispositions, at least for the time being.

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