

Pluralism and the Hypothetical in Heinrich Hertz's Philosophy of Science

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Abstract:

In this paper I argue against readings of Hertz that overly assimilate him into the thought of late 20th century anti-realists and pluralists.

Firstly, as is well-known, various images of the same objects are possible according to Hertz. However, I will argue that this envisaged pluralism concerns the situation before all the evidence is considered i. e. before we can decide whether the images are correct and appropriate. Hertz believes in final and decisive battles of the kind he participated in while doing experiments in electrodynamics.

Secondly, I will argue that the concept of representation is still quite appropriately applied to important aspects of images, namely when it comes to fundamental physical equations. In this context Hertz explicitly allows that "characteristics of our image, which claim to represent observable relations of things, do really and correctly correspond to them" (Hertz [1894] 1956, 9).

A final consideration is Hertz's consistent appeal to the concept of the hypothesis. I will argue that his use of the concept does not indicate that he contributed to an increasing hypothetization of science, if this trend is understood in a strong sense, i. e. as the belief that the correctness of scientific theories cannot be established for principled reasons. As mentioned, when it comes to experimental evidence Hertz believes in decisive battles.

1. Introduction

In the introduction to his *The Principles of Mechanics* Hertz famously claimed:

We form ourselves images or symbols of external objects; and the form which we give them is such that the necessary consequents of the images in thought are always the images of the necessary consequents in nature of the things depicted ... The images we here speak of are our conceptions of things. With the things themselves they are in conformity in *one* important respect, namely, in satisfying the above-mentioned requirement. For our purpose it is not necessary that they should be in conformity with the things in any other respect whatever. As a matter of fact, we do not know, nor have we any means of knowing, whether our conception of things are in conformity with them in any other than in this *one* fundamen-

tal respect ... Various images of the same objects are possible, and these images may differ in various respects (Hertz [1994] (1956), 1 ff.).

On the basis of these and similar remarks some writers have made a number of claims about Hertz's philosophy of science that I intend to comment on in this paper.

More particularly, I have in mind the following three claims. Firstly, Ludwig Boltzmann argues that Hertz's picture theory implies that it cannot be our *aim* to look for an absolutely correct theory. Rather, there might be different theories that are equally correct.¹ While Boltzmann maybe right that Hertz's theory has this implication, I want to argue that this was not Hertz's view. He conceived of the pluralism of theories or images in mechanics as a *transitory* stage in the development of science and was convinced that only one of the images can be the correct image in mechanics. Hertz – even in *The Principles of Mechanics* – aims to identify the unique theory or image.

Secondly, Gregor Schiemann has argued:

To one reality, which Hertz, too, conceives realistically, can now correspond a multiplicity of theories. The world seems remote and the concept of representation inappropriate (Schiemann 1998, 30).

Schiemann describes this as a “loss of truth in theoretical cognition” and as the “the loss of world in the image.”

While I think there is some truth in this picture of Hertz's account, I also think that the world has not been completely lost in his images. In fact it was one of Hertz's main objectives to figure out exactly what in a theory represents the world (or nature) and what does not.

Thirdly, I want to deal with Schiemann's claim that Hertz was part of a trend in the second half of the nineteenth century towards “an increasing hypothesization of scientific propositions” (Schiemann 1998, 28). While I will not deny that Hertz may have contributed to this development (due to a reception of his writings like Boltzmann's that misconstrues Hertz's views), I will argue that the notion of a “hypothesis” and *a fortiori* “hypothesization” – if taken in a strong sense – is not a very useful tool for characterizing the distinctive features of Hertz's philosophy of science.

The evidence for my claims relies on two points, which I will introduce in sections 2 and 3. In section 2 I will argue that Hertz's main ob-

1 “Daraus folgt, dass es nicht unsere Aufgabe sein kann, eine absolut richtige Theorie ... zu finden” (Boltzmann 1905, 216).

jective in his epistemological writings was the question of separating what in our knowledge is due to nature and what we as knowing subjects have added. This is an important point because Hertz believes that there should be an ultimate theory that separates these features. As it will turn out, Hertz's criteria for individuating theories allow for only one such theory. The second observation concerns Hertz's use of the term "hypothesis." In section 3 I will introduce a weak and a strong reading of "hypothesis." Only a strong reading of Hertz's use of "hypothesis" would provide evidence for his alleged pluralism. On the basis of this distinction, and the determination of his main epistemological objective, I will analyze his writings in electrodynamics and mechanics that touch on the issue of hypothesis and pluralism (sections 4 and 5).

2. The Constitution of Matter

In 1884, while in Kiel as a Privatdozent, Hertz delivered a popular lecture course entitled *The Constitution of Matter*. In the introduction to the lecture course he discusses the relation of physics and philosophy with respect to the question of the nature (or constitution) of matter. According to Hertz this used to be a genuine philosophical question. Presumably he has in mind not only ancient and early modern debates, but in particular the disputes about dynamism and atomism in the first half of the 19th century.²

However, according to Hertz, the natural sciences had by his time taken over the question from philosophy.

Today's philosophy, insofar as it is based on Kant, to an increasing extent removes the question of the constitution of matter from the sphere of its interests and assigns it to the natural sciences, reserving for itself at most a control over final results. There is no longer any doubt that we are here dealing with empirical facts and things that – as in the case of the number of planets and the chemical elements – cannot be dealt with a priori (Hertz 1999, 25).^{3,4}

2 See (Carrier 1990).

3 "Die heutige Philosophie, so weit sie sich auf Kant stützt, scheidet immer mehr die Frage nach der Constitution der Materie aus ihrem Interessenkreis aus und weist sie den exacten Naturwissenschaften zu, sich höchstens eine Controlle der letzten Resultate vorbehaltend. Es kann kein Zweifel mehr daran bestehen, daß es sich hier rein um Erfahrungsthatsachen [handelt] sowie um Dinge, die sich so wenig a priori entscheiden lassen, wie die Frage nach der Zahl der Planeten und

Hertz goes on to present an overview over the advances in chemistry and the kinetic theory of gases that provide evidence for an atomic structure of matter. Before discussing these issues in detail (this constituting the rest of the lecture course) he deals with some objections a philosopher might raise.

A philosopher might object that the physicist's account cannot answer the original philosophical question. Since the physicist's atoms are extended, the question of the constitution of matter can again be raised with respect to the atoms themselves. Hertz essentially replies that – while conceding that physics has transformed the original question – physics and philosophy deal with different questions and have different aims. The physicist deals with the facts of nature, while the philosopher deals with the difficulties the understanding has in conceiving nature.⁵

What is interesting in this context is the characterization of the philosopher's project. It is the philosopher's job "to present the facts consistently and to separate which of those are due to the things themselves and what we have added."⁶ Several times in his life Hertz takes up the question of what is due to nature or things themselves, and what is due to us.

For instance, in a newspaper-article on von Helmholtz's 70th birthday in 1891, Hertz characterizes von Helmholtz's research in physiology in terms of the following questions:

How is it possible for vibrations of the ether to be transformed by means of our eyes into purely mental processes which apparently can have nothing in common with the former; and whose relations nevertheless reflect with the greatest accuracy the relations of external things? In the formation of mental conceptions what part is played by the eye itself, by the form of the im-

der chemischen Elemente ...” (The translations from *Die Constitution der Materie* are mine. In some cases I have consulted Jesper Lützen's translations of some passages.

- 4 For an analysis according to which both the *Die Constitution der Materie* as well as *The Principles of Mechanics* fall into a Kantian tradition of a “metaphysics of corporeal nature” see (Hyder 2003). For a critical discussion see (Lützen 2005, 123 ff.).
- 5 “Ich untersuche die Thatsachen der Natur, und Du untersuchst die Schwierigkeiten, welche der menschliche Verstand findet, sie zu begreifen” (Hertz 1999, 32).
- 6 “... die Thatsachen begrifflich widerspruchsfrei darzustellen, zu sondern, was von ihnen in den Dingen selbst liegt, und was wir hinzuthun, ...” (Hertz 1999, 32).

ages which it produces, by the nature of its colour-sensations, accommodation, motion of the eyes, by the fact that we possess two eyes? Is the manifold of these relations sufficient to portray all conceivable manifolds of the external world, to justify all manifolds of the internal world? (Hertz 1896, 336).

These questions concerning visual perception can be asked with respect to all of knowledge. Thus Hertz continues:

We see how closely these investigations are connected with the possibility and legitimacy of all natural knowledge. The heavens and the earth doubtless exist apart from ourselves, but for us they only exist insofar as we perceive them. Part of what we perceive therefore appertains to ourselves: part only has its origin in the properties of the heavens and the earth. How are we to separate the two? (Hertz 1896, 336/7).

In what follows I will try to show that Hertz's epistemological considerations and even some of his work in theoretical physics is best understood as an answer to this question: how are we to separate what is due to the things (or to nature) from what we have added? It will become evident that what he considers as a philosophical question at first will turn into a question that a (theoretical) physicist has to deal with.

To return to *The Constitution of Matter*: Hertz's reply to the second philosophical objection is already an attempt to come to terms with the issue I have just sketched. The objection concerns the properties we attribute to atoms.⁷ It seems that we cannot attribute to atoms any of those properties which we attribute to macroscopic objects. On the one hand, there are sensible (secondary) properties like color, which for all we know atoms do not have. But, on the other hand, even in the case of other macroscopic properties like elasticity we cannot attribute them to atoms because the main motivation for atomism is that we envisage explanations of the macroscopic properties in terms of those of the atoms. To attribute macroscopic properties to the atoms would undermine this explanatory project. So it seems that nothing remains.

Let us answer in the name of physics as follows: First, there still remains something if we leave out everything we have imagined. There remains a system of conceptually defined magnitudes which are connected among themselves and to the macroscopic properties of matter via strict mathematically formulated relations. Even if it is not allowed to consider these for their own sake, and to attribute conceivable meanings to them,

⁷ For a discussion of the background of this objection see (Heidelberger 1993, 205 ff.).

they retain their value as auxiliary magnitudes for the sake of those relations.⁸

This seems to be a first attempt to separate what is due to nature and what we have added ourselves. If we subtract that which we have imagined (*alles Gedachte*), what remains is a “system of conceptually defined magnitudes which are connected among themselves and with the macroscopic properties of matter *via* strict mathematically formulated relations.” Hertz considers the following example:

If it is not, for example, permitted to talk about the diameter of the atom in the strict sense, but what I call the diameter of the atom for a particular gas retains its meaning: It is that length on the basis of which I can establish a relationship between the heat conductivity of a gas, its internal friction, its dielectric constant and its refractability.⁹

In this case the relationship that remains if we subtract everything imagined is that between the heat conductivity of a gas, its internal friction, its dielectric constant and its refractability, whereas the diameter of the atom cannot be taken to be a literal description of what there is – it is (merely) imagined (*gedacht*). So there is a contrast of two kinds of features – the relationship between heat conductivity, internal friction, etc. can be read literally or realistically, whereas claims about the diameter of the atom should not be read literally or realistically.

But how are we to understand the non-literal descriptions, e. g. of the atom? Hertz considers two options. First, fictionalism: According to Hertz, many physicists are content to consider atoms and their properties merely as useful fictions (*Hilfsfictionen*). According to such a conception it is the aim of a theory to give a simple description of ob-

8 “Lassen sie uns darauf im Namen der Physik das Folgende antworten: Zunächst bleibt immer noch etwas übrig, wenn wir alles Gedachte fortlassen. Es bleibt übrig ein System von begrifflich definirten Größen, welche unter sich und mit den makroskopischen Eigenschaften der Materie durch streng mathematisch formulierte Beziehungen verbunden sind; ist es nicht erlaubt dieselben um ihrer selbst willen zu betrachten, und ihnen vorstellbare Bedeutungen beizulegen, so behalten sie doch ihren Werth als Hilfsgrößen um jener Beziehungen willen” (Hertz 1999, 35).

9 “Ist es mir also z. B. nicht erlaubt, im eigentlichen Sinne von dem Durchmesser eines Atoms zu reden, so behält doch das, was ich den Durchmesser eines Atoms für ein bestimmtes Gas nenne, seine Bedeutung: es ist eine Länge, mit deren Hülfe ich eine Beziehung zwischen Wärmeleitfähigkeit des Gases, seiner inneren Reibung, seiner Dielectrizitätsconstanten und seinem Lichtbrechungsvermögen aufzustellen vermag” (Hertz 1999, 35).

servable phenomena. What transcends sensation is classified as a mere fiction, a fiction that helps to achieve simplicity. Given fictionalism, the properties we attribute to matter have to fulfill two conditions: First, their introduction has to be consistent and, second, the calculations that ensue should be as simple as possible – “that is, they have to be appropriate (*zweckdienlich*)” (Hertz 1999, 35).

The fictionalist reading, however, is *not* the one Hertz advocates. Hertz does not consider the properties and relations in question to be fictions that serve the purpose of achieving a simple description of observed phenomena. Rather, he considers them to be *necessary conditions for imagination* (*Vorstellbarkeit*). According to Hertz it is a general and necessary condition of the human mind that we can neither represent things intuitively (*anschaulich vorstellen*), nor define them conceptually (*begrifflich definieren*), without adding properties (Hertz 1999, 35).

What we add are therefore not wrong conceptions, rather they are the conditions for imagination. We cannot simply take them away and replace them with better ones; rather, we either have to add them or to do without conceptions in this realm.¹⁰

It is in this context that Hertz introduces the notion of a *picture* for the first time to capture the idea that theories contain both features which can be taken to represent reality and others which depend ultimately on the human mind.

Thus let us guard ourselves from believing that we can investigate the nature of the things themselves by considering the atoms; let us also guard ourselves from confusing the non-essential properties, which we are forced to ascribe to them, with the essential properties, which are merely space and time relations. However, let them not make us believe that all labour is lost if of the things which are real but cannot themselves enter the mind we have made pictures, which coincide with the things in certain respects (*Beziehungen*) whereas in others they depend on our conceptions.¹¹

10 “Was wir hinzufügen sind dann nicht falsche Vorstellungen, sondern es sind die Bedingungen der *Vorstellbarkeit* überhaupt; wir könnten sie nicht fortnehmen und bessere an ihre Stelle setzen, sondern wir müssen sie hinzuthun oder auf alle Vorstellungen in diesem Gebiete verzichten” (Hertz 1999, 36). Hertz later changes his mind about whether these conceptions can be replaced by better ones (replacing conceptions is his main purpose in his theoretical work on electrodynamics).

11 “Hüten wir uns also zu glauben, wir könnten durch Betrachtung der Atome das Wesen der Dinge selbst erforschen, hüten wir uns auch die unwesentlichen Eigenschaften, die wir ihnen nothgedrungen beilegen müssen, mit den wesentlichen zu verwechseln, welches lediglich Zeit- und Raumbeziehungen sind; aber

The main point for our question is that there is a contrast between “conceptually defined magnitudes which are connected among themselves and with the macroscopic properties of matter *via* strict mathematically formulated relations” on the one hand, and conceptions (Vorstellungen) on the other. The strict mathematically formulated relations are the kind of things that can be right or wrong. They represent nature. They are what he refers to as “essential properties.” Claims about conceptions, (Vorstellungen) however, such as the properties we attribute to atoms (like having a certain diameter), cannot be read realistically, but are nevertheless not *wrong*. Claims about the diameter of an atom are *neither right nor wrong* according to Hertz. These conceptions are what we add to nature or to the things themselves.

3. Hypotheses

This is a good point to introduce the notion of a hypothesis. I take a hypothesis to be a proposition – usually consistent with what we already know – which is introduced as an assumption to explain known phenomena. A proposition can be represented by a statement and is either true or false. There are two features of this characterization that will be relevant for the following discussion. Hypotheses are

- (i) either true or false and
- (ii) assumptions, i. e. there is insufficient evidence for them.

The lack of evidence mentioned in (ii) may be either a contingent, transitory feature of the current state of science or it may be a principled matter. The first reading as to why there is a lack of evidence is presumably the common sense reading of what we mean by “hypothesis.” If propositions are classified as hypotheses due to lack of evidence in the non-principled sense, I will call them *hypotheses in the weak sense*. The second reading can be backed up by considerations like Popper’s according to which we are never able to verify a hypothesis. Propositions that lack evidence for principled reasons will be called *hypotheses in the strong sense*. Since the lack of evidence can only be either a matter of

lassen Sie uns auch nicht glauben, wir hätten unsere Mühe verloren, wenn wir von den Dingen die wirklich sind, aber nicht in unseren Geist eingehen, Bilder geschaffen haben, die mit jenen Dingen in einigen Beziehungen übereinstimmen, während sie in anderen wieder den Stempel unserer Vorstellungen tragen” (Hertz 1999, 36).

principle or not a matter of principle, it is an implication of these definitions that a hypothesis cannot be both a hypothesis in the weak sense and a hypothesis in the strong sense.¹²

Returning to *The Constitution of Matter*, we can classify the claims about the relation between conceptually defined magnitudes on the one hand and those about the diameter of the atom on the other as follows: The latter cannot be hypotheses because they are statements that are neither right nor wrong. This classification makes sense because – given the characterization as necessary conditions for imagination – they are not the kind of thing for which it is reasonable to seek evidence. The former, however, (the mathematical relations) can be true or false – they are the kind of thing for which evidence is sought. There is no evidence in the text that indicates whether such claims should be read as hypotheses in the weak or in the strong sense.

4. Maxwell's Theory

Hertz's papers on electromagnetism are particularly interesting because they introduce a two-fold pluralism – of theories on the one hand and representations of theories on the other. Hertz – as we will see – believes that his work has put an end to both of these pluralisms.

In the introduction to his collection of papers on electromagnetism, *Electric Waves*, Hertz characterizes his own achievements by contrasting the situation before and after his experiments.

From the outset Maxwell's theory excelled all others in elegance and in the abundance of the relations between the various phenomena which it included. The probability of this theory, and therefore the number of its adherents, increased from year to year. But as long as Maxwell's theory depended solely upon the probability of its results, and not on the certainty of its hypotheses, it could not completely displace the theories which were opposed to it. The fundamental hypotheses of Maxwell's theory contradicted the usual views, and did not rest upon the evidence of decisive experiments (Hertz [1892] 1962, 19).

12 For this distinction see Gregor Schiemann, "Werner Heisenberg's position on a hypothetical conception of science," this volume. Hypotheses in the weak sense correspond to Schiemann's 'provisional assumptions'. Hypotheses in the strong sense imply the 'abandonment of claims to truth'.

So before Hertz performed his experiments there was no certainty of the hypotheses and there were no decisive experiments.

In this connection we can best characterise the object and the result of our experiments by saying: the object of these experiments was to test the fundamental hypotheses of the Faraday-Maxwell theory, and the result of the experiments is to confirm the fundamental hypotheses of the theory (Hertz [1892] 1962, 19/20).

Given the use of the past tense and the contrast of the epistemological situation before and after his experiments, I take it that Hertz wants to say that the decisive evidence sought for in Maxwell's theory has now been found.

Let me briefly comment on Hertz's use of "hypothesis" in this context. He frequently uses the term "hypothesis" in the *Electric Waves*. Thus, for example, he refers to the hypothesis that light-waves are identical to electromagnetic waves (Hertz [1892] 1962, 19, 136). He furthermore classifies Maxwell's equations as "hypotheses" as long as his experiments had not taken place (Hertz [1892] 1962, 19). So the question arises whether Hertz takes hypotheses in the weak or in the strong sense. Given the quotations above it is not very plausible to claim that Hertz believed that Maxwell's equations lacked evidence for principled reasons. On the contrary, it seems plausible to assume that Hertz believes that the question of the fundamental equations of electrodynamics has been settled with his experiments. Maxwell's equations used to be hypotheses in the weak sense.

But what exactly has been so decisively confirmed? What is it that we call the Faraday-Maxwell theory?" Hertz famously answered:

To the question "What is Maxwell's theory?" I know of no shorter or more definite answer than the following: – Maxwell's theory is Maxwell's system of equations. Every theory which leads to the same system of equations, ... I would consider as being a form or special case of Maxwell's theory; every theory which leads to different equations, ... is a different theory (Hertz [1892] 1962, 21).

What has been confirmed are the mathematically formulated relations between physical magnitudes, (to use the terminology of his *The Constitution of Matter*) namely Maxwell's equations.

With respect to the issue of pluralism it should be pointed out that before Hertz performed his experiments there used to be a pluralism of theories (fundamental equations for electro-dynamic phenomena). This

pluralism has now disappeared. Hertz believes that there is decisive evidence against competing theories such as Weber's. So the pluralism of theories has turned out to be transitory.

Furthermore, it follows from Hertz's views that there *cannot* be a pluralism of theories in the future. The reason is this: The evidence Hertz provides is decisive evidence for Maxwell's equation. *A fortiori* an electromagnetic theory either yields Maxwell's equations, or it is wrong. But by definition every theory that yields these equations is identical with Maxwell's theory. So a pluralism of theories that takes account of the evidence is impossible.

The pluralism of theories is not the only pluralism Hertz discusses. He contrasts Maxwell's theory with its representations. Hertz distinguishes three representations of Maxwell's theory: Maxwell's representation, the representation as a limiting case in von Helmholtz's electrodynamics and his own. All of these are representations of the *same* inner significance or content (Inhalt). What is common to all of these representations is the system of Maxwell's equations. For a representation to be a representation of Maxwell's theory it is both a necessary and sufficient condition to yield these equations. Representations add physical significance to the system of equations by invoking physical conceptions (Vorstellungen) such as "pictures of electrified atoms" or "concrete representations (Vorstellungen) of the various conceptions as to the nature of electric polarisation, the electric current etc." (Hertz [1892] 1962, 19). As Michael Heidelberger points out, the representation (the physical conception) "designates the ultimate unobservable agent which produces the phenomena" (Heidelberger 1998, 18). For example, in the case of one body acting on another at a distance, Hertz distinguishes four fundamental conceptions (standpoints): "the pure conception of direct attraction," the pure conception of indirect (or mediated) attraction, as well as two intermediary conceptions. These are claims about the microphysical causes of the observable phenomena.

We have a plurality of fundamental conceptions (standpoints) about apparent action at a distance in the case electro-dynamic phenomena. The different representations of Maxwell's theory (there are three of them) rely on several of these possible standpoints (Hertz discusses four standpoints). Von Helmholtz's, Maxwell's and Hertz's own representation make use of these fundamental conceptions.

With respect to the first standpoint (the pure conception of direct attraction) Hertz is very explicit that it has been rejected:

Casting now a glance backwards we see that by the experiments above sketched the propagation in time of a supposed action-at-a-distance is for the first time proved. This fact forms the philosophic results of the experiments; and, indeed, in a certain sense the most important result. The proof includes a recognition of the fact that the electric forces can disentangle themselves from material bodies, and can continue to subsist as conditions or changes in the state of space (Hertz [1892] 1962, 19).

Hertz explicitly points out that this result is independent of the correctness of a particular theory. Thus, his experiments have not only implications for competing theories, but also for competing fundamental conceptions. On the one hand, they provide decisive evidence for Maxwell's equations, on the other hand they demonstrate that the fourth standpoint (action is mediated) is not only possible but actually obtains. Thus claims about fundamental conceptions are not beyond the reach of experimental evidence.

Let me come back to the plurality of representations. Hertz criticizes von Helmholtz's representation, which makes use of one of the intermediary standpoints:

It assumes that the action of the two separate bodies is not determined solely by forces acting directly at a distance. It rather assumes that the forces induce changes in the space (supposed to be nowhere empty), and that these again give rise to new distance forces (Hertz [1892] 1962, 23).

In the limit of diminishing distance forces von Helmholtz's theory yields Maxwell's equations. It is thus a representation of Maxwell's theory. However, Hertz objects that "it is impossible to deny the existence of distance forces, and at the same time to regard them as the cause of the polarizations" (Hertz [1892] 1962, 25). So Hertz rejects von Helmholtz's representation because the physical conceptions it invokes are inconsistent.

Maxwell's own representation is – according to Hertz – an inconsistent mixture of the fourth standpoint and the second standpoint. (I will not go into the details here.) Hertz own representation is the attempt to disentangle the conceptions that Maxwell used in his representation. Hertz attempts to

exhibit Maxwell's theory, i. e. Maxwell's equations from this fourth standpoint. I have endeavoured to avoid from the beginning the introduction of any conceptions which are foreign to this standpoint and which might afterwards have to be removed (Hertz [1892] 1962, 27).

Hertz describes some of the conceptions that characterize Maxwell's own representation:

Maxwell originally developed his theory with the aid of very definite and special conceptions as to the nature of electrical phenomena. He assumed that the pores of the ether and of all bodies were filled with an attenuated fluid, which, however, could not exert forces at a distance (Hertz [1892] 1962, 27).

He characterized his theoretical papers as the attempt to develop a representation of the system of Maxwell's equation that can do without pictorial conceptions (*Vorstellungen*) of the kind just mentioned:

I have ... endeavoured in the exposition to limit as far as possible the number of those conceptions which are arbitrarily introduced by us, and only to admit such elements as cannot be removed or altered without at the same time altering possible experimental results (Hertz [1892] 1962, 28).

Hertz wants to do without those conceptions that are part of the second standpoint. Maxwell's theory should be presented entirely from the point of the fourth standpoint.

It is true that in consequence of these endeavours, the theory acquires a very abstract and colourless appearance ... But scientific accuracy requires of us that we should in no wise confuse the simple and homely figure, as it is presented to us by nature, with the gay garment which we use to clothe it. Of our own free will we can make no change whatever in the form of the one, but the cut and colour of the other we can choose as we please (Hertz [1892] 1962, 28).

Hertz considered the issue of separating what is due to nature on the one hand and, on the other, what we have added on as a *philosophical* question in *The Constitution of Matter*. It was therefore a question the physicist did not have to deal with. In the "Introduction" to his *Electric Waves* this question has now been transformed into a question that a (theoretical) physicist needs to deal with. It was important for Hertz to contrast "the simple and homely figure, as it is presented to us by nature" and "the gay garment which we use to clothe it." Though there is some interpretative controversy about what exactly the "gay garment" and the "simple and homely figure" refer to, it is important to notice that there is such a distinction.¹³ On the one hand there are certain fea-

13 (Heidelberger 1998, 21) and (Lützen 2005, 106), see also the discussion in section 6.1.

tures which represent nature, while on the other hand those which have no such function.

What seems to be clear is that Maxwell's equations ought to be read realistically, i. e. that they represent nature. It should be equally clear that the physical conceptions, which belong to the second standpoint and which have been eliminated, belong to what Hertz calls the "gay garment." They are those conceptions that have been arbitrarily added by us (or rather by Maxwell).

Let me summarize those points that are relevant for the issues we discussed at the outset.

First, Hertz uses the notion of "hypothesis" frequently but he uses it in the weak sense only. There is no evidence in the texts we have discussed so far that there are parts of theories that are both, either true or false as well as in principle beyond the reach of empirical evidence.

Second, what Hertz ends up with is a distinction between the simple and homely figure as it is presented by nature on the one hand, and the gay garment on the other. Those parts of theories that are constitutive of the former represent nature. The concept of representation is therefore still an appropriate concept to characterize the relation between theory and nature – at least to some extent.

Finally, both the pluralism with respect to theories as well as the pluralism with respect to representations turned out to be transitory. The plurality among theories was narrowed down to one by Hertz's experiments (and his criterion for individuating theories ensures that there cannot be more than one theory); the plurality of representations by invoking criteria such as consistency (in the case of von Helmholtz) and simplicity or economy (in the case of Maxwell). However, whether or not physical conceptions and thus representations are defensible is also a matter of empirical consideration, as Hertz's remark about the most important result of his experiments (propagation in time of an alleged action at a distance force) indicates.

5. The Principles of Mechanics

Finally, I will discuss the questions outlined at the outset with respect to *The Principles of Mechanics*. The central term Hertz invokes in this context is that of an image (*Bild*, "picture" would have been a better translation). This is significant because in *The Constitution of Matter* Hertz had used two metaphors in the context of characterizing how we talk about

nature: the notion of a sign and that of an image. In the context of a discussion of the concept of matter he had introduced the notion of a sign:

I compare [the concept of] matter with paper-money, which our understanding issues in order to organize its relations to the things. Paper-money is a sign for something else, and precisely on the fact that it is a sign depends its value and meaning. Its own character is irrelevant ...¹⁴

At other times, as we have seen, he invoked the notion of a picture:

[O]f the things, which are real but cannot themselves enter the mind, we have made pictures, which coincide with the things in certain respects whereas in others they depend on our conceptions (Hertz 1999, 36). (See above for full quote.)

Even though Hertz uses the notion of sign (*Zeichen*) or symbol occasionally in the "Introduction" to his *The Principles of Mechanics*, image is the predominant concept he makes use of. This is significant because the two metaphors suggest different claims with respect to the question to what extent the world is represented. Whereas "picture" in Hertz's terminology implies that there is a correspondence (or coincidence) with the things pictured in certain respects (but not in others), Hertz's characterization of a sign is less explicit in this respect.

Choosing picture or image rather than sign as the main conceptual tool can therefore be taken as a first indication that Hertz still believes that certain aspects of nature can be represented.

5.1 Images

In order to come to terms with the questions sketched at the outset of this paper I will now analyze Hertz's concept of an image, as he used it in *The Principles of Mechanics*.

According to Hertz, we introduce images when we try to predict phenomena, i. e. what he calls the "most direct, and in a sense most im-

14 "Ich vergleiche die Materie mit einem Papiergeld, welches unser Verstand ausgiebt, um seine Beziehungen zu den Dingen zu regeln. Das Papiergeld ist ein Zeichen für etwas anderes und gerade in diesem, daß es ein Zeichen ist, liegt sein Wert und seine Bedeutung. Seine eigene Beschaffenheit ist gleichgültig ... (Hertz 1999, 117/8). Hertz was familiar with von Helmholtz's theory of signs (see Schiemann 1998).

portant, problem which our conscious knowledge of nature should enable us to solve” (Hertz [1894] 1956, 1):

We form for ourselves images or symbols of external objects; and the form which we give them is such that the necessary consequents of the images in thought are always the images of the necessary consequents in nature of the things pictured (Hertz [1894] 1956, 1).

The first thing to be noted is that Hertz makes use of the concept of an image in a narrow and in a broad sense. Images in the narrow sense are parts of theories that refer to particular things in nature. This is the sense in which the concept of a symbol or image is used in the above quotation. When he compares the different images of ordinary mechanics it is rather theories as a whole that he has in mind. The above-quoted requirement for images is valid both for the narrow sense as well as for the broad, as becomes clear in the sequel of the introduction where he exclusively deals with images in the broad sense (see Hüttemann 2001).

But how do we compare consequents of images with consequents of things? What are the constitutive elements of images? Hertz refers to *fundamental ideas* and to *principles* which connect the ideas as the main elements that are characteristic for a particular image. Principles of mechanics are defined as

[a]ny selection from amongst such and similar propositions, which satisfies the requirement that the whole of mechanics can be developed from it by purely deductive reasoning without any further appeal to experience (Hertz [1894] 1956, 4).

The whole experiential content of a theory is captured by its principles.

The examples of images Hertz discusses in the “Introduction” of his *The Principles of Mechanics* are the customary exposition (Darstellung) of mechanics, which is characterized through the fundamental ideas of space, time, mass and force as well as Newton’s laws of mechanics and d’Alembert’s Principle. The ideas of space, time, mass and energy plus Hamilton’s Principle constitute the “energetical” image. Hertz’s own image presupposes just three fundamental ideas – space, time and mass – plus a fundamental law that serves as his principle.

Still, the question remains: How are we to compare whether “the necessary consequents of the images in thought are always the images of the necessary consequents in nature of the things pictured.” The first book of *The Principles of Mechanics* does not deal with this problem; it treats the fundamental ideas and introduces definitions without mak-

ing any reference to experience. "The subject matter of the first book is completely independent of experience" (Hertz [1894] 1956, 45). It is only in the second book that such a connection is established. At the beginning of the second book Hertz introduces three *rules* (Festsetzungen) for his fundamental ideas. The first of these rules concerns time:

Rule 1. We determine the duration of time by means of a chronometer, from the number of beats of its pendulum. The unit of duration is settled by arbitrary convention (Hertz [1894] 1956, 140).

There are similar rules for space and mass. Hertz seems to think of them as providing definite and determinate values for a determinable.

So what we see is that over and above the fundamental ideas and principles these rules are constitutive for the concept of an image as well:

Thus only through these rules can the symbols (Zeichen) time, space and mass become parts of our images of external objects. Again, only by these three rules are they subjected to further demands than are necessitated by our thought (Hertz [1894] 1956, 141).

By these rules the images become images of external things.

In the "Introduction" to the *Electric Waves* Hertz distinguished between Maxwell's theory on the one hand and its representations on the other. How does the concept of an image connect to these concepts?

Hertz introduces the notion of an image or picture as follows: "The images which we here speak of are our conceptions (Vorstellungen) of things" (Hertz [1894] 1956, 1). So one might hold – as Michael Heidelberger does (Heidelberger 1998, 21) – that an image is the same thing as a representation in the *Electric Waves*, because – as we have seen – representations were essentially constituted by conceptions. However, if one takes into account how Hertz spells out in detail what belongs to the different images of mechanics (image is here taken in the broad sense), there is a conspicuous absence of what Heidelberger has called "the ultimate unobservable agent which produces the phenomena" (Heidelberger 1998, 18). What constitutes images are the fundamental concepts, the fundamental equations formulated in terms of these concepts plus the rules (Festsetzungen). Jesper Lützen points out that this difference, i. e. the presence of conceptions concerning ultimate agents explaining the phenomena in the *Electric Waves* and their absence in *The Principles of Mechanics*, maybe due to the fact that mechanics as opposed to electrodynamics is the fundamental physical theory. In electrodynam-

ics we can develop conceptions (Vorstellungen) of polarization, etc., in terms of mechanical concepts so as to explain electrodynamical phenomena. In the case of mechanics we cannot develop conceptions in terms of more fundamental concepts (see Lützen 2005, 106).

This observation plus the role fundamental equations play both in Hertz's characterization of Maxwell's theory as well as in the images provides evidence for the claim that "image" is more of a successor of "theory" than of "representation." Nevertheless, besides the fundamental equations, which he took to be constitutive for Maxwell's theory, he adds some further constituents of images such as the fundamental concepts and the rules (Festsetzungen). There is one further element that seems to give some support for Heidelberger's reading, namely the hidden masses that Hertz postulates. These masses have some similarities with the conceptions discussed in the *Electric Waves*. However, Hertz nowhere refers to the hidden masses as an image. They are a part of an image, not an image themselves.

The plurality of images we envisage in *The Principles of Mechanics* is a plurality of fundamental mechanical equations, sets of fundamental concepts plus some auxiliary hypotheses (such as the hypothesis concerning hidden masses). There is no longer a two-folded pluralism (of theories and of representations) as there was in the *Electric Waves*.

5.2 Criteria for the Evaluation of Images

Whether Hertz's pluralism is transitory is an issue that concerns the criteria for evaluating the images. The question is whether Hertz believes that these criteria will ultimately single out a unique image.

Hertz introduces three criteria for the evaluation of images: correctness, permissibility and appropriateness. Let me turn to correctness first. Correctness is the requirement that Hertz mentions in the passage we quoted at the very beginning: "the necessary consequents of the images in thought" have to be "the images of the necessary consequents in nature of the things pictured" (Hertz [1894] 1956, 1).

What are the implications of a theory's correctness? Immediately following the above quotation Hertz continues: "In order that this requirement may be satisfied, there must be a certain conformity (Übereinstimmung) between nature and thought" (Hertz [1894] 1956, 1). But what sort of conformity does Hertz have in mind? A few pages

later Hertz discusses the customary image of mechanics and, in particular, the fundamental law's credentials with respect to correctness:

Upon the correctness of the image under consideration we can pronounce judgment more easily ... No one will deny that within the whole range of experience up to the present the correctness is perfect; that all those characteristics of our image, which claim to represent observable relations of things, do really and correctly correspond to them (Hertz [1894] 1956, 9).

Hertz claims that if an image is correct we are allowed to conclude that systems really correspond to our image so far as the fundamental law is concerned.¹⁵ Hertz reaffirms his realism with respect to the fundamental mathematical equations.¹⁶

As in his earlier writings Hertz keeps to the view that certain parts of theories or images, if correct, represent nature. *Pace* Schiemann (1999) I hold that the concept of representation is still appropriate for characterizing Hertz's views about the relation of images and the world – at least with respect to fundamental equations.

The question of whether or not an image is correct is essentially a matter of whether or not the fundamental law is correct:

[The experiential part], in so far as it is not already contained in the fundamental ideas, will be comprised in a single general statement which we shall take for our Fundamental Law. No further appeal is made to experience. The question of the correctness of our statements is thus coincident with the question of correctness or general validity of that single statement (Hertz [1894] 1956, 139, translation augmented).

This fundamental law is a hypothesis in the weak sense. Hertz considers it “provable” – at least by future experience:

We consider the law to be the probable outcome of most general experience. More strictly, the law is stated as a hypothesis or assumption, which comprises many experiences, which is not contradicted by any experience, but which asserts more than can be proved by definite experience at the present time (Hertz [1894] 1956, 145).

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- 15 There seems to be one caveat. Hertz talks about *observable* relations, not about relations in general. There is, however, no evidence that Hertz has in mind the observable/unobservable distinction as it was discussed in 20th-century philosophy of science. Rather, as in the case of “experience,” his use seems fairly liberal and seems to comprise everything that is within the reach of experimentation.
- 16 This kind of realism is sometimes called “structural realism”; see (Ladyman 1998).

To sum up: Images ought to be correct – that is why we construct them in the first place. What this boils down to essentially¹⁷ is the requirement that the fundamental law has to be correct. A fundamental law or principle – if not yet confirmed – is a hypothesis in the weak sense only; it can – at least in principle – be decisively confirmed.¹⁸ Hertz is very explicit that these hypotheses are either right or wrong. Comparing his image of mechanics with the customary image Hertz writes:

... it is important to observe that only the one or the other of the two images can be correct: they cannot both at the same time be correct ... This is the field in which the decisive battle between these different fundamental assumptions of mechanics must be fought out (Hertz [1894] 1956, 40/41).

Hertz does believe that there will be a battle between the various images and he believes that the battle will be decisive. Thus there will be a decisive answer to the question whether one or the other theory is correct.

One thing we learn from this is that Hertz did not believe that images are hypotheses in a strong sense – i. e. hypotheses that we are unable to provide sufficient evidence for some principled reason.

The above quote, however, does not yet imply that Hertz considered the pluralism of images he described as merely transitory. Hertz introduces two further criteria for the evaluation of images. These are the criteria of *permissibility* and *appropriateness*. An image is permissible if it does not contradict the laws of our thought, i. e. if it is logically consistent. Images, which contradict laws of thought, are *inadmissible*. Hertz holds that “two permissible and correct images of the same external objects may yet differ in respect of appropriateness” (Hertz [1894] 1956, 2).

An image can be appropriate in two respects. Firstly, it can be more appropriate than another image because it is more *distinct*. This is the case if it “pictures more of the essential relations of the object” than its competitor (Hertz [1894] 1956, 2). What Hertz has in mind can

17 I write “essentially” because Hertz introduces further empirical hypotheses, e. g. the hypothesis of concealed masses and certain assumptions about the continuity of nature (Hertz [1894] 1956, 146).

18 There is one passage where Hertz claims that “that which can be derived from experience can be annulled through experience” (Hertz [1894] 1956, 9). This, however, should not be taken to indicate that Hertz believes in hypotheses in the strong sense. As the immediately preceding passage makes clear, what Hertz wants to claim is simply that our evaluations of correctness can take into account only past (and present) experiences. So our evaluations might be revised in the light of future experiments.

best be illustrated by his discussion of the customary image of mechanics. We know of essential features of forces which are not an integral part of the customary picture of mechanics. Therefore, it is not as distinct as Hertz's own image.

Of natural motions, forces and fixed connections we can predicate more than the accepted fundamental laws do. Since the middle of this century we have been firmly convinced that no forces actually exist in nature which would involve a violation of the principle of conservation of energy ... Again these elementary forces are not free. We can assert as a property which they are generally admitted to possess, that they are independent of place and time (Hertz [1894] 1956, 10).

Secondly, an image may be more appropriate than another if it is more simple, i. e. if it contains "in addition to the essential characteristics, the smaller number of superfluous or empty relations" (Hertz [1894] 1956, 2). Again, what Hertz means by this criterion can best be illustrated by his discussion of the role of forces in the customary picture.

We see a piece of iron resting upon a table, and we accordingly imagine that no causes of motion – no forces – are there present. Physics, which is based on the mechanics considered here and necessarily determined by its basis, teaches us otherwise. Through the force of gravitation every atom of the iron is attracted by every other atom in the universe. But every atom of the iron is magnetic, and is thus connected by fresh forces with every other magnetic atom in the universe. Again, bodies in the universe contain electricity in motion, and this latter exerts further complicated forces which attract every atom of the iron. In so far as the parts of the iron contain themselves electricity, we have fresh forces to take into consideration; and in addition to these again various kinds of molecular forces. Some of these forces are not small: if only a part of these forces were effective, this part would suffice to tear the iron to pieces. But in fact, all the forces are so adjusted among each other that the effect of the whole lot is zero; that in spite of a thousand existing causes of motion, no motion takes place; that the iron remains at rest. Now if we place these conceptions before unprejudiced persons, who will believe us? (Hertz [1894] 1956, 13).

An image of mechanics (such as Hertz's own), which avoids such forces, is a simpler image of mechanics.

Images will picture typically essential as well as inessential relations. As we have seen, Hertz advocates a realistic attitude towards essential relations (mathematical structure). Claims about these essential relations – if not already confirmed – are hypotheses in the weak sense.

With respect to the inessential or empty relations Hertz holds:

Empty relations cannot be altogether avoided: they enter into the images because they are simply images, – images produced by our mind and necessarily affected by the characteristics of its mode of portrayal (Hertz [1894] 1956, 2).

At this point we have to draw the same conclusion we drew with respect to what Hertz called the “inessential relations” in *The Constitution of Matter*. Claims concerning these ineliminable empty relations are neither right nor wrong. They are not the kind of things for which evidence is possible. They are therefore no hypotheses – neither in the weak nor in the strong sense.

It is exactly with respect to these features of images that Schiemann’s claim concerning the limited applicability of the concept of representation is correct. Empty relations do not represent anything.

Let me come back to the issue of pluralism. As I already mentioned, Hertz believes that images do not only differ with respect to correctness and permissibility but also with respect to appropriateness. Whether or not an image is permissible and whether or not it is correct are questions that allow for decisive answers (though his discussions of the details of the images shows that it is not so easy to figure out to what extent an image in fact conforms to these criteria).

The striking thing is that – despite certain ambiguities – Hertz seems to believe that ultimately it will be possible to find a unique image, which does best with respect to appropriateness.

... we cannot decide without ambiguity whether an image is appropriate or not; as to this difference of opinion may arise. One image may be more suitable for one purpose, another for another; only by gradually testing can we finally succeed in obtaining the most appropriate (Hertz [1894] 1956, 3).

6. Conclusion

According to Hertz different images of mechanics are possible. But this envisaged pluralism concerns the situation before all the evidence is in, i. e. before we can decide whether the images are correct and appropriate. There is no place at which Hertz suggests that there might be a plurality of images that equally conforms to all three criteria. Hertz believes in final and decisive battles of the kind he participated in while doing experiments in electrodynamics.

Admittedly, Hertz's rhetoric in *The Principles of Mechanics* sounds much more pluralistic than in the *Electric Waves*. This is presumably due to the fact that in *The Principles of Mechanics* he defends a minority view of mechanics. The pluralistic rhetoric is a way of introducing the image of mechanics he favors. At the end of the day, however, according to Hertz there will be a decisive battle and the stage of pluralism will *a fortiori* turn out to be transitory – just as it was the case in electrodynamics. So Boltzmann misrepresents Hertz's views when he claims that Hertz's picture theory implies that it cannot be our *aim* to look for an absolutely correct theory.

We have also seen that the concept of representation is still quite appropriately applied to important aspects of images. Hertz explicitly allows that “characteristics of our image, which claim to represent observable relations of things, do really and correctly correspond to them” (Hertz [1894] 1956, 9). More particularly, he thinks of the fundamental equations at this point.

Finally: Hertz uses the concept of a hypothesis throughout his work. But he uses it in a weak sense. When it comes to experimental evidence Hertz believes in decisive battles, as we have seen. There is no trend in Hertz towards an increasing hypothesization – given this trend is understood in a strong sense, i.e. as leading to a conception according to which the correctness of scientific theories cannot be established for principled reasons.

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