Experimental Knowledge and the Theory of Producing it: Hermann von Helmholtz

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"I for myself consider[...] experiments as the essential basis of science" (Hermann von Helmholtz 1877)

This workshop deals with a topic of key importance for the understanding of science. Experiments are in fact the revolutionary achievement of early modern science and the main basis for today's knowledge production. Against this background it seems most reasonable to ask about the production of experimental knowledge. But this question has also a topicality for the history and philosophy of science. These two disciplines – as you can also learn from the prospectus to this workshop – are still struggling with the task to identify characteristics of this kind of knowledge production. The lack of conceptual clarification reveals a remarkable distance between the two disciplines on the one and their scientific subject on the other side. The distance has its reasons both on part of the humanities and the sciences. The example that I have chosen for my talk could show how the sciences themselves took part in making it difficult to reasonably reflect on the experimental procedure.

In my view, Hermann von Helmholtz, whose contributions to the practice and theory of the production of experimental knowledge will be the subject of my talk, is one of the central figures in the development of early modern science. He could base his work upon elaborated methods of experimentation in the physical sciences and made an important contribution to transferring them to parts of the biological sciences. His experimental practice has many different aspects, most of which he only partly included in his conception of science. Moreover, his conception of science, apart from being only a reduced presentation of his own practical diversity, even points into another direction than his practice. Roughly speaking, the difference is that he gives less importance to the experiment than it probably had in his own research. An examination of how sciences themselves had their share in impeding a reflection on their experiments could be interesting taking Hermann von Helmholtz as an example. However, this will not be part of my talk.

Regardless of its misinterpretations, Helmholtz's public reflection about the nature of the experiment and its role in the sciences is a historically important description, which also helps to analyze his own works. It is a part of his conception of science and nature, which can be seen as an ideal type of science and its goals. The formulation of these ideas did not only include experiences from Helmholtz's own scientific practice, but also influenced from his wider scientific and cultural environment. Both contributed to a transformation of his conception of science and nature, which also had an impact on his ideas about experiments. Due to the public importance of his texts Helmholtz's conception of science and nature retrospectively had the effect of giving an orientation to his contemporaries' works. Helmholtz's ideas about experiments were of an educating character.

But, their historical reach seems to be limited in an important respect. Helmholtz's understanding of experiments is based on the idea that their planning, realization and evaluation lies in the hands of a person or group acting according to decisions of free will. In my opinion this idea is characteristic for the foundation of the experimental method in early modern times, not however for several forms of its present structures. Above all, the increasing technization of producing knowledge reduces the role of the subject in conducting experiments.

My lecture consists of three parts. In its first part I would like to present a summary of Helmholtz's own theory of experiment and the change of his conception of science and nature. In the second part I would like to discuss three examples of his experimental practice, which were taken in chronological order from three different periods of his work; in the third part I would like to compare the examples with the change of his conception of science and nature.

I will leave out any remarks regarding his person, as I suppose that the participants of this workshop know more about Helmholtz than any such remarks could cover. If not, we could refer to it in the discussion.

1. Helmholtz's Theory of Experiment and the Change of His Conception of Science and Nature

It corresponds to Helmholtz's *empiristic understanding of science* that he provides the experiment with a key position in science. To his understanding, scientific knowledge is based not on metaphysical principles or concepts, but on "experience". Nothing but experience justifies the claim to validity of knowledge and only experience may revise it – as Helmholtz realized more and more in the course of his scientific career. According to him "experience" does not only mean scientific experience, but it also includes everyday experiences. In his popular lectures he spoke of "daily", "natural" or "common" experience and meant lifeworldly forms of well-ordered and reliable contents that guide our actions (Helmholtz 1852, 1857, 1862/63, 1868, 1869, 1878c, 1885 ff. § 26).

a) Connection between everyday life-world experience and scientific experience

According to Helmholtz there is a close connection between everyday life-world experience and scientific experience, a fact that he also included in his theory of experiments. In some respect, *the scientific experiment is just an extension of the ordinary forms in which we gain knowledge.* In the first edition of 1856 of the "Treatise of Physiological Optics" (Handbuch der physiologischen Optik) he stated:

> Finally, the tests we employ by voluntary movement of the body are of the greatest importance in strengthening our conviction of the correctness of the perceptions of our senses. And thus, as contrasted with purely passive observations, the same sort of firmer conviction arises as is derived by the process of experiment in scientific investigations. [...] It is only by voluntarily bringing our organs of sense in various relations to the objects that we learn to be sure as to our judgments of the causes of our sensations. This kind of experimentation begins in earliest youth and continues all through life without interruption. (Helmholtz 1909 ff., p. 29).

A discussion of this quote and of similar places can show the basic characteristics in which Helmholtz saw common ground between the production of experimental knowledge in everyday life-world and in science. Both forms are different from "purely passive observation" by *actions that are based on decisions of free will and serve the determination of causes.* Only by bringing our bodies "in various relations to the objects" can we be "sure as to our judgments of the causes of our sensations". For example, if we want to identify the causes of the perception of a table, it is not sufficient to observe the table. We must rather look at it from various sides. In Helmholtz's view, this elementary experiment is the only way to know that perception assumes an object that is resting in space and that exists independently of our perception. Science has to become active in a similar way, in order to determine the causes of phenomena: It intervenes in the course of natural events, by isolating objects and exposing them to selected influencing factors. One of Helmholtz's examples is the expansion of liquid mercury due to heat. Accordingly, heat can only be identified as the necessary and sufficient cause of the expansion by means of experiments (Helmholtz 1856, § 26).

In both examples the conditions for the appearance of a phenomenon are isolated and made observable by *action based on decisions of free will.* In his famous speech "The Facts in Perception" (Die Tatsachen in der Wahrnehmung) from 1878 he said

> The chief reason, however, why the power of any experiment to convince is so much greater than that of observing a process going on without our assistance, is that with the experiment the chain of causes runs through our own self-consciousness. We are acquainted with one member of [the chain of] these causes – the impulse of our will – from inner intuition, and know through what motives it came about (Helmholtz 1878b, p. 136).

In order to plan the creation of a physical cause, to ascribe it to the action of one's own, and to find its effects, no free will has to be assumed. When replacing this precondition by other appropriate assumptions, the remaining elements of Helmholtz's description of producing experimental knowledge will continue to be valid. Instead of understanding changes of conditions as a consequence of actions based on free will, they could for example also be seen as systematically organized or intentionally effected interventions in the course of nature.

In everyday life-world and in science the experiment serves to determine *causes.* According to Helmholtz, causes can be factors that effect changes of states. In this respect the movement of a person's body in relation to a table is the cause for the person's changing perception of that table. Or, to cite another example: The table as a resting object in space is the cause of its perception. A cause in this sense I call *"material cause".* In addition to this meaning there is another one – the meaning of the cause as a law of nature, which in Helmholtz stands for what "repeats in the same and the most regular way" or the "typical behaviour of an object" (Helmholtz 1878a, p. 232). I call this concept, which expresses a relation between phenomena, *"formal cause".* Helmholtz applies both meanings to the lifeworldly and the scientific experimenting.[1]

That experiments provide for *"strengthening our conviction of the correctness of the perceptions"* is based on the fact that they deliver knowledge of the causes of the relevant phenomena. In this respect experiments are also able to confirm the (pureley passive) observation. The knowledge of regularities, which is already known from observation, gains clarification and certainty by means of experiments. According to this it might be possible to identify a table as content of a perception

1 It was not before the end of the 1860's that Helmholtz calls laws as causes and uses them for characterizing the content of perception. Comp. Schiemann 1997, Section B.II.3.a, Chap. β.ii.

without having made any movement of the body. The assumption of the table as the external cause of its perception only would need any action.

Helmholtz did not create this *hierarchy between the observation of phenomena and the experimental discovery of their causes.* He took it from the stock of modern philosophy of science, as paradigmatically devised by Francis Bacon or James Stuart Mill. In Helmholtz it is linked with his mechanistic conception of nature and can also be described as a hierarchy between the two meanings of cause. But this aspect would mainly apply to scientific experiments and therefore cannot be discussed at this point, which concerns their similarities with lifeworldly perception and actions.

The *distinction between observation and experimentation* presupposed by Helmholtz is questionable, and he himself did not always adhere to it. In the second edition of the "Treatise of Physiological Optics" he attributed all spatial perception to

> the movement of our bodies placing us in other spatial relationships to the perceived objects, and therefore changing the impression that they make on us (Helmholtz 1885 ff., § 24, also comp. Helmholtz 1868, p. 365).

There is no observation or identification of objects without body movement for when perception is actually created through body movement. Helmholtz understands body movements creating perception as principally changeable through experience and decisions of free will. With this generalization of his approach, perception arises out of experimental actions in the everyday life-world. First of all, generating experimental knowledge in the life-world means to perceive. This view paves a way for the phenomenological theory of perception and of science, as e.g. expressed by Edmund Husserl. For Husserl, the unity, which the experience of perception forms with the related body movement, is essential to the concept of the body in the meaning of "Leib" and the subjectivity that builds upon it (Schiemann 2005, chap. 1.1.2, section 2.1.2).

To sum up, it can be stated that there are three initial characteristics of the experimental production of knowledge, insofar these are derived from Helmholtz's conception of science: action based on decisions of free will; the aim of determining causes; and securing the claim to validity of knowledge. Helmholtz's theory of scientific experiment is based on everyday life-world. However, the discussion of the role of experiments in everyday life-world does not only serve as a foundation of science. It is also the starting point for Helmholtz's theory of perception.

b) Difference between experiments in everyday life-world and science

But, in Helmholtz there is also a clear difference between experiments in everyday life-world and in science within the conceptual frame that they share. The knowledge of the everyday life-world has a *symbolic character* in contrast to scientific knowledge. The perceived image of a table is the symbol of the real table, because there is, according to Helmholtz, no similarity between a perceived image and its referent. Alone the succession in time of the changes of the image that is caused by the movements of the body – the transforming views of the table, when watching it from different sides – corresponds to the succession in time of these movements. Helmholtz describes the result of this correspondence as *representation* (Abbild). Perceptions have a symbolic and a representational character. Without scientific methods, the percipient subject has only knowledge of the symbolic part. Scientific work consists of clearing the perception of the symbolic part and finding causes on the basis of its representational part. Thus, science can start from human perception:

> We now find, in conclusion, that our sensations are merely signs of changes taking place in the external world, and can only be regarded as pictures in that they represent succession in time. But, for this very reason they are in a position to show directly the *conformity to law*, in regard to succession in time, of natural phenomena. [...] That which our organs of sense perform is clearly sufficient to meet the demands of science (Helmholtz 1869, p. 223).

In the representational part of perception, which the scientific shares with lifeworldly perception, Helmholtz lays the foundation for the *claim to truth* of scientific experimental knowledge. The *change in his conception of science* mainly consists in the relativization of this claim to truth. The change can be exhibited through the example of the *concept of cause*, which also has a narrower definition in science as in the life-world.[2]

In the latter quote, Helmholtz considered the specific task of science to formulate laws of nature of the "succession in time [...] of natural phenomena". This concept of law or *formal cause* is distinguished from those that are also applied in the life-world through its quantifiable character. For science, Helmholtz defines law as an "unchangeable relationship between variable quantities" (Helmholtz 1878a, p. 240). The concept of law is hereby abrogated in a mathematical differential equation between physical quantities. Also Helmholtz subjects the concept of *material cause* in science to specification. In his mechanistic concept of nature, material causes are mechanically moved particles and the forces acting between them. These causes elude lifeworldly perception and may only be observed indirectly in science.

In his *early conception of science*, Helmholtz primarily considered the concept of cause to be material cause. Phenomena should be reduced to mechanical forces between moved atoms. He thus perceived "the ultimate aim of physical science" to be, "to merge itself into mechanics" (Helmholtz 1869, p. 221). The material causes underlying the phenomena were to him, to use an expression of his contemporary Friedrich Nietzsche, the "true world" (Nietzsche 1980 ff., VI, p. 80 f.). The complete knowledge of this world was the target of experimental practice and the fulfilment of the absolute claim to validity, which he attached to science.

At the beginning of the 1870s the *process of change* started in which Helmholtz began to distance himself from his mechanistic program. The program partly became a hypothesis useful for research, the truth of which could possibly prove itself in the future. The interest of experimental research moved from non-perceivable mechanic substances and their forces to observable phenomena. This change was reflected on a conceptual level in that in the concept of cause, the law received greater importance. I shall return to this process of change in the third section. Here, several further criteria must first be named, which Helmholtz ascribed to the scientific experiment more or less independently of his changed conception of science and through which it distinguishes itself from lifeworldly knowledge.

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2 As regards the transformation of Helmholtz's conception of science, comp. Schiemann 1997, Part B.

Helmholtz believed that mathematical laws have a *simple structure* and can therefore be proven in simple experiments. While the everyday life-world (as the objects of the humanities) is characterized by an irreducible complexity, nature is governed by simple laws.

> The essential differentia of these [the experimental sciences to which mathematics are applied – G.S.] sciences seems to me to consist in the comparative ease with which the individual results of observation and experiment are combined under general laws of unexceptionable validity and of an extraordinarily comprehensive character. In the moral sciences [...] this is just the point where insuperable difficulties are encountered. [...]
> The experimental sciences have one great advantage in the investigation of general laws of nature: they can change at pleasure the conditions under which a given result takes place, and can thus confine themselves to a small number of characteristic instances, in order to discover the law (Helmholtz 1862, p. 88 ff.).

The difference between formal and material causes is relevant for the understanding of the limits of experiments in science and everyday life, which limits Helmholtz couched in his conception of science. A *limit of scientific experiments* conjoins formal cause. It can be drawn from his writings that laws as a mathematical relation between measurable quantities cannot be discovered systematically through scientific experiments. The first inventive thought of a new law does not happen inductively, but intuitively:

> the first inventive thought that must precede wording [can] always only happen in a way similar to aesthetic intuition, as a hunch of a new regularity. Such new regularity is to find a previously unknown similarity in the way how certain phenomena follow each other in a group of typically corresponding cases (Helmholtz 1892, p. 348).

The initial hunch for a new scientific law is similar in its aesthetic character to the initial appearance of a new insight in humanities, which at most proceed according to Helmholtz experimentally, in a lifeworldly sense. The scientific experiment has the function of a necessary condition in the discovery of new laws of nature. Only in verifying the presumed laws, for Helmholtz the scientific experiment is necessary and sufficient.

From the character of material cause a *limit of perceptual lifeworldly knowledge* is derived. According to Helmholtz, knowledge in everyday life-world is only gained through direct sense perception, while scientific knowledge advances to imperceptible objects. However, he did not assume these objects to follow different laws than perceptible objects.

To sum up, the *specific characteristics mentioned up to here of the scientific experimenting are first, the claim to truth, second, the mathematical structure of knowledge according to the laws of nature, third, the intuitive form of discovering new laws, and fourth, the not necessarily perceptible objects.* These four characteristics can be allocated to those shared with the everyday life-world as extension or specifications (see the table). It results in a definition of the experiment that allows for a lot of different forms and functions.

Table: Helmholtz's conception of experimental knowledge
in everyday life-world and science

<table>
<tr><th></th><th>everyday life experience/perception</th><th>scientific experiments</th></tr>
<tr><td rowspan="2">objects</td><td colspan="2">perceptible objects
(no creation of phenomena)</td></tr>
<tr><td></td><td>imperceptible objects
(no discussion of the difference of nature and technology)</td></tr>
<tr><td rowspan="4">methodological aspects</td><td colspan="2">action based on decisions of free will
(may be replaced by: systematically organized or intentionally effected interventions in the course of nature)</td></tr>
<tr><td rowspan="3"></td><td>close connection of theory and experiment</td></tr>
<tr><td>intuitive discovery of new laws (as guess or joke)</td></tr>
<tr><td>removal and calculation of possible sources of error</td></tr>
<tr><td rowspan="2">purpose</td><td colspan="2">determination of material and formal causes</td></tr>
<tr><td></td><td>discovery and verification of laws of nature</td></tr>
<tr><td rowspan="4">epistemic aspects</td><td colspan="2">representational character</td></tr>
<tr><td>symbolic character (everyday life experience is more specific)</td><td></td></tr>
<tr><td colspan="2">securing the pragmatic claim to validity of insight</td></tr>
<tr><td></td><td>securing the scientific claim to truth</td></tr>
</table>

2. Three examples of Helmholtz's experimental practice

From here I would like to move on to the second part, which deals with examples of Helmholtz's experimental practice. It was not until recent years that history of science began to pay attention to this topic. Conferences held on the occasion of the centenary of Helmholtz's death caused an increase in investigation, which made considerable corrections of the previous picture of Helmholtz. In addition to descriptions of his pronounced conceptual and theoretical orientation, analysis were made on the skillfulness and ability in his experimental pracitce (Krüger (Ed.) 1994, Cahan (Ed.) 1994). He improved existing experimental methods, developed new experimental designs, discovered new phenomena, increased the precision of measurements, and supported the discussion of errors. Against this background the complex *interaction of theory and practice* became obvious. To explain the development of his scientific theories as well as the development of his understanding of science often requires an involvement of the independent significance that Helmholtz attached to the practice. Authors such as Jed Z. Buchwald and Timothy Lenoir expounded the problem of the separation of theory and practice in Helmholtz's works (Buchwald 1994a und 1994b, Lenoir 1994). Other authors have highlighted Helmholtz's rhetorical ability, which refers less to his own experimental knowledge than to that of others (e.g. Bevilacqua 1994 and Kremer 1994).

From these investigations, which cover nearly Helmholtz's entire work, I have selected three examples from three different object fields, which aim at demonstrating the wide range of forms and functions of his experiments. This broad field is determined through diverse constellations between theory and practice. The examples are taken in chronological order from three different periods of his work. The first example is the one that most refers to practice and deals with his early physiological research. It shows dynamics of generating experimental knowledge that is relatively independent of specific theories. The second example, which clearly refers to a specific theory, deals with his acoustic works from the middle of his lifetime. Although these works are based on detailed theoretical assumptions, they have independent experimental elements of knowledge. As a last point of this part of my talk I would like to speak about his later electrodynamic works, in which theory and practice are closley coordinated.

a) Helmholtz's early physiological research

Helmholtz's early physiological research was made between the years 1843 and 1850, and in the context of his criticism of the vitalistic theory of the inner warmth. He sought to limit the area, in which the alleged effect of vital energy had to be excluded. Although these works falsified the vitalistic assumptions, the entire understanding of the organic was integrated in the *new mechanistic paradigm* of physiology, which conceptually is not comparable with vitalism. The precondition to accept only experimentally measurable phenomena was a characteristic of this paradigm. *This tended to result in the beginning of a process, where the structural features of biological theories were co-ordinated, if not sub-ordinated, to the generation of experimental knowledge.*

Helmholtz selected the *activity of muscles* as an area where vital energies have probably no effect. He wanted to provide evidence for the possibility to generate under controlled conditions the heat production similar to that which was measured in living organisms. For this purpose he stimulated prepared frog's legs to provoke contractions and measured the thereby produced increase in temperature. This investigation brought Helmholtz to new research questions. First of all, he found out that the maximum of the contractions only began with a delay in time after the stimulation. The discovery of this phenomenon contributed to the idea to measure the *speed of nerve stimulations.* The measurements required a considerable increase in *precision* and the use of new methods of *error analysis and calculation* (least squares method). Helmholtz succeeded in determining the speed in 1850. Soon after that, this determination was integrated in the physiological practical courses as a standard experiment (Olesko and Holmes 1994, p. 106 f.).

b) Helmholtz's acoustic experiments

Unlike the early physiological experiments, the results of which were not easy to foresee, Helmholtz's acoustic experiments – the second example – were determined from the outset by *theoretical targets.* These based upon his works on physiological optics. In the period between 1855 and 1856 – a time in which also his "Treatise of Physiological Optics" was published – Helmholtz developed the fundamental ideas of his acoustics (Vogel 1994). The works based upon that found a summarised representation in "On the Sensations of Tone: As a Physiological Basis for the Theory of Music" (Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik) in 1863. Helmholtz tried to transfer the insights of physiological optics to the physiological acoustics assuming Georg Simons Ohm's theory of tone, according to which tones and tone colors are caused by sine waves. In order to proof this theory, Helmholtz for one thing built devices, by means of which he simulated vowels of the human voice by artificially generated sine waves. For another thing, he developed a resonator sytem as a model of the ear, which decomposed the accord of different tones into its basic components. *Such experiments may be understood as a materialization of his theoretical assumptions.*

However, this subordination of the experiment to a theory did not prevent that independent knowledge was also generated which in addition had repercussions on the theoretical development. So Helmholtz could discover certain sum tones, as well as their seperation from beats in certain frequencies (Helmholtz 1954, p. 171, McDonald 2001, Chap 5.5). A closer experimental examination of the acoustic perception caused him to add to another field to the dichotomy of experience consisting of a physical and a physiological area – namely the psychological (Vogel 1994).

c) Helmholtz's works on electrodynamics

Helmholtz's works on electrodynamics have been discussed controversely. A reason for the variety of evaluations was the question about the relation of his own theory to that of James Clerk Maxwell. Does it largely remain in the horizon of Newton's physics (Buchwald 1985, p. 233 ff., and Kaiser 1994), or is it rather characterized by seeking to converge to Maxwell's field approach (Woodruff 1968), or is it even a new independent concept generally going beyond both Newton's and Maxwell's physics (Buchwald 1994a und 1994b)?

The latter position pretends the possibility to specify conceptual conditions, under which *the difference of theory and experiment in Helmholtz was dissolved.* Buchwald compares Helmholtz's conception of electrodynamics with the two competitive theories of Maxwell and Wilhelm Weber. Regardless of their general conceptual and structural differences both theories were based on the common assumption that the instruments for electromagnetic experiments measure interactions of entities that are not identical with the laboratory objects. According to Buchwald, Maxwell's theory assumes an interaction between the instruments and the electromagnetic field, Weber's theory posits an interaction between the electrical particles as subject matter of the measurement. *Helmholtz's conception refused the abstraction of laboratory objects.* Instead he understood these objects as carriers of states that would only interact with states of the same type (Buchwald 1994a, p. 338 f. and 341). Examples could be the states of electric charge or states of electric current. Buchwald went on stating that Helmholtz used the measurement of the interaction to calculate their energy, from the change of which he derived actions of force (loc. cit. p. 340 f.). In Buchwald's view this approach supported a new type of experimenting, which made the *discovery of new phenomena* easier, as there was no need to explain them with an already given theory, that goes beyond the given laboratory objects; they could rather be seen as an expression of new object states. It was not Helmholtz – he stated –, but his followers who implemented the approach into practice. As an outstanding example, Buchwald refers to *Heinrich Hertz's electromagnetic experiments.* In his investigations – so Buchwald – Hertz wanted to discover interactions between object states which entirely corresponded to Helmholtz's approach. Buchwald attached a less theory-driven, but rather phenomena-driven character to Helmholtz's and Hertz's electrodynamic works.

3. Comparision of the experimental practices with the development of his conception of science and nature

The examples that I discussed in the second part are very specific to certain contexts and have their origin in changing stages of Helmholtz's work. They represent different cases of producing experimental knowledge, which perhaps can be integrated in a typology.

The *early physiological research* certainly show a dynamics specific to experimental knowledge and a dynamics of a theoretical knowledge that is adapted to it. But they are linked to the framework of a programmatical conception of science and nature which prescribes a direction of their course. The conception of science raises the experiment in the investigation of living beings, to coin a later phrase from Helmholtz, to the "essential basis of science". The mechanistic conception of nature assumes that mechanical movements of invisable atoms are the *material or "true" cause* of animal warmth. The target of experimental investigation of life consists, according to the mechanistic conception of nature, of a complete description of these causes and the explanation of phenomena based on these. Although science remains far from attaining this objective, it's attainability is not doubted. Experimental work aims at proving the presumed mechanistic causes.

The *acoustic experiments* show in turn experiments that are materializations of theories.[3] The mechanistic conception of nature in this case, no longer has the mere function of a research-orientated heuristics, but develops definite ideas of the processes the phenomena are based on. But instead of examining these processes using physiological material, Helmholtz reconstructed them as mechanistic models. *His interest shifts partly from material to formal causes.* Not so much the discovery of the supposed atomic movements, but rather the structural relations between the different phenomena and thereby their law-like character come to the fore.

That mechanical models can create nearly the same phenomena as human acoustic organs is certainly not already a proof that the operation mode of these organs is also based on mechanical processes. The explanation of the phenomena delivered via analogue mechanical models is thus of hypothetical value. Insofar we can speak of a *hypothesization of the claim of knowledge* in comparison with early physiological experiments.

The *electrodynamic case* finally represents a theory that is fitted to the discovery of laboratory phenomena. In relation to the other two cases, this example is furthest away from the mechanistic

3 I suppose that this case has some similarity to today's simulation experiments.

conception of nature. Helmholtz attempts to retain every statement on non-perceivable processes, which the observed laboratory phenomena should be based on. His concept, which could be characterised as being positivistic, is concentrated on the observed phenomena and the relationship existing between them. *The focus of the research now rests on formal causes.* With regard to the claim to validity of scientific knowledge, hypothesization that is linked to the maintaining of the mechanistic conception of nature is thus arrested.

However, a closer examination of Helmholtz's conception of science can show that its positivism did not evade the *relativization of claims to validity* which was typical for his later conception of science and anticipated an epistemic feature that has been characteristic for scientific knowledge up to the present. For example in his conception of science, the division between law and hypothesis became permeable.[4] He enhanced the validity of laboratory phenomena, but at the same time admitted that it might be possible to describe them with various theories, which are incompatible with each other, but which are empirically equivalent.

The three experimental practices ascribe a *central role to the acting experimenter.* The great weight which Helmholtz hereby ascribes to the subject corresponds with his view that experiments require actions based on decisions of free will. In this regard the examples have a historical character.

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[4] See Schiemann 1997, Section B.III.1.b.

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