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ORIGINAL ARTICLE

Ceteris Paribus Laws in Physics

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Abstract Earman and Roberts (in Synthese 118:439–478, 1999) claim that there is neither a persuasive account of the truth-conditions of ceteris paribus laws, nor of how such laws can be confirmed or disconfirmed. I will give an account of the truth conditions of ceteris paribus laws in physics in terms of dispositions. It will meet the objections standardly raised against such an account. Furthermore I will elucidate how ceteris paribus laws can be tested in physics. The essential point is that physics provides *methodologies* for dealing with disturbing factors. For this reason disturbing factors need not be listed explicitly in law-statements. In virtue of the methodologies it is possible to test how systems would behave if the disturbing factors were absent. I will argue that this suffices to establish the tenability of the dispositional account of ceteris paribus laws.

1 Introduction

Newton's second law has for a long time been *the* paradigm of a law of nature.

> A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed. (Newton 1999, 416)

For a long time it has been taken to be universal in the sense that it holds *under all circumstances*.[1]

Not all laws that play a role in the explanatory practice in the sciences are universal in this sense. Galileo's law '$s = ½ gt^2$' for falling bodies describes the

[1] For the purposes of this paper I disregard the fact that Newton's mechanics has been replaced.

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behavior of falling bodies provided they fall in a vacuum. The Schrödinger equation with the Coulomb-potential describes the behavior of hydrogen-atoms provided no external fields are present (for further reference: (H)).

Laws that describe the behavior of systems implicitly or explicitly assuming that there are no interfering factors or that certain conditions remain constant are usually called *ceteris paribus* laws (henceforth: cp-laws). As we have already seen cp-laws exist not only in biology or economics but also in physics. In this paper I want to argue that the objections usually raised against the claim that cp-laws might be respectable items in the natural sciences can be resolved in the case of (fundamental) physics.

In what follows I will focus on non-lazy, exclusive cp-laws. Exclusive cp-laws state that systems display a certain behavior *provided there are no disturbing factors*—whereas comparative cp-laws require that certain (unspecified) factors remain *constant* (See Schurz 2002 for this distinction). A cp-clause is *lazy* if all exceptions to the law (or disturbing factors) can be listed and it is merely a matter of convenience and the result of "laziness" that the conditions are not listed explicitly (see Earman et al. 2002, 283 for this distinction).

In the next two sections I will outline the main problems that accounts of cp-laws have to face. With respect to one of these problems, viz. providing truth conditions for cp-laws, I defend a dispositional account and argue that traditional objections can be met (Sects. 4, 5). In the remainder of the paper I explain how the other major problem can be met, i.e. how cp-laws can be tested. Even though what I have to say about the testing of cp-laws need not be understood in terms of the dispositional account, the two parts together establish that the dispositional account of cp-laws is a tenable option.

2 Provisos, Dilemmas and Other Frustrations

What is wrong with non-lazy, exclusive cp-laws? The problems concerning cp-laws are usually introduced by way of a dilemma. Many laws, such as Galileo's law are false if the law is read as a strict (universal) generalization. The claim "Whenever a body falls, it falls according to the equation: $s = \frac{1}{2} gt^2$" is false, because in water and other media the equation does not correctly describe the behavior of the bodies in question. Similarly the claim "Hydrogen atoms obey the Schrödinger-equation with a Coulomb-potential" is false if read as a strict generalization, because there may be electrical or magnetical fields. That is the first horn of the dilemma. If on the other hand the law is hedged by a *ceteris paribus* clause (henceforth cp-clause) Galileo's law becomes "Whenever a body falls, it falls according to the equation: $s = \frac{1}{2} gt^2$, *unless some interfering factor intervenes*". (Restricting the law to *free* falling bodies is hedging too.) Similarly the claim "Hydrogen atoms obey the Schrödinger-equation with a Coulomb-potential, *unless some interfering factor intervenes*" is hedged. These claims appear to be trivially true, at least as long as the notion of an interfering factor is not further specified. If what is meant by an interfering factor is simply 'a factor that makes the law turn out to be false', the hedged claim says no more than "The relation $s = \frac{1}{2} gt^2$ holds, unless it does not". [In what follows I will call this the 'Lange dilemma' (Lange 1993, 235)].

After discussing several attempts to solve this problem Earman and Roberts have drawn a rather pessimistic conclusion:

> […] there is no persuasive analysis of the truth conditions of such laws; nor is there any persuasive account of how they are saved from vacuity; and, most distressing of all, there is no persuasive account of how they meld with standard scientific methodology, how, for example, they can be confirmed or disconfirmed. In sum, a royal mess. (Earman and Roberts 1999, 470/1).

In the light of this assessment any account of cp-laws has to address at least two problems:

First, the *Semantic Problem*: What are truth-conditions for cp-laws? We have to be able to specify truth-conditions for generalization such as (H). Without the cp-clause the generalizations in question are false, if on the other hand a cp-clause ("provided there are no interfering factors") is added, the generalizations appears to become empty or trivially true (Lange's dilemma). Any account of cp-laws has to overcome this dilemma. The first step is to spell out the truth-conditions for cp-laws.

Second, the *Confirmation Problem*: How can these generalizations or cp-laws be confirmed or disconfirmed? Here the problem is that as long as the notion of an interfering factor is not constrained such generalizations appear to be immune to disconfirmation. Corresponding to Lange's dilemma there is a confirmation dilemma: Without the cp-clause the generalizations in question will almost certainly be disconfirmed; if on the other hand a cp-clause ("provided there are no interfering factors") is added, the generalizations appears to become immune to disconfirmation.

3 The Semantics of cp-laws

My proposal for the semantics of cp-laws will draw on suggestions that have already been discussed in the literature (Mill 1836; Cartwright 1989; Hüttemann 1998; Lipton 1999; Bird 2005). These suggestions, however, need to be augmented in order to be plausible vis-à-vis certain objections that have been raised.

One of these authors (John Stuart Mill) explicitly denies that laws have exceptions:

> There are not a *law* and an *exception* to that law – the law acting in ninety-nine cases, and the exception in one. There are two laws, each possibly acting in the whole hundred cases, and bringing about a common effect by their conjunct operation. […]. (Mill 1836 quoted after Mill 2008, p. 56, original emphasis)

Reading 'laws with exceptions' as 'exclusive cp-laws' and 'tendencies' as 'dispositions' Mill's suggestion can be reformulated as a pair of claims:

(A) Exclusive cp-laws ought to be read as strict laws about dispositions.
(B) If there appears to be an exception, i.e. if the tendency is not manifest, this should be understood as an effect of a 'conjunct operation' of more than one disposition.

In the remainder of this section I will provide evidence for (A). This evidence comes from part-whole-explanations. At the same time an analysis of part-whole-explanations allows us to make Mill's notion of a 'conjunct operation' in (B) sufficiently precise, so that a standard objection against dispositionalist accounts can be met.

3.1 Part-Whole-Explanations

Quantum Mechanics does not only provide us with the conceptual tools to describe the temporal evolution of a given physical systems in terms of the Schrödinger-equation. It also provides us with the means to construct descriptions of compound physical systems—given the descriptions of the parts on their own and their interactions. The part-whole-relation as it is described here should be distinguished from the mereological part-whole-relation. It obtains in virtue of physical composition laws. The fact that Quantum Mechanics has a law of combination or composition is not very often made explicit, but there are exceptions. The physicist Arno Bohm explicitly mentions as one of the basic assumptions or axioms of quantum mechanics:

> 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). (Bohm 1986, 147)

This is quantum mechanic's law of composition ('COMP' for further references) for the case of non-identical physical systems (or non-identical 'particles'). It is only in virtue of this law that part-whole-explanations in quantum mechanics are possible.

Part whole-explanation is certainly not the only kind of explanation to be found in physics but an important one. In solid-state physics, for instance, when we explain the behaviour of an ideal crystal we try to understand the properties of the crystal in terms of those of the ions and the electrons and their interactions. I will first illustrate this explanatory strategy through a simple example that does not take into account interactions and will then sketch an example that does take interactions into account.

The example in question is the explanation of the energy spectrum of carbon-monoxide (CO): carbon monoxide molecules consist of two atoms of mass m_1 and m_2 at a distance x. Besides vibrations along the x-axis, they can perform rotations in three-dimensional space around its centre of mass. This provides the motivation for describing the molecule as a rotating oscillator, rather than as a simple harmonic oscillator. The compound's (the molecule's) behavior is explained in terms of the behavior of two subsystems, the oscillator and the rotator. (The two sub-systems are not spatial parts but rather sets of degrees of freedom.) Bohm, who discusses this example in his textbook on quantum mechanics, describes this procedure as follows:

> We shall therefore first study the rigid-rotator model by itself. This will provide us with a description of the CO states that are characterised by the quantum number $n = 0$, and will also approximately describe each set of states with a given vibrational quantum number n. Then we shall see how these two models [The harmonic oscillator has already been discussed in a previous chapter of Bohm's book. A. H.] are combined to form the vibrating rotator or the rotating vibrator. (Bohm 1986, 128).

Thus, the first step consists in considering how each subsystem behaves if considered as an isolated system. The second step consists in combining the two systems by relying on COMP.

Bohm considers the following subsystems: (1) a rotator (the rotational degrees of freedom of the CO-molecules), which can be described by the Schrödinger equation with the Hamiltonian: $\mathbf{H}_{\mathrm{rot}} = \mathbf{L}^2/2\mathrm{I}$, where $\mathbf{L}$ is the angular momentum operator and I the moment of inertia. (2) an oscillator (the vibrational degrees of freedom of the CO-molecules), which can be described by the Schrödinger equation with the following Hamiltonian: $\mathbf{H}_{\mathrm{osc}} = \mathbf{P}^2/2\mu + \mu\omega^2\mathbf{Q}^2/2$, where $\mathbf{P}$ is the momentum operator, $\mathbf{Q}$ the position operator, ω the frequency of the oscillating entity and μ the reduced mass.

He adds up the contributions of the subsystem by invoking COMP. Thus, four laws are involved in this part-whole explanation:

1. The law for the compound (the CO-molecules): The compound behaves according to the Schrödinger-equation with the Hamiltonian $\mathbf{H}_{\mathbf{comp}} = \mathbf{H}_{\mathbf{rot}} + \mathbf{H}_{\mathbf{osc}}$. (This is the explanandum)
2. The law for the rotator (the rotational degrees of freedom of the CO-molecules): The rotator behaves according to the Schrödinger equation with the Hamiltonian: $\mathbf{H}_{\mathrm{rot}} = \mathbf{L}^2/2\mathrm{I}$.
3. The law for the oscillator (the vibrational degrees of freedom of the CO-molecules): The oscillator behaves according to the Schrödinger equation with the Hamiltonian: $\mathbf{H}_{\mathrm{osc}} = \mathbf{P}^2/2\mu + \mu\omega^2\mathbf{Q}^2/2$.
4. The law of composition (COMP) that tells us how to combine (2) and (3)

We explain the behavior of the compound as described in (1)—the explanandum—in terms of (2), (3) and (4)—the explanans.

The case considered is particularly simple because the parts do not interact. This is generally not the case.

One example of a part-whole explanation that takes into account interactions is the classical treatment of the ideal crystal. The regular structure of the crystal is generated by the ions. Within the so-called harmonic approximation they are, however, not supposed to sit motionless at their lattice-sites. According to the model the ions perform oscillations around the sites of the lattice, which are described as the mean equilibrium positions of the ions. These oscillations are considered small in comparison with the inter-ionic spacing, which means that only nearest-neighbor interactions are relevant. Furthermore, it is supposed that the potential between nearest neighbors is harmonic (Ashcroft and Mermin 1976, 422–427). On the basis of these assumptions we can specify the classical Hamilton function of the ideal crystal. The Hamilton function is constructed in terms of the dynamics of the constituents, which are understood as isolated (kinetic energy terms), and their interactions (potential energy). These contributions are added up

$$H = \sum_i E^i_{kin} + (1/2) \sum_{ij} U_{ij} q_i q_j$$

where $E^i_{kin} = p_i^2/2m$ is the kinetic energy of the parts, and $U_{ij} = \partial^2/\partial q_i \partial q_j$ $U(q_1 \ldots q_{3N})$ describes the interactions between the parts (with the q_is being coordinates). Adding up the contributions in this way presupposes a classical analogue of COMP for classical phase space. On the basis of the Hamilton function we can determine the thermal density of the crystal, which is given by

$$u = (1/V) \left(\int d\Gamma \, exp \{-bH\} H \right) \Big/ \left(\int d\Gamma exp \{-bH\} \right)$$

in which *V* stands for the volume, $d\Gamma$ for the volume element in crystal phase space and $\beta = 1/k_B T$ where k_B is the Boltzmann-constant and *T* the temperature. The thermal density of the crystal permits us to calculate the behavior of the compound system, including measurable thermodynamic properties such as the specific heat c_v.

What is different in this case is that the contributions of the parts don't add up linearly. This is taken account of in terms of the interactions/potential energy terms.

The explanatory strategy in part-whole-explanations can be summarized as follows:

The behavior of a compound system is part-whole-explained if it is—at least in principle—possible to deduce (to explain) it on the basis of

1. laws concerning the behavior of the components considered in isolation
2. laws of composition and
3. laws of interaction.

The important point for our discussion is that in fundamental (classical and quantum) physics we do have laws of composition and laws of interaction that tell us how the parts contribute to the behavior of a compound (see Hüttemann 2005).

3.2 Dispositions

Why are part-whole-explanations evidence for a dispositional reading of at least some laws?

As working definitions I employ the following notions of categorical and dispositional properties: A dispositional property is a property that, if it is instantiated by an object, may nevertheless fail to be manifest. In general it becomes manifest only given certain contingent conditions obtain. A glass, for instance, may be fragile but the disposition will become manifest (i.e. the glass will break) only if specific stimulus conditions obtain (e.g. striking of the glass). By contrast, if objects or systems possess categorical properties (e.g. the roundness of a billiard ball) they will be manifest unconditionally. Therefore, for a system to instantiate a categorical property and to manifest a categorical property amounts to the same thing. Note that on my reading there is no categorical difference between categorical and dispositional properties. The former are simply limiting cases of the latter.[2]

Why do we need dispositions to understand part-whole-explanations? A basic ingredient of the explanans in a part-whole-explanation is the reference to the Hamiltonians of the constituents which represent the behavior the constituents *would manifest if they were on their own*. However, this behavior of the parts (which is represented by the Hamiltonians for the parts) is not manifest while they are parts of a compound. While the usual examples of dispositions such as fragility and solubility need positive triggering conditions to become manifest, in our case the manifestation conditions are negative. For the behavior of a part, (as it is represented by a Hamiltonian) to be (completely) manifest it is required that the system in question is isolated or on its own.

The vibrating rotator illustrates the dispositional character of the properties of the parts: each subsystem contributes to the overall energy of the compound. But the behavior of the subsystems is not (completely) manifest. (The distinction between complete and partial manifestation will be drawn in Sect. 4.) If it were manifest, the associated spectral lines could be measured—at least in principle. But they can't. The only energy states that are manifest are those of the compound.

The explanation relies on how the parts would behave if they were isolated, i.e. on how the rotator would behave if the oscillator were absent. But the parts are not isolated. The manifestation of the behavior of the rotator and the oscillator together provide an instance of a 'conjunct operation', to use Mill's terminology. The behavior of the subsystems is not (completely) manifest due to the presence of the other subsystem[3]—however, the subsystems *contribute* to the behavior of the compound and are thus partially manifest. Similarly in the case of the crystal: The explanation relies on how every ion would behave if it were on its own, even though they are not.

To sum up: In part-whole explanations the behavior of compound systems is explained in terms of the behavior the parts *would* display if they were on their own. This behavior is not manifest because there are other parts or factors. The behavior that we attribute to the parts is thus a behavior that becomes manifest given certain circumstances obtain—the absence of disturbing factors. In this sense part-whole-explanations presuppose that the properties of the parts of the compound are dispositional properties. *A fortiori* we have good reasons to take those laws that describe the behavior of systems that might be parts of other systems to be attributing dispositions to physical systems.

What does the dispositional reading boil down to in the case of the law for the vibrational degrees of freedom of CO-molecules? The law-statement "The

[2] See Hüttemann 2009 for a detailed account of drawing the distinction between categorical and dispositional properties in this way. A more traditional account as for example "F is a disposition iff there are an associated stimulus condition and manifestation such that, necessarily, x has F only if x would produce the manifestation if it were in the stimulus condition." (discussed in Choi and Fara 2012, Sect. 2) would work too.

[3] Note that in this case one subsystem works as an interfering factor for another subsystem even though (at least in the model) there are no forces at work. It is an interfering factor in virtue of the fact that the second subsystem's behaviour is not (completely) manifest.

vibrational degrees of freedom of the CO-molecules behave according to the Schrödinger equation with the Hamiltonian: $\mathbf{H}_{osc} = \mathbf{P}^2/2\mu + \mu\omega^2\mathbf{Q}^2/2$" should not be read as attributing a categorical property to the (sub-)system in question (characterised as the vibrational degrees of freedom). If the attributed behavior were a categorical property it would be manifest unconditionally. That, however, is not the case, as we have seen. We should read the law statement as attributing the behavior in question conditionally—conditional on the absence of other factors—i.e. as attributing a dispositional property. The law-statement should be understood as claiming: "The vibrational degrees of freedom of the CO-molecules *are disposed to* behave according to the Schrödinger equation with the Hamiltonian: $\mathbf{H}_{osc} = \mathbf{P}^2/2\mu + \mu\omega^2\mathbf{Q}^2/2$". The relevant triggering condition is isolation.

3.3 The Solution of the Semantic Problem for cp-laws

If cp-laws (in the sense of law-statements) can be taken to attribute dispositions to physical systems we can easily provide a semantics for cp-law(-statements), so as to avoid the Lange dilemma. According to this account a cp-law(-statement) is true provided the type of system in question has the disposition that the cp-law-statement attributes to the system.

"cp: All As behave according to Σ" (where "Σ" stands e.g. for the Schrödinger-equation with a particular Hamiltonian) is replaced by "All As are disposed to behave according to Σ". Reconstructing law-statements as statements about dispositions rather than about overt behavior turns cp-laws into strict laws, because all As without exception have the disposition. No cp-clause is needed. Lange's dilemma does not apply.

4 The Dispositional Account: Objections and Replies

The dispositional account thus provides a neat solution to the Lange-dilemma. The dilemma does not even arise because what the law says ("All As are disposed to behave according to Σ") is no longer hedged by a cp-clause. However, there are obvious and well-known problems with this account:

Dispositions may be present without being manifest. This gives rise to the question whether citing a disposition does indeed anything to explain the actual behavior of a system.

> Thus if what one wants explained is the actual pattern, how does citing a tendency – which for all we know may or may not be dominant and, thus, by itself may or may not produce something like the actually observed pattern – serve to explain this pattern? (Earman and Roberts 1999, 451f)

However, in Sect. 3.1 we have seen how dispositions explain actually observed behavior. In the case of the behavior of carbon monoxide the explanation refers to the dispositions of the two subsystems – the oscillator and the rotator. The dispositions are described by (cp)law-statements: the dispositions to behave in certain ways provided there are no disturbing factors. Since the two subsystems mutually serve as disturbing factors, none of these dispositions is (completely) manifest. Nevertheless, both dispositions *contribute* to the overall behavior according to a law of composition. The law of composition (COMP) makes this contribution *quantitatively precise*: it determines the exact behavior of the compound if there is more than one factor present. It also makes the notion of *partial* (as opposed to complete) manifestation precise: A disposition is *partially* manifest if it contributes to the behavior of a compound system given the presence of other contributing dispositions. What the example illustrates is that because in fundamental physics there are explicit laws of composition, which tell us what happens if various dispositions are present (such as COMP in the case of quantum mechanics), Mill's 'conjoined operation' can be explicated and made quantitatively precise.[4] In the case of the ideal crystal it has to be taken into account that the contributions of the ions are modified by interactions. But also in this case the contribution of the dispositions to the behavior to be explained can be made quantitatively precise. Earman's and Roberts's objection can thus be dealt with.

Caveat: In proposing this solution I have relied on precise and strict laws of composition such as (COMP). *If* there are such laws the above objection can be rejected. Outside fundamental physics, for instance in chemistry or biology, there probably aren't such laws and similarly for non-fundamental sub-disciplines of physics. However, if there are local, phenomenological rules, which tell the scientists how contributions add up, the above account will work in these areas too.

A second problem concerns the question whether the dispositional account can indeed avoid the dilemma for exclusive cp-laws. Even though it is true that the laws on this construal no longer appeal *explicitly* to cp-clauses, the Lange dilemma seems to turn up at a different place (Lipton 1999, 166). The dispositionalist has to specify the triggering conditions for the disposition in order to give the disposition ascription a determinate content. The conditions under which the disposition will manifest itself are exactly those that require explicating the cp-clause (Lipton 1999, 166/7). The dispositionalist reconstructs the law "cp, all As behave according to Σ" as: "All As are disposed to behave according to Σ". This is informative only to the extent that the triggering conditions for the disposition can be spelt out. So here we are again—or so it seems. Something informative must be said about the cp-clauses.

By way of response I will distinguish two ways to spell out the manifestation conditions for the dispositions in question (which I have not distinguished up to this point). According to the first option ***the disposition to behave according to Σ*** becomes manifest provided there are no *interfering* factors. According to the second option ***the disposition to behave according to Σ*** becomes manifest provided there are no *other* factors at all (whether interfering or not), i.e., if the system in question

[4] On my account dispositions are "contributors": the presence of a subsystem's disposition makes a difference (contributes) to the behavior of the compound. What that difference is depends on the law of composition. This notion of contribution has to be distinguished from that of Molnar. According to Molnar "A manifestation is typically a contribution to an effect, an effect is typically a combination of contributory manifestations" (Molnar 2003, 195). Molnar's "effect" is what I call "the behavior of the compound"; in my terms the 'effect' is the manifestation of the dispositions of the compound. As I understand it the contributions/manifestations for Molnar are real entities that mediate between the disposition and the overt behavior (effect). I try to get along without such mediating entities.

is on its own—if it constitutes its own closed world, so to speak. The first option is problematic because something informative must be said about interfering factors and must be integrated into the specification of the disposition. As long as the notion of an interfering factor can be spelt out as 'whatever prevents the manifestation of the disposition' the disposition ascription is analytically true and thus trivial. The second option is more promising. According to this option the notion of an *interfering factor* is not an integral part of the specification of the disposition. Rather, the disposition becomes manifest if the system in question is on its own, *if it is isolated*. The problematic notion of an inferring factor can thus be avoided.

One might object that this move is of no great help because we still have to deal with an indefinite number of factors that need to be absent. Rejoinder: Talking about 'interfering factors' generated Lange's dilemma. If what is meant by an interfering factor is simply 'a factor that makes the law turn out to be false', a cp-claim says no more than "Every A is B, unless it is not" (see Sect. 2). We have avoided this term and have thus a precise claim under what conditions the systems in question will show the attributed behavior. But there is something right to the objection: This option has to deal with the following problem: According to this reading the dispositions become completely manifest in certain *ideal* situations that are never realized. But how can these ideal situations be relevant for the real world—given that there is an indefinite number of factors, which undermine isolation? The answer is that the ideal situations make explicit how the system would behave if it were on its own. And that is exactly what part whole explanations refer to in the explanans. It is assumed that the ideal case is relevant for the non-ideal case, because the ideal behavior *contributes* to the real situation and the law of composition gives us a precise account of this relevance.

However, there is another question that remains: How can law-statements that attribute these dispositions be tested in the presence of (a possibly indefinite number of) other factors? This is an important epistemic problem but does not concern the *semantics* of the cp-laws. I will now turn to the confirmation problem.

5 Testing cp-laws

A dispositional account of cp-laws is a tenable option only if it can explain how cp-laws can be *tested*. This is what I called above 'the confirmation problem' for cp-laws. In what follows I will present an account of the epistemic acceptability of cp-laws from a dispositionalist perspective.[5] More specifically, I will argue, following Pietrosky and Rey (1995, 93) that there must be an independently confirmable factor that explains why the consequent does not occur.[6] That requirement is not sufficient because there are well-known counterexamples (see Sect. 6). It must furthermore be

[5] The account developed in this section will help to dispell some of the worries raised by Schurz concerning the testability of what he now calls "ceteris rectis laws" (Schurz, this volume, Sect. 3).

[6] Pietroski and Rey require (among other things): *For all x, if Ax, then (either Bx or there exists an independently confirmable factor that explains why ¬Bx)* (my reformulation). The second disjunct (the case of ¬Bx) does not cite potential disturbing factors explicitly, but rather involves a second order quantification over potential interfering factors.

possible to vary the factor experimentally or theoretically so that we can determine how the system would behave in the absence of disturbing factors.

5.1 Example

Let me illustrate my claim by discussing two candidates for cp-law-statements:

> (N1) Every body continues in its state of rest or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it. (Newton 1999, 416)

According to the confirmation dilemma we are confronted with the following problem: Without the phrase "unless it is compelled to change that state by forces impressed upon it" it can easily be disconfirmed; with the phrase it appears to be immune to disconfirmation, because it seems to say not much more than: "unless it does not". Every counter-instance may be immunized by postulating the occurrence of some force.

If this assessment were correct and complete we would have exactly the same evidence for the following completely fictitious alternative to Newton's first law:

> (N1*) Every body rotates, unless it is compelled to change that state by forces impressed upon it.

Both N1 and N1* are hedged; they contain explicit cp-clauses. Both are furthermore on a par in that it is unlikely that we will ever come across a complete manifestation of the respective disposition.

Nevertheless we think of Newton's first law as true whereas we hold N1* to be false. But what are the reasons for holding N1 (in contrast to N1*) to be true? The short answer is that we have not taken into account that there are methodologies which allow us to test apparently immunized claims such as N1 or N1*. We accept N1 rather than N1* because N1 can be confirmed and N1* can be disconfirmed. Confirmation and disconfirmation work in these cases because physics provides methodologies for testing laws that pertain to ideal situations. The methodology allows us to determine what would happen if the interfering factors were absent. In every case of an interfering factor the influence on the systems' behavior can be made quantitatively precise. This allows us to see whether the different nomological connections postulated in N1 and N1* hold.

The quantitative determination of the influence of interfering factors can proceed by experimental or theoretical means. To give an example: A charged object may fail to manifest the behavior attributed by N1 due to the presence of a magnetic field. If we are able to manipulate the field we will see that the behavior of the charged object approximates more and more the behavior postulated in N1 if the force on the electron is minimized. This confirms N1. By contrast minimization of external forces on the charged object yields no approximation to the behavior postulated in N1*. This disconfirms N1*.

An experimental manipulation of a disturbing factor will not always be possible. However, there are also theoretical means to determine the influence of disturbing factors. If, for instance, a comet moves in the gravitational field of the sun, Newton's second law plus the law of gravitation will tell us how the comet would move if the mass of the sun were minimized and how it would move if the sun had no mass at all. On the basis of these laws we are able to determine that the comet would move according to N1 rather than according to N1*. One way of understanding this procedure is the following: We treat the system in question (the comet) and the disturbing factor (the sun) as a compound system. The behavior of the compound can be part-whole-explained in terms of the dispositions of the subsystems, their interactions and laws of composition. The part-whole-explanation provides a means to theoretically vary the interfering factor. We can just calculate what would happen if, for instance, the mass of the sun were different or if it would vanish.

The rationale behind both the theoretical as well as the experimental procedure is that what happens in the ideal circumstances (isolation) where the disturbing influences are not operating, continues to be a contribution to what happens when other disturbing influences are also operating. In moving from the ideal to the real world we add in the disturbances using the relevant law of composition as explained in Sect. 3.1.

5.2 Epistemic Acceptability

On the basis of the above considerations I suggest we should complement Pietroski's and Rey's requirement:

- For all x, if Ax, then (either Bx or there exists an independently confirmable factor that explains why ¬Bx) by the following condition:
- There is evidence for the claim that in the absence of disturbing factors, A is nomologically sufficient for B, i.e. (A → B) is a law.[7]

Such evidence presupposes that the quantitative influence of the disturbing factor in question can be determined, such that it is known how the system would behave in the absence of the disturbing factor.

The important point is that for a cp-law to be epistemically acceptable the potential disturbing factors need not be cited explicitly—it is not required that a finite list of factors can be presented.

6 Dealing with Counter-Examples

Let me finally show that on the basis of the augmented conditions for the epistemic acceptability of cp-laws counter-examples can be dealt with. Woodward (2002) has pointed out that the law "All charged objects accelerate at n m/s^2" qualifies as an acceptable cp-law for *any n*, according to Pietroski's and Rey's account. For *any n* it is possible to find an independently confirmable factor, e.g. electric fields that explain deviations from the cp-law in question.

In dealing with this case it is important to clearly distinguish the system from the disturbing factor. Part of the problem is that there are various readings of

[7] For a similar suggestion see (Schrenk 2007, 158–161).

Woodward's counterexample. One way to read the example is to take the charged object as the system in question and the electric fields as the disturbing factors. On the basis of our augmented account of the epistemic acceptability of cp-laws this reading yields *one* cp-law that is epistemic acceptable: "All charged objects accelerate at 0 m/s^2". For any other *n* the claim is false. Variation of the disturbing factors by either experimental or theoretical means yields the conclusion that in the absence of the disturbing factors (external fields etc.) charged objects do not accelerate. What we get is Newton's first law applied to charged objects.

According to another reading the system whose behavior is characterized by the cp-law is not the isolated charged object but rather the *charged object in a field F*. In this case the disturbing factors are *additional* fields over and above F. Again, if we vary the disturbing factors, i.e. the *additional fields*, we get just one cp-law as a result—not a whole class. In the absence of disturbing factors the acceleration of the charged object in F will be such and such. Thus, after (1) clearly separating the system under investigation and the disturbing factor and (2) taking on board our refined notion of epistemic acceptability, Woodward's examples cease to be problematic.

Two aspects of the testing of cp-laws have to be kept separate. First, we need to be able to know what would happen if no disturbing factors were present. For this we need an experimental or theoretical methodology that allows us to vary the disturbing factors. The second aspect of the confirmation/disconfirmation of cp-laws consists in checking the alleged nomological connection. In the case of the charged object in a field F these two aspects amount to the following. The first aspect consists in varying the *additional* fields in order to find out what happens in their absence. The second aspect consists in finding out how the charged object behaves in the field F, which is considered as a *part* of the system under consideration. This second aspect typically requires the variation of the charge and the Field F. This second type of variation, however, concerns factors that are *internal* to the system—it does not concern external disturbing factors. The second aspect, i.e. the variation of the system-internal factors, will be part of the confirmation of *any* law—whether cp or strict. What is characteristic of the confirmation of cp-laws is the first aspect: The experimental or theoretical variation of the disturbing factors.

7 Conclusion

Let me put things together: I have spelled out a semantics for cp-laws in terms of dispositions. The objections usually raised against dispositional accounts have been countered by spelling out Mill's notion of 'conjunct operation' in terms of composition laws and laws of interaction.

Secondly I have augmented Pietroski's and Rey's account of the epistemic acceptability of cp-laws from a dispositional perspective in order to show that a dispositional reading of cp-laws is tenable. For cp-laws to be confirmable the disturbing factors have to be variable either experimentally or theoretically, so that it can be determined whether A and B are indeed nomologically related.

Thus, a cp-law cp(A → B) is epistemically acceptable, if the following conditions are met:

1. For all x, if Ax, then (either Bx or there exists an independently confirmable factor that explains why ¬Bx),
2. There is evidence for the claim that in the absence of disturbing factors, A is nomologically sufficient for B, i.e. (A → B) is a law. Such evidence presupposes that the quantitative influence of disturbing factors can be determined, such that it is known how the system would behave in the absence of these factors.

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