Between Classical and Modern Theory of Science

Hermann von Helmholtz and Karl R. Popper compared epistemologically[1]

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With his influence on the development of physiology, physics and geometry, Hermann von Helmholtz – like few scientists of the second half of the 19th century – is representative of the research in natural science in Germany.[2] The development of his understanding of science is not less representative. Until the late sixties, he emphatically claimed the truth of science; later on, he began to see the conditions for the validity of scientific knowledge in relative terms, and this can, in summary, be referred to as *hypothesizing*.[3] Helmholtz's works thus reflect the erosion of an understanding of science whose origins date back to Aristotle and which determined modern natural science till far into the 19th century. Scientific knowledge was presented with an absolute claim to exclusiveness and invariability. By analogy with the investigations into the change of the concept of science in the 19th century conducted by Alwin Diemer and Herbert Schnädelbach, I call this concept "classical".[4] Helmholtz's early position is a typical example of this. I will refer to it in the third part of my contribution (III).

I consider the radical abdiction of emphatic truth claims a sign of a "modern" concept of science as it is aimed at today by authors such as Thomas S. Kuhn, Paul K. Feyerabend and Richard Rorty.[5] The fact that the modern theory of science has abandoned the claim of truth is usually understood as a reaction to the radical changes in physics, above all in atomic physics (special theory of relativity and

1 With this title, I refer to Joseph Schwertschlager's publication "Kant und Helmholtz, erkenntniss-theoretisch verglichen" (Freiburg: Herder 1893).

2 For Helmholtz's person, cf. the biography by Koenigsberger (1902 f.), which, from the scientific viewpoint, is in fact insufficient in many respects but still unequalled as regards the richness in material; for his work, cf. Cahan (Ed.) (1994) and Krüger (Ed.) (1994). A detailed survey of Helmholtz's life and work presents Rechenberg (1994).

3 Similar developments could be proved with G. Kirchhoff, E. Du Bois-Reymond and C. G. J. Jacobi. For Jacobi, cf. Pulte (1993).

4 Diemer (1968), Schnädelbach (1983).

5 Kuhn (1976), Feyerabend (1976), Rorty (1981).

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quantum mechanics) and in the logical bases of mathematics at the beginning of our century.[6] It can be demonstrated by the example of the change in Helmholtz's understanding of science that such interpretations are too short-sighted: In the second part of my paper I will explain how Helmholtz, already in the past century, made first approaches to an understanding of science, which were incompatible with his own former position and which pointed to the modern age to an astonishingly large extent.[7] He did not, however, leave the horizon of classical thinking. He is not a thinker at the transition from classical to modern understanding of science but has remained a classical thinker (as regards the theory of science) (II).

A comparison with Karl R. Popper's logic of research will illustrate how closely he nevertheless approached modern understanding of science. Popper was among those contemporary theorists of science who have underlined the hypothetical and relative character of scientific knowledge with all emphasis, thereby exerting great influence.[8] In Popper's logic of research, hypothesizing of scientific knowledge is definitely much more advanced than in Helmholtz's theory of science. What begins vaguely to emerge with Helmholtz has already become an explicitly formulated programme with Popper. Although Helmholtz and Popper are not on a direct line of epistemological development and Popper refers to Helmholtz only rarely and casually,[9] there are in fact surprising points of contact which have not been taken notice of so far and which appear above all if one looks at Helmholtz's understanding of science against the background of Popper's logic of research. I will therefore start by briefly reconstructing Popper's position (I), and in the second part I will relate it to the understanding of science that Helmholtz adopted later on.

It should be anticipated that Popper did not, however, give up the claim of absolute validity without reservation. In contrast to the modern authors referred to above, he wants explicitly to maintain the classical idea of truth as the declared objective of science – and this relates him directly with Helmholtz. A comparison between

6 Representative of many others and with many references: Welsch (1988).

7 The change in Helmholtz's understanding of science and theory of knowledge was noticed at an early date (cf. Conrat (1904). Erdmann (1921)). However, increased attention was paid to it only recently (cf. König (1968), Hörz and Wollgast (1971), Heimann (1974), Winters (1985), Buchwald (1994), Hatfield (1994), Heidelberger (1994) and Schiemann (1994)). Cf. also Cahan (1994) concerning the invariants in his understanding of science.

8 In addition to Popper and the theorists of science already referred to, i. e. Kuhn and Feyerabend, mention must above all be made of W. V. O. Quine. Popper's influence goes far beyond the theory of science. Cf. Schilpp (Ed.) (1974).

9 As far as I know, Popper mentions Helmholtz only in Popper (1930 ff.), p. XVIII, p. 30 and p. 207, and in Popper (1956), Vol. 2, p. 138, and Vol. 3, p. 172. It can be gathered from these few remarks that Popper categorized Helmholtz as a representative of Kant's tradition of physics (Popper (1956), Vol. 3, p. 172, and Popper (1930 ff.), p. 30), who advocated a mechanistic reduction programme (Popper (1956), Vol. 2, p. 138) and who, with his empiristic foundation of geometry, comes under the antecedents of Einstein's theory of gravitation (Popper (1930 ff.), p. XVIII and p. 207).

Popper and Helmholtz thus reveals not only the modernism of Helmholtz's position but also the still absolutely classical elements in Popper's logic of research.

I

It is the central idea of Popper's theory of science that all scientific knowledge has a merely hypothetical character. When stating the reasons for this point of view, Popper starts from the assumption that the task of science is above all of a theoretical nature and consists in explaining phenomena. According to him, explaining is already the strictly logical business of deduction:[10] From premises given inclusive of laws and boundary conditions, conclusions are drawn and theorems formulated which describe the phenomenon to be explained.[11] The truth of the explanation thus depends on the truth of the premises.

According to Popper, a positive decision on these can in principle never be taken. He refers to the logical impossibility of inductively deriving, from special observational statements, laws which have the character of universally quantified propositions with an unlimited domain of individuals. While laws are, therefore, not verifiable, they can nevertheless be disproved, i.e. falsified, by observational statements.[12] (The law "All noble metals conduct current" is not verified by any number of singular statements on noble metals, but becomes, strictly speaking, invalid if only a single non-conducting noble metal is discovered.) On the other hand, Popper is convinced that observational statements cannot be verified either. Such statements refer to objects or processes which can be directly perceived or identified by indirect measurements. However, neither perceptions nor measurement operations are free from theoretical assumptions and assumptions only hypothetically valid. It is the experience's "being laden with theory" which makes the validity of the empirical basis of science a relative one.[13] At the level of theories it leads retroactively to the conclusion that alternative theories may pave the way to new approaches. It thus contributes to the establishment of a plural conception of theories.[14]

From the above it follows that, for Popper, scientific knowledge is hypothetical in two ways: It can only be supposed that the propositions of a law and the observa-

10 Like Hempel and Oppenheim later on (1948). With Popper, I relate the concept of deduction or of the "deductive verification of theories" not only to the empirical check (the result being a verification or falsification of individual theorems derived), but also to the examination of the freedom from contradiction and of the non-tautological character of theories as well as to inter-theoretical comparisons (Popper (1935), p. 7 f.).

11 Popper (1935), p. 31 ff.

12 Popper (1935), p. 3 ff.

13 Popper (1935), p. 58 ff.

14 Schäfer (1988), p. 58 f.

tional statements are true.[15] His theory of science is not, however, modern because of this characterization but because of its positive assessment for the methodology of research. According to Popper, "by removing the idol of security, even of gradual security, one of the greatest obstacles on the path of research is overcome."[16] Only the abandonment of absolute validity claims sets free creativity and rationality. With the compulsion to inductively justify theories, Popper says good-bye to all logical rules for the evolution of theories. He sees new theories emerge from a process of trial and error, in the course of which both fortune and inspiration contribute to progress.[17]

Instead of judging the scientific character of a scientific theory by the possibility of confirming predictions, Popper makes falsification the characteristic property of a scientific theory. Accordingly, in order to be referred to as scientific, an empirical theory must state in a logically incontestable way which processes must not occur in its object area.[18] It thus includes the provocative request to all potential critics to look for precisely these processes in order to contribute to the disproval of the theory by proving the existence of such processes. The greater the class of processes excluded, the greater – according to Popper – the "empirical content" of a theory. And the more attempts to disprove the theory are made, the "more well-proven" it is. Formulated paradoxically, the relation to experience is demonstrated by the successfully imposed prohibition of experience. This rather strange definition reflects the well-known, highly developed specialization of a modern science whose narrow object areas are defined the better the clearer they can be differentiated from others.

Although Popper's methodology backs up in many respects a multiplicity of theories,[19] he nevertheless sticks to his opinion that science should strive for a comprehensive, true theory. The basis of this inconsistency is Popper's concept of truth in terms of the theory of correspondence and his metaphysical realism. He calls this realism metaphysical – and in the case of Popper this means at the same time hypothetical – because it can neither be proved nor disproved and does, therefore, not differ from the opposite standpoint of idealism. Like other metaphysical assumptions, realism is of great heuristic usefulness for Popper. Based on the evidence of an ordinary intellect, realism postulates a reality which lies behind the phenomena. It must be the objective of science to understand this unique reality ever more correctly. Popper therefore judges its theories both by their compliance with reality and – this is the same to him – by whether they are constantly approaching the truth in the sense of a complete, exclusively valid explanation of the world.[20]

15 Cf. the definition of the hypothesis concept in Popper (1973), p. 21.

16 Popper (1935), p. 225.

17 Popper (1935), p. 6 f., Popper (1963), p. 49 ff., and Popper (1973), p. 168.

18 Popper (1935), p. 43 ff.

19 Popper (1973), p. 25 ff, 65 ff.

20 Popper (1973), p. 49 ff. and 347 ff., and Popper (1963), p. 215 ff.

II

The classical idea of truth adopted by Popper designates a remote aim which is unattainable. As Kant would have it, it is the idea that regulates research.[21] In a similar way, Helmholtz's later orientation towards progress is bound to the classical understanding of science. In his famous speech "Die Thatsachen in der Wahrnehmung" [The facts of perception] delivered in 1878 he calls the idea that "the comprehension (of the natural phenomena) will have to be completed" "the regulative principle of our thought".[22] Like Popper, Helmholtz connects the idea of an absolutely valid explanation of nature with a realistic understanding of the world outside. With reference to the – literally – "daily() perception", he assumes a reality independent of consciousness. In so doing, he puts this realism explicitly on the same level as idealism, as an irrefutable and therefore "metaphysical hypothesis", and attributes to both of them "full scientific justification".[23]

Helmholtz and Popper also share the empiristic point of view as far as the justification of scientific validity claims is concerned. Helmholtz does not, however, advocate an exclusively deductive concept but an essentially inductive one. For Helmholtz, the hypothetical character of the validity claims of propositions of laws follows from the conclusion – also drawn by Popper – that inductions cannot be completed. Scientifically, Helmholtz understands by induction a method with the aid of which conclusions are drawn from special experience to general propositions of laws. Induction is the guiding element in the discovery and justification of laws and designates their empirical origin.[24] In his opinion, the inductive method cannot be completed for the simple reason that it is based on the observation of individual cases, and on this basis it cannot be excluded that experience which is in contradiction with a law forms part of the observation.[25] Two years before his death he writes: "All knowledge of natural laws is inductive, induction is never absolutely completed."[26]

It is characteristic of Helmholtz's late theory of science that he goes further and considers his empiristic theory of perception to be the reason for the non-completion

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21 Kant (1787), p. 702 ff.

22 Helmholtz (1878a), p. 243. Cf. Popper (1973), p. 42. While Helmholtz links the comprehensibility of nature to the assumption of a "last unchangeable as the cause of the changes observed" (ibid), Popper refuses such an essentialism (Popper (1973), p. 217 ff.).

23 Helmholtz (1878a), p. 239.

24 Helmholtz (1862), p. 169 ff., Helmholtz (1856 ff.), p. 447 f., ff., Helmholtz (1874a), p. 414 ff., Helmholtz (1892), p. 338 ff. Helmholtz's understanding of induction essentially corresponds to the understanding – also shared by Popper – as it is still customary today, according to which "inductive inference" designates "an inference from special theorems (which describe, for example, observations, experiments etc.) to general theorems, to hypotheses or theories" (Popper (1935), p. 3).

25 Helmholtz (1856 ff.), pp. 447 f. and 451 f., Helmholtz (1885 ff.), p. 581 f.

26 Helmholtz (1892), p. 358.

of inductions. In his opinion, inductive inferences are also constitutive for elementary processes which determine everyday perception and form the basis of all knowledge. Its susceptibility to error and its variability could, in principle, be transcended neither by natural science nor by logic.[27] While Popper in his deductive theory of science does not doubt the validity of classical logic, with Helmholtz there are some first signs that it may be considered hypothetical.

Helmholtz calls the result of a scientific induction a hypothesis. In another step of verification, which Helmholtz also calls "deduction", its openness to truth can be successively reduced. For Helmholtz, deduction is a method for the empirical confirmation of law-like hypotheses and, in its logical form, it does not differ from the method of induction.[28]

> Glauben wir ein Gesetz gefunden zu haben, dann tritt ... das Geschäft des Deducirens ein. Dann haben wir die Consequenzen unseres Gesetzes möglichst vollständig abzuleiten, aber freilich zunächst nur, um sie an der Erfahrung zu prüfen, so weit sie sich irgend prüfen lassen, und um durch diese Prüfung zu entscheiden, ob das Gesetz sich als gültig bewähre und in welchem Umfange.

> [When we believe that we have found a law, the business of deduction starts ... We then have to derive the consequences of our law as completely as possible, however, in the beginning only for the purpose of checking them against experience as far as they can be checked at all, and to decide on the basis of this check whether the law proves to be valid and to what extent.][29]

As the "business of deduction" presupposes a sufficiently logical structure of the theoretical context in which the law is formulated, there is a relationship to Popper's deductive logic of research – although only a remote one. In contrast to this logic, Helmholtz does not, however, think of the falsification of the negative consequences or predictions but only of the verification of the positive ones. As a result, he maintains that neither deduction nor induction can be completed. When Helmholtz states that one has to check "to what extent" a law "proves to be valid", he gives expression to the fact that the validity of the law depends on the limitation of the area of application. Like Popper, he takes the high degree of scientific specialization into consideration. For Helmholtz, the determination of the extent does not, however, result in the justification of the hypothetical character but, conversely, it leads to a minimization of the hypothetical element. By deduction, "the hypothetical element is

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27 Helmholtz (1878a), p. 233 and 243, Helmholtz (1892), p. 359 f., Helmholtz (1885 ff.), p. 576 ff.

28 Cf. note 24. For the logical equivalence of induction and deduction, cf. Mill (1843), part 1, p. 213 f. Helmholtz does not make the formal relation between induction and deduction a central theme. When he defines induction he refers, however, explicitly to Mill (Helmholtz (1856 ff.), p. 447 f.), whose theory of science was supposedly of great importance to him.

29 Helmholtz (1878c), p. 183.

eliminated the more ... the further the investigation" can be conducted "*into special aspects*".[30] This is, however, a work which actually never ends.[31]

It essentially depends on the validity character of the empirical basis, which is only relative with Popper (because of its "being laden with theory"), up to which level this corrective adjustment of the hypothesis can be continued. The fact that, with Helmholtz, the conditions of scientific validity are reduced to elementary perceptual events which are shaped by both everyday experience and theoretical assumptions (geometrical ones, for example) means that he begins to see the empirical basis in relative terms. In addition, various aspects of his theory of knowledge and science can be indicated which, in retrospect, can be considered as preliminary forms of Popper's statement that "experience is laden with theory". For example, it can be inferred from his remarks concerning the hypothetical character of realism and idealism that he considers empirical concepts (without which observational statements cannot be made) as being bound to epistemological prerequisites.[32] The importance scientific theories may have for the representation of the empirical basis is shown in his famous publications concerning the empirical justification of the non-Euclidean geometries. In these papers he demonstrates clearly that statements on physical space are no longer possible in a unique way but only in a different though equivalent one.

With reference to the work done by Bernhard Riemann, Helmholtz concludes from the characteristics of the free movement and non-variable shape of solid bodies that, in addition to the Euclidean geometry, there may also be non-Euclidean geometrical systems. Through measurement it would be possible to empirically determine which system is realized in the space. The real structure of the space is, however, irrelevant for the physical calculations as an equivalent transformation of the different systems into one another is possible.[33]

The representation of space and of the physical laws related to it thus depend on the decision on the geometrical system used in each individual case. Whereas only the structure of the Euclidean system was thought to be identical with the structure of the space, statements on what is empirically given in the space are now possible only on the condition of theoretical assumptions which can, in principle, be freely selected and are therefore only of relative validity. With this, Helmholtz approaches a con-

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30 Helmholtz (1897 ff.), Vol. I.1, p. 19 (set-off by the author).

31 Helmholtz (1878c), p. 183.

32 Helmholtz (1878b), p. 648 f.

33 Riemann (1867), Helmholtz (1868a), Helmholtz (1868b), Helmholtz (1878b) and the rather popular publications Helmholtz (1870), p. 1 ff., and Helmholtz (1878a), p. 229 ff. I confine myself to mentioning only such elements in Helmholtz's publications in the field of geometry, which – in retrospect – are related to a modern understanding of scientific knowledge. With his work, Helmholtz himself pursued an absolutely classical aim. He wanted to contrast the hypothetical understanding of geometry advocated by Riemann with an understanding based on indubitable facts. Accordingly, the title of Helmholtz (1868b) ("Ueber die Thatsachen, die der Geometrie zum Grunde liegen") can be read as a direct antithesis to Riemann (1867) ("Ueber die Hypothesen, welche der Geometrie zugrunde liegen").

ventionalistic understanding of geometry as it was later adopted by Henri Poincaré. With the multitude of possible geometrical representations he gives an early example of the pluralism of theories which (as with Popper) goes together with the loss of something whose existence cannot be doubted.

What I have so far said about Helmholtz's late understanding of science can be summarized as follows: As regards the laws and the empirical basis, a two-fold hypothetical character of scientific knowledge can already be found with Helmholtz.[34] The fact that the validity claim is seen in relative terms is not only understood as a provisional openness to truth. With regard to the empirical basis it has a fundamental character which must also retroact upon the level of the laws. A knowledge of laws that would be completely free from hypotheses is therefore no longer possible. Helmholtz formulates this as the conclusion that no law is safe from being changed. When he faces "a new strange phenomenon", he writes in 1877, the "true natural scientist" deliberates on "whether the well-proven laws of the effect of forces known for quite a long time must not be modified"; of course, "this could only be a modification which is not in contradiction with the whole rich experience so far acquired."[35] Even if it were only a matter of gradual modifications, it is already clear that even the "best proven" laws – Helmholtz mentions in this context Newton's law of gravitation – might be concerned.[36]

Since the originally hypothetical character of laws cannot be altogether eliminated,[37] science must remain open for revisions. Helmholtz also formulates this claim implicitly when he objects to "dogmatic systems" which are lacking scientific status. This expresses a proximity to Popper's logic of research which is perhaps merely accidental but nevertheless remarkable. Like Popper at a later date, Helmholtz also chooses astrology as an example of dogmatism to contrast it with as-

34 Helmholtz uses scientific hypotheses in the following three senses: In the sense of invisible entities not yet found or assumed to be fictitious, laws not yet sufficiently verified or not fully verifiable, and finally, in the sense of irrefutable epistemological prerequisites. Cf. Schiemann (1994).

35 Helmholtz (1878c), p. 183.

36 Helmholtz considered not only special natural laws but also the general principles of mathematical natural research – one might think here, for example, of the Lagrange equation in the field of mechanics – to be fallible: "was die ... (naturwissenschaftlichen Axiome) betrifft, so sind sie theils von bestrittener Richtigkeit, theils einfache Folgerungen aus dem Princip der Causalität, das heisst aus dem Triebe unseres Verstandes, alles Geschehende als gesetzmässig, ... zu betrachten." [As to the ... (scientific axioms), some of them are of disputed correctness, others simple conclusions from the principle of causality, that is to say, from the inclination of our mind to consider all that happens to be in accordance with the laws of nature.] (Helmholtz (1878b), p. 642). For the hypothetical understanding of causality advocated by the late Helmholtz: Helmholtz (1878a), p. 243 f., Helmholtz (1885 ff.), p. 593, and the fragment in his unpublished works included in Koenigsberger (1902 f.), Vol. I, p. 247.

37 "Unwürdig eines wissenschaftlich sein wollenden Denkers aber ist es, wenn er den hypothetischen Ursprung seiner Sätze vergisst." [It is, however, beneath a thinker who wants to be scientific, when he forgets about the hypothetical origin of his sentences.] Helmholtz (1878a), p. 239.

tronomy as a science.[38] He literally indicates the "infallibility" of dogmatism to be the distinguishing trait of the unscientific character:

> Chatrakteristisch aber für die Schulen, die auf solchen als Dogmen angenommenen Hypothesen ihr System errichteten, ist die Intoleranz ... . Die überzeugten Anhänger müssen deshalb für jeden einzelnen Teil eines solchen Gebäudes denselben Grad von Infallibilität in Anspruch nehmen ...
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> [Intolerance ... is characteristic of the schools which built up their system on such hypotheses considered to be dogmas. ... The convinced adherents must therefore claim the same degree of infallibility for each single part of such a building ...][39]

To Helmholtz, the conclusion that scientific knowledge is hypothetical has in fact an absolutely research-promoting character. His understanding of science becomes more tolerant towards alternative concepts,[40] it permits different theories in one object area,[41] abandons absolute validity claims founded ontologically and relaxes regulations regarding the contents of scientific objectives.[42] However, one could call his understanding of science modern only if he made the hypothetical nature the first virtue of the scientific character. He is, however, far from doing so. For him, hypotheses remain a flaw in science – it would be better if they did not exist and unless they can be entirely removed, they must in any case be minimized. In addition, Helmholtz's late understanding of science is not free from contradictory remarks. The justification of the hypothetical character is sometimes found directly beside elements of the former classical understanding which he has retained.

In his terminology Helmholtz makes a clear distinction between hypotheses put forward inductively and successfully verified laws which he provides with the claim of strict general validity throughout his life[43] – irrespective of their "merely approximate provability".[44] Helmholtz also pursues a strategy aimed at eliminating the hypothetical content following from inductions. The method concerned is a non-inductive method which, despite its similarity with Popper's research methodology, might be confused with it only if one is to forget the difference between Helmholtz's inductive approach and Popper's deductive approach. It is to be assumed that, because

38 Helmholtz (1878c), p. 188, and Helmholtz (1874b), p. 433, Popper (1963), p. 37 f., p. 188.

39 Helmholtz (1878c), p. 175 f.

40 Cf. his second lecture on Goethe: Helmholtz (1892).

41 In addition to geometry, this applies also – although only in the sense of a temporary permissibility – to electrodynamics (for the latter, cf. Kaiser (1994) and Buchwald (1994)) and to the theory of perception (cf. Turner (1994)).

42 This can be proved by the development of his mechanistic understanding of nature (cf. note 60 and the relevant text).

43 Helmholtz (1854), p. 82, Helmholtz (1862), p. 169 f., Helmholtz (1869) p. 347 f., Helmholtz (1878a), p. 240, Helmholtz (1886), p. 318, Helmholtz (1887), p. 283 and p. 287, and Helmholtz (1892), p. 339 and p. 353 f. In Popper's non-inductive research logic, the demand for strict general validity, which is always implied in the concept of law and is explicitly raised by him for the field of practical research (e. g. Popper (1973), p. 220) is, of course, unproblematic.

44 Helmholtz (1878a), p. 393.

of his own experience, in his late understanding of science Helmholtz believes that, in addition to induction, the effectiveness of an intuitive talent can also lead to the formulation of new laws. In contrast to the laws found by induction and in contrast to the discovery of laws which, according to Popper, cannot be logically controlled, Helmholtz does not, however, call the result of an intuitive perception hypothetical, but places it in the vicinity of events of religious enlightenment. Scientific intuition is "generated by a deep look into the relation of the whole",[45] a "suddenly emerging idea, (a) ... divination, ... a kind of divine inspiration".[46]

III

It is remarkable that the transfiguration of the claim of scientific knowledge as it is expressed in such remarks is not a relic from Helmholtz's early understanding of science. Approximately up to the end of the sixties, he dissociates himself strictly from all findings which have not been obtained by induction.[47] During this time, he also claims special validity of the induction as a scientific method, as compared with the methodology applied in the liberal arts. Scientific induction has the character of a "logical induction", because it can "be carried out from the single case(s) of observation and experience" "to the perfect form of logical inference, ... to the formulation of laws valid without exception".[48]

At that time Helmholtz doubted the unlimited validity of logical or mathematical theorems as little as the absolute reliability of the inductive method.[49] Accordingly, he does not call the result of inductions "hypothetical" (in the beginning, he uses the term "hypothesis" only in exceptional cases) and does not see a reason why he should supplement it by subsequent deduction. The validity of laws found by induction would merely have to be tested "on more complex cases".[50]

Helmholtz based his early understanding of science, which exclusively followed the principles of induction, on the special features of the experimental procedure. It is possible in experiments to "arbitrarily vary the conditions on which success is achieved" and "one could therefore confine oneself to only a small number of characteristic cases of observation ... in order to find the law."[51] In practical technical experiments, the infinite number of cases covered by a universally valid law is re-

45 Helmholtz (1878c), p. 185.

46 Helmholtz (1892), p. 348. Cf. also Helmholtz (1878a), p. 232 f. and Helmholtz (1881), p. 253 and p. 257.

47 Above all in his polemic against Goethe and the romantic natural philosophy, cf. Helmholtz (1853), p. 40 ff., and Helmholtz (1855), p. 89.

48 Helmholtz (1862), p. 175 and p. 171.

49 Helmholtz (1862), p. 175 f.

50 Helmholtz (1862), p. 177.

51 Helmholtz (1862), p. 177.

duced to the variation of a single condition with the other circumstances remaining fixed and identical. A single characteristic experimental set-up corresponds to the natural law. With Helmholtz, the realist, this idealized description of experimental work is, of course, not based on the idea that both the laws and the artificially constructed experimental set-ups are inventions of the human mind. According to his empiricism, laws are not generated in practice but are "found".

Helmholtz's early understanding of science follows the tradition of empiristic conceptions as they were paradigmatically advocated in natural research by Galileo Galilei and Isaac Newton at the beginning of modern times – a tradition which, from the epistemological point of view, can hardly any longer be compared with a modern logic of research. Entirely bound by the pathos of truth of early modern times, Galilei, for example, assumed that during an experiment, abstract and concrete statements are reciprocally harmonized with one another and brought into agreement. The logical structure of the laws obtained in this way was evidence of a definition of the essential determinations of nature which existed in pure form only in technical working hypotheses.[52]

In contrast to the hypothesizing of scientific knowledge based on the theory of perception and advocated later, the early Helmholtz contrasted the objective truth found experimentally with the merely subjective evidence of perception. His understanding of science has not yet become reflexive. Perception is the object of natural science, in particular of the physiology advocated by him, without the latter being itself the object of perception. Claiming absolute validity, physiology states that subjective events of perception are of merely relative validity. Only later is it said conversely that scientific experiments, too, cannot in principle transcend the merely relative validity of a perception founded – to put it in modern terms – on the world of everyday life.[53]

The claim of absolute validity means a concentration of the scientific objectives on definite subject matters. Instead of orientating himself in a merely regulative way by the abstract postulate of the comprehensibility of nature, Helmholtz gives to understand in a hardly misleading fashion that he believes in the possibility of a complete explanation of nature that would be actually completed and exclusively valid.[54] To arrive at such a true explanation was the actual motive of the classical understanding of science as it was founded by natural research in modern times.[55]

52 Cf. Galilei (1632), p. 219 f., Galilei (1638), p. 5 and Galilei (1890 ff.), Vol. VI, p. 232, and Vol. VII, p. 211.

53 This change can be elucidated by comparing passages which Helmholtz deleted in the 2nd ed. of the "Handbuch der physiologischen Optik" (in particular Helmholtz (1856 ff.), p. 441 ff.) with passages newly included in this edition (in particular Helmholtz (1885 ff.), p. 590 ff.

54 Helmholtz (1847), p. 4 ff., Helmholtz (1862), p. 182, and Helmholtz (1869), p. 377 ff.

55 Unless it was explicitly maintained that the complete truth about nature could be found, as it was, for example, by Francis Bacon and René Descartes, the development of the knowledge

Throughout his life Helmholtz shares with modern natural research the orientation by the paradigm of mechanics. In 1869 he underlines for the last time that it is the "final goal of natural sciences to transform into mechanics".[56]

Although changes in Helmholtz's understanding of science already appear in the fifties and sixties, during this period it nevertheless remains strictly within the framework of the classical concept. There are hardly any clear signs and astonishingly little evidence of the erosion of the certainties of truth which started afterwards.[57] Furthermore, it is striking that the change takes place in the astonishingly brief period between the end of the sixties and the beginning of the seventies. As early as 1874 the outlines of Helmholtz's new position can be reconstructed.[58]

The question arises as to which external factors may have contributed to this change. The reception by Helmholtz of the English empiricism and of the understanding of science on the part of English physicists is certainly of great importance.[59] In addition, in Helmholtz's professional career, the whole process of changes coincides with his turning more and more to physical problems.[60] It cannot be excluded that the transformation in his understanding of science was substantially stimulated by the crisis in his mechanistic understanding of nature whose limited scope was recognized in the seventies – and Helmholtz had not been unaware of this.[61] First, the atomistic ontology advocated by him was exposed to increasing criticism. While Helmholtz was convinced, even at the end of the sixties, that the antique theory of elements had at last and definitely been scientifically confirmed by

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of nature still to be expected was not devised as an infinite process (for example, by Galileo Galilei, Johannes Kepler and Isaac Newton).

56 Helmholtz (1869), p. 379.

57 First evidence of the increased influence of the theory of perception on the understanding of science is found in § 26 of Helmholtz (1856 ff.). As has been shown, elements of a modern understanding of science are also implied in Helmholtz's works on geometry in the years from 1868 to 1870 (cf. note 33). Impulses, inherent in physics, for the development of Helmholtz's understanding of science can be found in Winters (1985).

58 Helmholtz (1874a) and Helmholtz (1874b). Most investigations into the change in Helmholtz's understanding of science (cf. note 7) claim that there is a turning point in his development. The dates established differ depending on which elements of the change are given special attention. On the whole, the turning points found are in the period between 1862 (Hatfield (1994)) and 1871 (Buchwald (1994) and Schiemann (1994)).

59 Only the most important information can be given here: Koenigsberger (1902 f.) reports on his journeys to England made in 1853; in 1870, Helmholtz publishes a book by John Tyndall on Michael Faraday; in 1871 and 1874, the 1st and 2nd part of the 1st volume of the "Handbuch der theoretischen Physik" by William Thomson and Peter Guthrie Tait; for James Clerk Maxwell cf. in particular Helmholtz (1881), p. 249 ff., and Helmholtz (1882 ff.), Vol. 3, p. 209. Heidelberger (1994) in particular underlined the influence of English physicists. For the reception of English empiricism, cf. note 28.

60 In 1871, Helmholtz discontinued his employment as Professor of Physiology in Heidelberg and was appointed Professor of Physics in Berlin.

61 Examples of the criticism of the mechanistic programme of explanation are Mach (1872) and Kirchhoff (1876).

chemical research work, already at the end of the seventies he had to be prepared for "new decompositions of the chemical elements now known".[62] Moreover, doubts were raised as to whether the structure of the elementary forces at the atomic level agreed with the idea of instantly effective central forces which Helmholtz had made the basis of his understanding of nature. It was above all the electrodynamic phenomena and their mathematical description by James Clerk Maxwell which upset the old mechanistic conception of the world in the past century.[63]

IV

The upsetting of formerly valid knowledge without reservation also marks the historical context in which Popper's logic of research has developed. His theory of science is among the intellectual reactions to the changes in mathematics and physics mentioned at the beginning, which took place in the first two decades of our century and remained central points of reference in Popper's work throughout his life.[64] The hypothetical understanding of scientific knowledge formulated by Helmholtz and Popper responds to the loss of the validity of fundamental assumptions in research by revoking, on grounds of principle, claims of scientific knowledge.

Such a reaction can scarcely be free from disappointment at the loss of truth which is taking place. It is, therefore, not surprising that Popper and Helmholtz jointly stick to the idea of an absolute truth in a special way: Truth not only determines the objective of science; reaching the truth must be possible in no other way than the scientific, and this means to both of them along the lines of empirical science.[65] In the case of Helmholtz, this scientism is in addition bound to the orientation by the principles of mechanics maintained by him. He does not react to the crisis of

62 Helmholtz (1878a), p. 240, and in contrast to this for example: Helmholtz (1869), p. 378 f.

63 Helmholtz states as early as 1871 (Helmholtz (1884), Vol. 2, p. 47) that Michael Faraday's theory of the geometry of magnetic lines of force (to which Maxwell's electrodynamics is directly linked) is basically in "contrast" to all physical theories "which operate with atoms and forces acting into the distance". Helmholtz himself voices first doubts about the structure of fundamental forces in the supplements to Helmholtz (1847) and in Helmholtz (1882 ff.), Vol. 2, p. 1003 ff.

64 Cf. Schäfer (1988), p. 12 ff.

65 By seeing the contrast between scientific and artistic knowledge in relative terms in his later understanding of science, Helmholtz does not revise his former conviction that natural phenomena could be defined only in terms of the inductive method applied in natural science, but puts this conviction more precisely (cf. Helmholtz (1862), p. 169 f., and Helmholtz (1892), p. 338 ff.). It can also be assumed that throughout his life, Helmholtz considered the method of natural science a model for the liberal arts (cf. Cahan 1994). I denote the trust in that scientific problems can, in principle, be solved by the methods of empirical science by the term "scientism". In particular with a view to his attitude towards sociology, Popper's critical rationalism can in this sense be called scientistic. Cf. Theodor W. Adorno, introduction to: "Der Positivismusstreit in der deutschen Soziologie". Neuwied 1969, p. 12 ff.

mechanism by abandoning this understanding of nature. On the contrary, along with the change in the understanding of science, which hypothesizes scientific knowledge of the whole of nature, he can immunize it against criticism.[66] A similar statement could presumably also be made on Popper's scientism.

If one wanted to place both authors on a line describing the development of the empirist theory of science, one could speak of an increasing dissociation from the inductive method. The fact that the claim of the validity of scientific knowledge is increasingly seen in relative terms coincides with the inductive method becoming more and more problematic. The claim of absolute validity is first supplemented by additional methods of verification and finally discarded, together with induction. This reflects an increasing scepticism regarding the validity of the empirical basis. It neither allows clear theories to be derived nor is it accessible without preliminary theoretical assumptions.

Because Helmholtz was bound to the inductive method throughout his life, he complied with the modern element in Popper's understanding of science only within narrow limits. However, it was part of his genius that he recognized the mood of the times at an early date. He may have suspected that, with the abandonment of the claims of absolute validity, all logical reconstructions of science, as they were once again tried by Popper, might be doomed to failure. With Helmholtz, there are already first signs of mathematics and logic being subordinated to the conception of relative knowledge based on the theory of perception. With this conception, he tries to solve the validity problem without reference to the absolute stages of a reality or of a thinking free from experience. These efforts take him close to a pragmatic conception of science which is today met with ever more approval[67] and whose disapproval marks Popper's critical distance to the modern age.[68] Without taking real or mental guarantees of validity as a non-circumventable basis at the end of his theory of knowledge Helmholtz sees "no other pledge" but the success of every work, and he can do nothing else but give "the advice: trust and act!".[69]

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66 Cf. Schiemann (1994).

67 Stegmüller (1983 ff.), Vol. 1, p. 1 ff.

68 Popper (1973), p. 339 f., and Popper 1956, p. 4 f.

69 Helmholtz (1878a), p. 243 f., and accordingly: Helmholtz (1892), p. 358.

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