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Laws and Dispositions*

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Laws are supposed to tell us how physical systems actually behave. The analysis of an important part of physical practice—abstraction—shows, however, that laws describe the behavior of physical systems under very special circumstances, namely when they are isolated. Nevertheless, laws are *applied* in cases of non-isolation as well. This practice requires an explanation. It is argued that one has to assume that physical systems have dispositions. I take these to be innocuous from an empiricist's standpoint because they can—at least in principle—be measured. Laws can be *applied* whenever such a disposition is present, they *describe* how the physical system would behave if the disposition were manifest.

1. Introduction. Physics is supposed to tell us how physical systems behave. The behavior of ideal gases, for instance, can be described by the following equation: $pV = RT$. The behavior of isolated hydrogen atoms can be described by the Schrödinger equation with a Coulomb potential. The description of the behavior of a hydrogen atom in a magnetic field requires another Hamiltonian. I take it to be uncontroversial that we find statements of this kind in physics textbooks, etc. I will call them *laws of nature*. So what laws of nature state is that physical systems of a certain kind, e.g., a massive particle together with a gravitational field display a certain behavior.

Discussions about laws of nature center upon the question whether the use of laws in science presupposes more than that mere regularities obtain in nature. The use of laws in science can be considered at various levels of abstraction. Usually scientific practice enters discussions on the nature of lawhood by way of rather abstract concepts such as ex-

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planation or confirmation (eg., van Fraassen 1989). In order to gain a better understanding of the function that laws have in physics, I will approach the topic by focusing on a more concrete aspect of physical practice, namely, the method of *abstraction*. In particular, I am interested in the conditions under which statements or descriptions of the type indicated above are applied to physical systems while this method is followed. Given the legitimacy of abstraction in physics—and I do not see any reason why one should question it—this practice provides strong evidence for an ontological conclusion concerning laws: *viz*. that the ascription of laws to a physical system presupposes the existence of a certain kind of disposition of the physical system.[1] In part, the following argument can be read as a rational reconstruction of some of the considerations Cartwright brought forward in arguing for the existence of causal capacities (Cartwright 1987, 183ff).

2. Application and Description—The Instantiation View. A necessary condition for a law to play a role in an explanation of the behavior of a physical system is that the law applies to the system. If it does not apply to the physical system in question it cannot play a role in its explanation. This is independent of whether one takes explanation to be an answer to a why-question or to be a D-N argument. Employing the notion of application has the advantage of being able to focus on the question of why a law is thought to be relevant for a particular physical system without having to present a detailed account of explanation, gaining understanding, or other epistemic activities. The domain of application of a law contains all those physical systems with respect to which the law is employed by physists in the abovementioned epistemic activities.

The reason why the conditions for the application of laws have not been the topic of intense debate is that there seem to be pretty obvious positions for the regularity theorist as well as for other views. Let us start with the regularity theorist. The basic intuition behind this view has been well captured by Carnap:

> The observations we make in everyday life as well as the more systematic observations of science reveal certain repetitions of regularities in the world. Day always follows night; the seasons repeat themselves in the same order; fire always feels hot; objects fall when we drop them; and so on. The laws of science are nothing more

1. There are certain epistemological problems in measuring dispositions that I will not deal with in this paper. I will only claim that some dispositions are measureable *in principle* (see Section 6).

> than statements expressing these regularities as precisely as possible. (1966, 1)

Laws describe the regularly occurring behavior of physical systems. "If we say that the regularities is all there is, shall we be so badly off?", van Fraassen asks (van Fraassen 1989, 183). He agrees with Carnap that all there is in nature is regularities. Nevertheless, he refrains from calling such descriptions of regularities "laws."

If laws describe regularities—and if that is all there is to be said about laws—it is fairly obvious under what condition laws can be applied to physical systems: precisely when the behavior of the physcial system is an instance of the regularity in question. For example, the law that hydrogen atoms behave according to the Schrödinger equation with Coulomb potential can be applied to a hydrogen atom only if the hydrogen atom behaves according to the Schrödinger equation with Coulomb potential.

Among those regularities which occur, non-regularity theorists typically try to distinguish those that are properly described as laws from those that should be counted as mere regularities. Let me just mention two seminal views.

According to Armstrong, this difference is due to a relation between universals (properties) that is instantiated every time there is an instatiation of a law but not in the case of mere regularities (1983, 85–88). This view implies the following condition for the application of laws. A law can be applied to a physical system if the relation between the relevant universals holds. Since this relation is supposed to somehow necessitate the regular behavior of the physical systems, it is therefore implied that a necessary condition for the application of a law is, that the physical systems in question display an instance of the regular behavior.

According to the view most notably proposed by D. Lewis, "a contingent generalization is a law of nature if and only if it appears as a theorem (or axiom) in each of the true deductive systems that achieves a best combination of simplicity and strength" (1973, 73). Thus, a law must be a true generalization in the first place, i.e., a description of a regularity. In order for such a generalization to be applicable to a physical system, the same condition as above has to hold, *viz.* the physical system in question must display an instance of the regular behavior.

Thus, according to both the regularity theorist as well as the non-regularity theorist, it is a necessary condition for the application of laws that an instance of the relevant regular behavior of the physical system is realized. This is what will be called *the instantiation view of laws* in what follows, and the condition it asks for will be called the *instantiation condition.*

3. The Instantiation View of Laws and Provisos. The problem with the instantiation view is that the condition for the application of laws is overly restrictive. The descriptions physics provides concern physical systems in isolation. I take a physical system to be isolated if its behavior is not disturbed or changed by other physical systems, i.e., if it behaves exactly the same way it would behave if it were the whole world. The problem that arises is, how to deal with all those cases where physical systems are not isolated.

It is exactly this problem that remains unsolved in a paper Hempel wrote in the late 1980s. He explicitly addresses our area of interest, *viz.* the conditions under which a law can be applied to a physical system. Hempel considers the description of a system of two interacting magnets. He then asks whether what the law says about the behavior of the system is disconfirmed if, due to the presence of disturbing factors such as an external magnetic field or a strong air current, the behavior deviates from what one expects. Hempel thinks that such a conclusion would be unjustified. In order to prevent it he proposes the introduction of provisos:

> The theory of magnetism does not guarantee the absence of such disturbing factors. Hence, [the description of the system] presupposes the additional assumption that the suspended pieces are subject to no disturbing influence, or, to put it positively, that their rotational motions are subject only to the magnetic forces they exert upon each other. . . . I will use the term "provisos" to refer to assumptions of the kind just illustrated, which are essential, but generally unstated, presuppositions of theoretical inferences. (1988, 23)

A little later he says:

> The proviso is to the effect not that [the description] is true, but that it states the *whole* truth about the relevant circumstances present. (1988, 31)

The introduction of the provisos as a condition of the applicability of laws makes explicit, according to Hempel, what has implicitly always been presupposed: A law can be applied to a physical system if what the law says with respect to it is the *whole* truth, i.e., if there are no disturbing factors. Thus Hempel's proposal comes to the same conclusion that we have come to in characterizing the instantiation view: It is a necessary condition for the application of laws that the relevant behavior is realized. Since disturbing factors would prohibit this realization, laws can only be applied to isolated systems. In introducing provisos Hempel may be successful with respect to making explicit what is commonly assumed anyway. The conception, however, is too restrictive. Hempel does not say how to deal with the case he started with. How shall we treat physical systems in the presence of disturbing factors?

Let me conclude this section by reformulating the problem that the instantiation view of laws must face. The instantiation condition for the applicability of a law is the requirement that the physical system in question behaves the way the law says it does. The relevant behavior has to be instantiated. This presupposes that the system is isolated in the sense that no disturbing factors are present. If there are such factors the law cannot be applied.

In the next section, I will present a method that is commonly used in physics and, furthermore, makes use of the fact that laws can be applied in cases where disturbing factors are present. If the instantiation view of laws were true, it would imply that this is not a legitimate method. This conclusion makes it necessary to look for an alternative account which makes sense of the applicability of laws in cases where disturbing factors are present.

4. The Method of Abstraction. In a textbook on quantum mechanics A. Bohm explains how to calculate the energy levels of carbon monoxide to a first approximation (Bohm 1986, 146). The carbon monoxide molecule is considered to be a combined system consisting of a rotator and a two-dimensional oscillator. The rotator's contribution to the energy levels is calculated without taking into account the presence of the oscillator. That is, the behavior of the rotator is described in abstraction. The energy contribution of the oscillator—i.e., its behavior—is calculated in abstraction as well. To all appearances, no such rotator exists. The carbon monoxide molecule is thus split up conceptually into two subsystems that are treated completely separately from each other. Both subsystems are described in isolation. Within the system of the carbon monoxide molecule, each subsystem has to be considered as a disturbing factor with respect to the other. Another example of abstraction is the behavior of metals. The metal is treated theoretically as a combined system of a crystal and an electron gas. The contribution of both of them to, say, the overall specific heat of the metal is calculated in abstraction from the other subsystem.

So the method of abstraction as it is used in physics can be characterized as follows: In a first step, the complex physical system is split up conceptually into subsystems. In a second step, these subsystems are treated as if they were isolated; their behavior in isolation is determined. Finally, the contributions of the subsystems are added up so as to determine the behavior of the complex system.

The method of abstraction as just described works if no interaction between the subsystems occurs. Even though the absence of interaction may not be the most common case in physics, explaining the system's overall behavior in terms of the contribution of subsystems is a widely practiced method in physics. On the basis of the instantiation view, however, this method is completely puzzling, as will be shown in what follows. This then should be considered a strong reason for rejecting the instantiation view and for seeking an alternative account that can explain the legitimacy of abstraction.

Let us discuss the difficulties of the instantiation view first. In the case of carbon monoxide we are dealing with one physical system, namely a carbon monoxide molecule. Three laws are applied to this physical system:

1) All rotators can be described by the Schrödinger equation with the following Hamiltonian: $\mathbf{H}_{rot} = \mathbf{L}^2/2I$, where $\mathbf{L}$ is the angular momentum operator and I the moment of inertia.
2) All oscillators can be described by the Schrödinger equation with the following Hamiltonian: $\mathbf{H}_{osc} = \mathbf{P}^2/2\mu + \mu\omega^2\mathbf{Q}^2/2$, where $\mathbf{P}$ is the momentum operator, $\mathbf{Q}$ the position operator, ω the frequency of the oscillating entity and μ the reduced mass.
3) All oscillating rotators can be described by the Schrödinger equation with the following Hamiltonian: $\mathbf{H} = \mathbf{H}_{rot} \otimes \mathbf{I} + \mathbf{I} \otimes \mathbf{H}_{osc}$, where $\mathbf{I}$ is the identity operator.

The challenge for the instantiation view or Hempel's proviso conception consists in explaining why and in what sense not only the last, but all of these three laws can be applied to carbon monoxide molecules. Neither the first nor the second law states the *whole* truth with respect to the oscillating rotator. The defense of the instantiation view must allow for the legitimacy of abstraction.

It has to be noted first that the *approximation approach* does not work: The first law *nearly* applies to the oscillating rotator, if the contribution of the disturbing factor to the energy levels is small. This might be true, but the relation between the two subsystems with respect to there being disturbing factors is completely symmetric. So, if the contribution of the oscillator is small as compared to the rotator, the application of the first law may appear justified. However, we are at a loss to understand why the second law can be applied as well.

The second option the proponent of the instantiation view might wish to take is the *independence approach*. There are three independent laws which describe three kinds of physical systems. There is one law for rotators, one law for oscillators, and one law for oscillating rotators. This is certainly correct. It is, furthermore, in accordance with the instantiation criterion of law-application. There are three systems that behave in different ways and the laws can be applied to them if the systems behave the way the laws say. However, if this is all one wants to say, abstraction cannot be practiced. The same laws that are used to describe isolated oscillators and isolated rotators are also employed when they are no longer isolated—in the presence of disturbing factors, so to speak. On the basis of the claim that there are three *independent* laws, it is not clear why the first law is not only used in the case of isolated rotators, but also for the description of oscillating rotators.

In a third attempt, the proponent of the instantiation view might opt for a *separation approach*. There really are only two laws. The third law contains no new information over and above the first two laws even with respect to oscillating rotators. As long as there is no interaction between the two subsystems, the oscillating rotator has to be considered as two independent physical systems and it is because of this independence that the method of abstraction is legitimate. That is, it is legitimate to analyze the behavior of the physical system, the proponent might want to argue, into the behavior of the subsystems because the separate subsystems are all there really is.

Here it must be objected, in the first place, that the third law *does* state something with respect to the combined system that is not contained in the first two laws, namely the way the contributions add up to produce the overall behavior. In the second place, it must be noted that by the instantiation criterion the first two laws cannot be applied to the subsystems of the oscillating rotator. This is so because laws can only be applied when an instance of the described behavior is realized. However, the energy levels of the isolated rotator and the isolated oscillator are not realized (in the sense of being measurable) when they are constituting a combined system. The only thing that can be measured is the energy spectrum of the carbon monoxide and this coincides neither with the spectrum of the rotator nor with the spectrum of the oscillator. There are no separate energy levels realized for the subsystems. So by the very criterion which the proponent of the instantiation view has to employ the first two laws cannot be applied to the carbon monoxide. The separation approach cannot explain abstraction. This is basically Cartwright's argument for the claim that the law of gravity is not true in the presence of other forces (1983, 54–73).

Against this argument, one might object that instantiation or realization should not be identified with measurability. Despite the fact that the energy contributions of the rotator and the oscillator cannot be measured, they are nevertheless realized in some sense, for otherwise they would not be able to contribute to the overall behavior. However, even if this use of "realization" is granted, the point still is that this strategy cannot be used by the defender of the instantiation view to explain *abstraction*. The only thing that can be identified *experimentally* is the energy spectrum of the carbon monoxide. Dividing this spectrum up into *contributions* of subsystems that are somehow realized might be unobjectionable. The contribution of a subsystem is the behavior it would display if it were isolated. But this move presupposes the identification of the subsystem's behavior in isolation, i.e., the method of abstraction, whose legitimacy is exactly what is in question here.

The fourth option is the *covering law approach*. There is really only one law, namely the third law. It is applied to oscillating rotators, oscillators, and rotators alike. The latter two are special cases of the former. Now this account is certainly true in the sense that by taking one or the other constant in the third law to be equal to zero, one obtains, say, the law for the rotator. In this sense the law for the oscillating rotator covers all the other cases as well. Thus, what we have is a recipe for generating laws for isolated systems from the law for the combined system.

However, the fact that we have a device to generate descriptions of different physical systems with the law for the combined system as a starting point does not imply that the instantiation condition for the application of a law governing isolated systems is fulfilled. After all, in the case under discussion the relevant physical system is not isolated, but a component of a more comprehensive system. The problem of justifying the applications of laws describing the constituents of a compound system has not even been touched yet. We do indeed make use of the recipe mentioned. We invoke the generated descriptions to characterize physical systems even in the presence of disturbing factors. But the question remains why we can legitimately do so. At least, according to the instantiation view, this is puzzling.

One might point to the fact that quantum mechanics tells us how to combine the descriptions of physical systems. And so it does. In Bohm's book it says:

> With the notion of the direct product of spaces we can formulate the basic assumption about the physical combination of two quantum mechanical systems:
> IVa. Let one physical system be described by an algebra of operators, A_1, in the space R_1, and the other physical system by an algebra A_2 in R_2. The direct-product space $R_1 \otimes R_2$ is then the space of physical states of the physical combinations of these two systems, and its observables are operators in the direct-product space. The particular observables of the first system alone are given by $A_1 \otimes I$, and the observables of the second system alone are given by $I \otimes A_2$ (I = identity operator).

> We reemphasize that IVa is a basic assumption of quantum mechanics and can only be justified by the fact that such physical systems exist. (1986, 147)

So it is this assumption or axiom that tells us that abstraction is legitimate, because it tells us how to combine the descriptions of subsystems in order to describe a combined system. It surely does and I have made use of it in formulating the third law. This prescription, however, does not accord well with the instantiation view. It is merely a variant of the fourth option. It does not explain why, on the instantiation view, the laws for rotators can be applied to rotators in the presence of disturbing factors even when no instance of the described behavior is present.

The main problem for the instantiation view is that description and application go together. The laws describe physical systems as isolated. In physics, however, laws are also applied to physical systems in cases in which they are not isolated, e.g., when they are constituents of a combined system. So what I propose is to separate description and application. Laws *describe* the behavior of physical systems under very special conditions that are hardly ever realized, namely, in isolation. But they can be *applied* to non-isolated systems as well. The question is, then, what the conditions for application are.

5. Dispositions. To say that laws describe how physical systems would behave in specified situations is to say that laws ascribe *dispositions* to physical systems. One must distinguish between possessing a disposition and displaying a disposition. A physical system displays a disposition that is ascribed by a law just in case the relevant conditions are realized, i.e., if the system is isolated. The physical system possesses this disposition whether or not these conditions are realized. Compare this to occurrent properties: possessing an occurrent property and displaying it always coincide. In case of dispositions this coincidence is restricted to special situations in which the manifestation conditions are realized.

The attribution of the display of a disposition is in general not unequivocal, it is, strictly speaking, a property of a combined system. Take the example of salt being dissolved in water. This is a state of the combined system of salt and water. We can take it both as a display of the salt's solubility and of the waters ability to dissolve salt. In the first case the water plays the role of the realization condition, in the second case the salt. However, in the special case we are interested in the realization condition is the absence of disturbing factors, the attribution is therefore unequivocal.

This seems to me a perfectly clear explication of the concept of a disposition. Dispositions have not fallen into disregard because the *concept* of a disposition is not clear. It is rather the epistemological problems supposedly connected to dispositions that led to their marginalization. Moreover, these problems provide the main motivation for attempts to reduce dispositions to occurrent properties, the latter properties seeming less dubious in epistemological respect (Mellor 1974). The problem in this context seems to be that it is generally assumed that we cannot have any evidence for attributions of dispositions to physical systems as long as the dispositions are not manifest or displayed. In the next section, I will distinguish two kinds of dispositions. I claim that with respect to one of them the evidence problem does not arise. Therefore I consider that kind of disposition as no less respectable than occurrent properties. They can therefore be used to solve our main problem, to develop an account of applicability-conditions for laws so as to allow for abstraction.

6. Continuously and Discontinuously Manifestable Dispositions. In order to explain how it is in principle possible to get empirical evidence for dispositions even though they are not manifest, I must introduce some rather cumbersome terminology. I would like to distinguish two kinds of dispositions: continuously manifestable dispositions and discontinuously manifestable dispositions.

The difference between continuously manifestable dispositions (CMDs) and discontinuously manifestable dispositions (DMDs) can be illustrated through the example of fragility and solubility. There may be various manifestation conditions for the fragility of, say, a glass. One of them is realized if the glass falls in a suitable way to the floor. The disposition is manifest precisely when the relevant conditions are realized. As long as it has not fallen it is not broken. This is an all-or-nothing affair. The state of the object changes *dis*continuously in the very moment the manifestation conditions are realized. Contrast this with the solubility of salt in water. The relevant manifestation condition is realized if enough water has been poured onto the salt. The behavior of the combined systems of salt and water is a continuous function of the degree to which the manifestation conditions have been realized. The more water that has been put onto the salt, the more manifest the disposition becomes. The transition to the realization of the manifestation condition is smooth. It is not an all-or-nothing affair. As already mentioned (Section 5) the display of the disposition is, strictly speaking, a property of the combined system of water and salt. Thus the smoothness or continuity of the transition has to be attributed both to the disposition of the water to dissolve salt and to the disposition of the salt to be dissolved in water. The solubility of salt in water as well as the ability of water to dissolve salt are examples of a *continuously* manifestable disposition (CMD), whereas fragility is an example of a *discontinuously* manifestable disposition (DMD).

The important point is that with respect to the availability of evidence for their obtaining CMDs and DMDs differ significantly. If we are interested in whether a system possesses a certain DMD, it is necessary for the appropriate manifestation conditions to be realized, unless the disposition in question can be reduced to other properties that are well known. Otherwise, we have no good reason to attribute a DMD to the system. Traditional accounts of dispositions, starting with Carnap, usually take all dispositions to be DMDs (Carnap 1936, 439).

The case of CMDs is different. Evidence for the claim that a system possesses a certain CMD is available even if the manifestation conditions are only partly realized. Let me illustrate how one might get evidence for CMDs, i.e., how one might measure CMDs even while they are not completely manifest.

Lithium fluoride is a crystal. Its specific heat can be expressed as follows:

$$c_V = (12/5)\pi^4 n k_B (T/\theta_D{}^L)^3$$

where c_V is the specific heat, if the volume is kept constant, n is the phonon-density, k_B the Boltzmann constant, T the temperature and θ_D the Debye-temperature, with $\theta_D{}^L = 730$ K (Ashcroft and Mermin 1976, 59).

This law concerns pure lithium fluoride crystals. A pure crystal of this kind probably has never existed and never will. This is at least what I will assume for the sake of the argument. The law attributes a behavior to the crystal in case there are no impurities that would work as disturbing factors. By assumption, this is a disposition that will never be completely manifest. We might, nevertheless, get empirical evidence for the disposition's obtaining. We may proceed as follows: First collect a few samples of impure lithium fluoride crystals. With the help of spectroscopic investigations and other means, we will be able to find out the amount of impurities in the samples. We can, therefore, order them according to the degree that the manifestation condition for the disposition is realized. The fewer the impurities, the more the relevant condition is realized. If we measure the specific heat of all of these samples, we are able to extrapolate to the behavior of the pure system as the limiting case.

As in the case of water and salt, the behavior of the combined system is a continuous function of the degree to which the manifestation condition has been realized. The transition to the realization of the manifestation condition is smooth. It is not an all-or-nothing affair. The less impurities there are, the more manifest the disposition of the lithium fluoride crystal becomes. If the disposition were discontinuously manifestable, something like a jump in the specific heat would occur as soon as the crystal becomes isolated. If one assumes that the disposition is a CMD, the extrapolation to the limiting case is completely legitimate.

One might object that if there is to be an extrapolation, the contribution of the subsystem we are interested in must be assumed to be fixed and unchanging rather than continuously manifestable. Something must indeed be kept fixed and unchanging if the behavior of the crystal is meant to be determined. It is certainly not the manifest behavior of the crystal, for then we would need no more than one measurement. What is fixed in these measurements is the *disposition* of the lithium fluoride crystal. However, this disposition is not manifest in any of the impure samples. This is why we need extrapolation. What is manifest instead is the behavior of the combined system of the crystal and the impurities. To take the lithium fluoride crystal to be a CMD with respect to its behavior in isolation is to assume that the combined systems behavior changes continuously on the way to realizing the manifestation condition, i.e., isolation.

The notion of a *contribution* that has been made use of in the above objection does not seem to me to be particularly helpful. The contribution of the crystal to the overall specific heat seems to be that part of it that the crystal would display if it were isolated. The notion of a contribution thus coincides with that of a disposition. Contributions somehow seem to be more manifest than ordinary dispositions because the term is used mainly with respect to such dispositions whose superposition with disturbing factors is particularly simple, *viz.* superposition through simple addition. In such cases, one is tempted to call the disposition or contribution manifest (even though it is not) because the abstraction of the contribution or disposition of the disturbing factors is so easy to handle.

The lesson is that CMDs are epistemologically as innocuous as any ordinary property. Empiricists therefore have no reason to recoil from employing the concept of a CMD.[2] We may therefore invoke the notion of CMDs in our solution of the application problem.

7. How CMDs Solve the Application Problem. According to the instantiation view description and application go together. A law can be

2. This is not to say that problems concerning the observable/theoretical distinction have been solved. "The disposition/display distinction cuts across the observable/theoretical distinction" (Mellor 1971, 80).

applied to a physical system only if the system realizes the behavior described in the law. This leads to the problem that laws can only be applied to physical systems in isolation, in contrast to the general practice in physics. As already indicated I propose to separate description and application. Laws describe how physical systems behave in isolation. Their application is not restricted to these cases, though. The question then is: What are the conditions under which a law can be applied to a physical system? Looking at the way physics is practiced, the most reasonable suggestion is that laws can be applied whenever the physical system possesses the CMD to behave the way the law says. The law of specific heat can be applied to the lithium fluoride crystal even in the presence of disturbing factors because we have evidence that the lithium fluoride crystal has the disposition to behave the way the law says, if it were isolated.

On the assumption that the condition of law application is the presence of a CMD, the method of abstraction no longer remains puzzling. What has to be explained is why and in what sense not only the third law, but also the first two laws can be applied to the system of the oscillating rotator. The first law can be applied to the subsystem of the rotator because the latter has a disposition to behave the way the law says when it is isolated. The same goes for the oscillator. So the laws can be applied to the subsystems of a physical system not because they describe how they *actually* behave, but because they describe how they *would* behave if they were isolated. However, if what the laws say concerns very special circumstances that are not realized in this case, why do we want to apply them in the first place? Because the way the systems actually behave in superposition situations is determined by their behavior in the isolated case—as long as there is no interaction. It is the third law that tells us how the behavior of the subsystems determines the overall behavior of the system. Here it is important that the dispositions are *continuously* manifestable. If they were DMDs, there would be no connection between the physical system's behavior in isolation and in superposition situations.

8. Relation to Other Views and Further Advantages. Joseph (1980) considers the view that laws have tacit *ceteris absentibus* clauses, i. e., to the effect that laws describe the behavior of physical systems in the absence of disturbing factors. This is the view I advocate. Joseph dismisses this account for the following reason:

> [t]his proposal conflicts with our preanalytic intuition that an analysis of the truth conditions for scientific laws must make it possible for all of them to hold in *this* (actual) world. It is unsatisfactory to

> be told that they can be explicated only in a way that results in each of them being true in a distinct (nonactual) world. (1980, 778–779)

It is exactly this worry that can be dealt with by introducing CMDs. For in order to legitimately *apply* laws, it is not necessary to rely on other worlds even though what the law *describes* may be counterfactual.[3]

So by analyzing a part of physical practice, *viz.* the method of abstraction, it turns out that it must be assumed that physical systems possess continuously manifestable dispositions. Laws of nature describe the behavior of physical systems when these dispositions are manifest. Their application to a physical system, however, requires only that the system possesses the disposition in question, not that it displays it completely.

As already mentioned, my argument starts from considerations that are similar to some of those in Cartwright's work on capacities. It turns out, however, that in order to understand the practice of abstraction,[4] it is not necessary to employ causal terminology. I take this to be an advantage, even though I must admit that continually manifestable dispositions are not yet widely recognized items in what is usually taken to be our ontological inventory. Nevertheless, I hope to have shown not only that CMDs can be measured, as Cartwright claims capacities can, but also that the very concept can be made reasonably clear.

Pietrosky and Rey have recently tried to save *ceteris paribus* laws from vacuity, that is from being either false or vacuous in the presence of disturbing factors. They are interested in an account that allows one to call laws "true" in such cases. On their account, someone who endorses a law in the presence of disturbing factors is committed to explaining the deviating behavior by citing relevant factors:

> On our view, then, a chemist holding that cp(pV $=$ nRT), is committed to the following: if a sample of gas G is such that pV $\neq$ nRT, then there are independent factors (e. g. electrical attraction) that explain why pV $\neq$ nRT with respect to G. (Pietrosky and Rey 1995, 91)

3. The notion of the truth of laws that Joseph employs has not been dealt with here besides citing Cartwright's claim that laws are false in superposition situations. Basically, it seems that we can either try to associate truth with description or with application. In the former case, laws would often be false even when successfuly applied as in abstraction. In the latter case, this consequence would be circumvented; nevertheless it would not be clear exactly how this use of "truth" is connected with the use of this concept in other contexts.

4. Cartwright describes this practice even though she employs the term "abstraction" differently (1987, 187).

Introducing implicit commitments into what the law says, allows one to call laws "true" even in the presence of disturbing factors. This view is perfectly compatible with my account of lawhood. Whereas their construal answers the question in what sense laws are true in superposition situations, I am interested in the ontological presuppositions of the application of laws in the presence of disturbing factors.

Besides making plausible why the method of abstraction is legitimate, the proposed view explains why laws sustain counterfactuals. Laws describe the behavior of physical systems in isolation, that is to say, situations that are very often not realized, i.e., situations that are contrary to fact. We have evidence for the physical systems' counterfactual behavior because we can measure CMDs even when they are not completely manifest.

A further advantage of the assumption that laws require dispositions is that it explains why physicists are not only interested in observation but also in experimentation, i.e., in creating phenomena. "To experiment is to create, produce, refine and stabilize phenomena" (Hacking 1983, 230). The best evidence for laws or dispositions is provided through situations in which disturbing factors are absent. If one assumes that physical systems are endowed with dispositions, the creation, production, etc. of phenomena can be understood as the realization of manifestation conditions. The knowledge one gains about the behavior of physical systems in isolation can then be used to understand the behavior of more complex systems as the method of abstraction illustrates.

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