Werner Heisenberg's Position on a Hypothetical Conception of Science

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Abstract:

Werner Heisenberg made an important – and as yet insufficiently researched – contribution to the transformation of the modern conception of science. This transformation involved a reassessment of the status of scientific knowledge from certain to merely hypothetical – an assessment that is widely recognized today.

I examine Heisenberg's contribution in particular by taking his conception of "closed theories" as an example according to which the established physical theories have no universal and exclusive, but only a restricted validity. Firstly, I characterize the historical process of hypothetization of claims to validity. Then, secondly, I reconstruct Heisenberg's conception, as far as it can be derived from his popular writings, relating it to the process of hypothetization. Finally, I touch on the history of its reception and compare it with conceptions of science that emphasize the significance of the hypothetical for the modern theories of natural sciences. Compared to these conceptions, Heisenberg's contribution turns out to be rather independent.

Werner Heisenberg made an important – and as yet insufficiently researched – contribution to the transformation of the modern conception of science. This transformation involved a reassessment of the status of scientific knowledge from certain to merely hypothetical – an assessment that is widely recognized today. The beginnings of this process can be traced back to the nineteenth century (e. g. John Herschel, William Whewell and Hermann von Helmholtz).[2] Taking Heisenberg as an example, I would like to investigate the influence of the foundation of quantum mechanics, which shaped his conception of science, on the relativization of claims to truth.

Heisenberg's conception of science itself, however, underwent a transformation and is not free of contradictions.[3] By restricting his ma-

1 Slightly revised and translated version of Schiemann 2007.

2 On John Herschel and William Whewell see Snyder 2009, on von Helmholtz see Schiemann 1997.

3 I have presented Heisenberg's conception of science in the context of a reconstruction of the central elements of his thought in Schiemann 2008.

trix mechanics to the calculation of measurable quantities, in 1925 Heisenberg tried to give quantum mechanics a foundation as free of hypotheses as possible. Later, questions concerning the reality of theoretical entities and about the truth of atomic theories, as well as their relation to other physical theories and to the concept of knowledge in the natural sciences – without impugning the formal structure of the foundation – led in the late 20s to a partial hypothetization of claims to truth.

Heisenberg's efforts towards a solution to these theoretical problems are closely linked to *practical contexts*. His enquiry into the question of claims to truth was influenced by exchanging ideas with other quantum physicists. It appeared to be part of Heisenberg's individual career strategy; within physics, it helped to implement a certain understanding of physics and to organize research in physics. Last but not least, it reacted to the political attacks that Heisenberg and other scientists had been facing since the Nazis came to power.

My contribution focuses on Heisenberg's conception of science, as far as it can be derived from his *Popular Speeches*. In her much-noticed book on the justification of quantum mechanics, Mara Beller referred to the general context-dependency of these texts (Beller 1996, 196). Heisenberg's biographer, David C. Cassidy, also supported this opinion (Cassidy 1992, 255). Inconsistencies that may be found between the contents of the various speeches are due, they claim, to the fact that Heisenberg intended to achieve different effects with different audiences. In my view, however, the interpretative possibilities of Heisenberg's conception of science depending on practical contexts are clearly of minor importance. The fundamental elements of his conception persist from his early lectures in the 1930s to his late lectures of the 60s and 70s. They are characterized on the one hand by an ambivalence which emphasizes the certainty of scientific findings, while at the same time, admitting that their claim to truth is limited on systematic and historical grounds.[4] On the other hand, Heisenberg constantly struggles to overcome this conflict. His striving for a unified solution is most clearly expressed in his "conception of closed theories." Following its first programmatic formulation in his speech "Recent Changes in the Foundations of Exact Science" ("Wandlungen in den Grundlagen der Naturwissenschaft"), which he held at the general meeting of the Association of German Natural Scientists and Physicians in 1934 (Heisenberg 1934), Heisenberg stood by his conception for all his life and without substantial changes, despite its varied theoretical and practical contexts.[5]

4 The ambivalence of Heisenberg's position on the question of the truth of scientific knowledge has not been discussed in secondary literature. Discussion has focused one-sidedly either on his orientation towards absolute claims to validity (Beller 1999, Carson 1995) or on his rejection of the classical ideal of objectivity (Chevalley 1988).

My paper is structured as follows: first, I am going to characterize the historical process of hypothetization of claims to truth. Secondly, I will then reconstruct Heisenberg's conception, as far as it can be derived from his popular Writings, relating it to this process of hypothetization. In the third part, I want to touch on the history of its reception and compare it with conceptions of science that emphasize the significance of the hypothetical for the modern theories of natural sciences. Compared to these conceptions Heisenberg's contribution turns out to be rather independent.

1. The Process of Hypothetization of Claims to Truth

Hypotheses have been known in science ever since its origins in antiquity. And yet it is only in the last 200 years, I contend, that they have begun to constitute a distinguishing feature of knowledge and self-conception in the natural sciences. The historical process of hypothetization of claims to truth is closely connected with emergence and decline of the mechanical worldview of classical physics. There are *two ways* – not always sharply distinguishable from each other – in which a statement can be said to be hypothetical: its truth is either assumed to have not yet been established, or it is considered not to be verifiable at all. In the first case, a provisional assumption can be confirmed, disproved or corrected in the course of further research. The second type of hypothesis, by contrast, is not expected to lose its nature of being open to truth. Both types can exist side by side in a given theory. A theoretical supposition about empirical objects can be assumed to be converted into truth, whereas a metaphysical assumption of the same theory can be believed to remain permanently hypothetical. But a competitive situation may just as well develop between the two types. This occurs, for instance, if the justification of one of the types is fundamentally dis-

5 Heisenberg's most important presentations of this conception are Heisenberg 1934, Heisenberg 1948, Heisenberg 1959, ch. VI, and Heisenberg 1973. On the secondary literature cf. section 4.

puted by some scientists. In this case – as some scientists claim – the possibility of being able to transform certain hypotheses into truth is challenged or, vice versa, the uncatchable openness to truth of all hypotheses – as assumed by others – is rejected.

I presume that both definitions of the hypothetical were useful for a long historical period, although the concept of truth during that period was subject to considerable transformations. The historical process of *hypothetization of claims to truth* that has occurred can be very briefly described as follows:

Since the beginning of the early modern era, i.e. the 16th and 17th centuries, *provisional assumptions* have become more and more important in the pursuit and formulation of knowledge in the natural sciences. The question of the claim to knowledge was discussed from the very beginning. Johannes Kepler's, René Descartes's, Isaac Newton's and Gottfried Wilhelm Leibniz's concepts of hypothesis are vivid examples of this.[6] The hypothetization that soon set in was spurred on by questions arising in practical research about observability – e.g. in the use of optical instruments –, and the role of models – e.g. mechanical models of submicroscopic processes. Provisional assumptions became the basis for the hypothetico-deductive model of theory construction as it is standard today. They are also found in explanations that reduce phenomena to processes as yet uninvestigated but assumed to exist, in predictions, in calculations using models and simulations – to give just a few examples.

The second form, however, the *abandonment of claims to truth*, was for a long time categorically rejected by modern natural science. The mechanistic worldview, prevalent in the classical physics of the 18th and 19th century, still postulated final, non-hypothetical knowledge and restricted the use of hypothetical statements to the first kind of hypotheticity. It was David Hume's empiricism that first brought a great deal of attention in the English-speaking world to the second kind of hypotheticity. According to Hume, only inductively secured knowledge could be gained from experience. Induction, however, does not hold by logical necessity. Thus, he argued, empirical knowledge can at best have a hypothetical character.

In the second half of the 19th century, the hypothetical character of the natural sciences increasingly caught the attention of natural scientists

6 On Kepler, Descartes, and Newton see McMullin 2009.

and philosophers in Germany, France and Britain.[7] During the 20th century, a hypothetical conception of the natural sciences was established, which differed from previous conceptions of science in its positive evaluation of the concept of hypothesis, as well as in the historical consciousness related to it. It rejects the absolute claim to validity of classical physics and is convinced that all knowledge in the natural sciences, including the fundamental theories, may be subject to a revision. There are mainly two approaches in the philosophy of science that express this view: Karl R. Popper's falsificationism and Pierre Duhem's and Willard van Orman Quine's thesis of the empirical underdetermination of theories.[8]

2. Heisenberg's Conception of Closed Theories[9]

Heisenberg's writings on the history and theory of physics are relevant to the two meanings of the hypothetical on account of his ambivalent position regarding scientific claims to truth. On the one hand he proceeds from the assumption that theories are hypothetically conceived structures which lose their openness to truth in the course of the continuing experimental investigation of the theories relating to empirical data. Thus, in a speech delivered in 1946 and entitled "Science as a Means of International Understanding" ("Wissenschaft als Mittel zur Verständigung unter den Völkern"), he says:

> I learnt "that in science the question of what is right and what is wrong is ultimately always answered: that it is not a matter of faith or worldview or hypothesis, but that one particular assertion simply turns out to be correct and another false; the decision about what is right is made ... by nature or if you will, by God, but certainly not by man" (Heisenberg 1946, 386).[10]

7 One example for Germany is presented by Pulte 2009, one for France by Heidelberger 2009.

8 On Duhem and Popper see Bartels 2009.

9 Cf. Schiemann 2008, Chap. III.2.

10 Ich lernte, "daß man nämlich in der Wissenschaft schließlich immer entscheiden kann, was richtig und was falsch ist, daß es sich hier nicht um Glauben oder Weltanschauung oder Hypothese handelt, sondern daß schließlich eine bestimmte Behauptung eben einfach richtig ist und die andere unrichtig; und welche richtig ist, darüber entscheidet ... die Natur oder, wenn Sie so wollen, der liebe Gott, jedenfalls nicht die Menschen."

What Heisenberg means by "right" is truth that is not a subject in non-scientific discourses, which are concerned solely with "belief," "world-view" or "hypothesis." In science, hypotheses arise in the early stage of the development of theories and in their application to new fields. In the structures of truth derived from theories one is confronted, he says, with "pure and unconcealed truth" (Heisenberg 1946, 393). This absolute conception of truth can be regarded as an expression of his Platonism.[11] According to this, science develops from hypotheses to knowledge which permits recognition of the fundamental laws of the world existing independently of this knowledge.

However, the historical change of physical theories at the beginning of the last century has unsettled the faith in the validity of their truth and thereby lent them a hypothetical character. Scientific claims to the truth have proved to be partly wrong and partly incompatible with one another in terms of content.[12] The ideal of objective knowledge, i. e. knowledge independent of the circumstances of observation, has proved to be realizable only to a limited degree.[13] It has become questionable whether a unified understanding of nature can be attained.[14] The partial unification of physical theories requires a high degree of abstraction that increasingly diverges from the concrete appearance of phenomena and it is capable of relating to the phenomena only hypothetically.[15] What is more, the pragmatic orientation of experimental research counteracts a truth-oriented process of knowledge acquisition:

> As practical activity became [in our century] the focal point in our view of the world, so the fundamental [scientific] thought patterns lost their absolute significance ... In science one became increasingly aware that our understanding of the world cannot proceed from any certain knowledge, cannot be founded on the rock of such knowledge, but that rather all knowledge is suspended as it were above a bottomless abyss. (Heisenberg 1946, 391).[16]

11 Cf. Liesenfeld 1992, Schiemann 2008 Chap. III.3.
12 Cf. below the example of quantum mechanics.
13 E.g. Heisenberg 1954, 399 ff.; Heisenberg 1959, 166 ff.
14 Heisenberg 1934, Heisenberg 1959, 96.
15 Cf. Heisenberg 1948, 338 f.; Heisenberg 1973, 418.
16 "In dem Maß, in dem das praktische Handeln [in unserem Jahrhundert] in den Mittelpunkt des Weltbildes rückte, verloren die grundlegenden [wissenschaftlichen] Denkschemata ihre absolute Bedeutung ... In der Wissenschaft wurde man sich immer mehr dessen bewußt, daß unser Verständnis der Welt nicht mit irgend einer sicheren Erkenntnis beginnen kann, daß es nicht auf dem Fels einer solchen Erkenntnis gegründet werden kann, sondern daß alle Erkenntnis gewissermaßen über einer grundlosen Tiefe schwebt"

We have thus a divergence between Heisenberg's orientation towards an absolute concept of truth and his awareness of the inevitable hypotheticity of scientific knowledge. The way he tries to resolve this conflict is made clear by his critique of the claim to validity of classical physics.[17] It is this critique that leads him to the conception of closed theories. The theories of classical physics, Heisenberg claims, have *no universal, but only a limited validity* and the limited fields of application are determined by the fundamental concepts of the theories concerned. Heisenberg attributes this function of fundamental concepts to the fact that experiments make them closely rooted in the kind of experience that is specific for the particular fields of application. The differences between the fields of experience reflect the differences between the concepts of the respective theories. In regard to the relations between the concepts of different theories, Heisenberg tolerates contradictory definitions. However, the differences between the experiences or fields of application do not prevent points of contact and overlap. The realm of one theory can also include the realms of other theories. Theories, therefore, have *no exclusive validity*.

Heisenberg specifies this structure of theories with his conception of closed theories. In this context, the term "closed" has a systematic and a historical meaning. The *systematic* meaning refers to the relation between coexisting closed theories. A closed theory forms a system that is closed in itself (Heisenberg 1934, 100), in which concepts are distinguished from laws and interconnected through a consistent system of axioms. The connection between these concepts is "so tight that it is generally impossible to change any of these concepts without destroying the whole system at the same time" (Heisenberg 1959, 81). This determination leads over to the *historical* meaning of the term "closed." Closed theories cannot be improved by minor modifications, i. e. modifications of their laws (Heisenberg 1973, 417). Major modifications, i. e. changes of concepts, lead to new concepts and theories (Heisenberg 1934, 100; Heisenberg 1959, 84; cf. Scheibe 1993, 252). Therefore,

17 For Heisenberg, the validity of a theory is founded upon its truth content. I follow here this understanding of the concept..

theories are also closed, because their historical development has come to an end.[18]

Heisenberg considers *four theories of physics* to be closed: Newton's mechanics, electrodynamics, including the special theory of relativity, thermodynamics, including its statistical version, and quantum mechanics. From the fact that they are closed, he draws the conclusion that they are "valid forever": "wherever experiences can be described with the concepts of these theories, be it in the most distant future, the laws of these theories will always prove to be right" (Heisenberg 1948, 339). This formulation is circular, as far as only those experiences are concerned to which the concepts are applicable. As there is always, however, a difference between concepts and experiences, the formulation is not tautological. Correspondingly, it extends to "all times," thus referring to validity that is not timeless, but invariant for all circumstances that are conceivable at a certain time – and therefore of a final nature.

The view of a *far-reaching stability* of reliable physical theories that is hereby expressed shows considerable plausibility; this is what makes Heisenberg's concept really interesting. Newton's mechanics, electrodynamics and thermodynamics continue to be of central importance to the engineering sciences where they find their most important application today; quantum mechanics has proved its validity in an unprecedented way during the 80 years since it was founded. Heisenberg's idea that theoretical stability is grounded in the close relation between concepts and experience is reflected also in present philosophy of science, such as, for example, in Ian Hacking (1992, 30).

By claiming a final validity for particular theories Heisenberg formulates a *non-hypothetical feature* of physical knowledge, which is only in part still linked to the traditional claims to truth – a relation which Heisenberg does not discuss explicitly. The mechanistic worldview of classical physics aimed at the unity of content-related knowledge. Heisenberg contests this aim by renouncing the universal validity of the theo-

18 Heisenberg's most important presentations of his conception are Heisenberg 1934, Heisenberg 1948, Heisenberg 1959, ch. VI, Heisenberg 1969, ch. 8, Heisenberg 1970 and Heisenberg 1973. In Heisenberg 1948, 338 f. he mentions four characteristics of closed theories: 1. inner consistency and axiomatization of concepts, 2. representation of experience within a certain area of application, 3. missing knowledge about the exact boundaries of the application areas, 4. basis for further research. On the secondary literature cf. section 2. On the characteristics of Heisenberg's closed theories cp. Scheibe 1993, Frappier 2004, Bokulich 2006.

ries. The closed character of the theories, which cannot be anymore improved upon, could oppose their unity. If the natural sciences consisted entirely of closed theories, they would acquire a plural character:

> [T]he edifice of the exact natural science" "can therefore scarcely become ... a coherent unity such that one could get from one point in it to all other rooms of the building simply by following a prescribed route. Rather, it is composed of various parts, each of which, although linked to the others in manifold ways, ... still represents an integral unit in itself. (Heisenberg 1934, 101).[19]

This view of scientific knowledge, akin to William James's pluralism (James 1925), does not necessarily contain a renunciation of claims to validity. The closed theories after all remain valid "for all times" in their particular fields of application. Heisenberg leaves room for doubt with regard to the claim to unity of knowledge, but not with regard to its final validity in individual areas. To put it differently, he saves the temporal dimension of the classical claim to truth by separating it from the claim to unity. For Heisenberg, it is still an objective of science to search for an all-embracing theory; but the attainment of such a theory may not be possible any more. The distancing from universal claims to validity could be attributed to the fact that Heisenberg doubted their finality and tried to save this attribute of traditional concepts of truth at least for particular theories.

Heisenberg discusses the anti-hypothetical content of his concept of truth in various places, for instance, when he investigates the question of the consequences of the *emergence of quantum mechanics* for the claim to truth of classical theories (Heisenberg 1936, 110 f.). Heisenberg believes that, against the background of modern theories, classical theories are not false, but remain true in their fields of application. It was wrong, however, that they went beyond their realm of application (e.g. by means of mechanical models of the atom). But only in the light of new theories does this inadmissible transgression become visible. Heisenberg did not doubt that, in the future, the applicational limits of quantum mechanics could similarly be determined by new theories,

19 "Das Gebäude der exakten Naturwissenschaft kann also kaum ... eine zusammenhängende Einheit werden, so, daß man von einem Punkt in ihm einfach durch die Verfolgung des vorgeschriebenen Weges in alle anderen Räume des Gebäudes kommen kann. Vielmehr besteht es aus einzelnen Teilen, von denen jeder, obwohl er zu den anderen in den mannigfachsten Beziehungen steht, ... doch eine in sich abgeschlossenen Einheit darstellt." Cf. also Heisenberg 1959, 96.

just as the limits of classical theories in the past. Through this, the conditions of a final validity would also be more specified for quantum mechanics.

The fact that the demarcations between the realms of application of closed theories can only be determined in the historical process refers to a first aspect of *the irreducible hypothetization* of these theories in Heisenberg's conception. The *determination of demarcations* can change all previous assumptions about the extension of the realms of validity. This process could be accomplished only with an ultimate closed theory. Prior to such a final circumstance, whose future realization Heisenberg does not rule out (Heisenberg 1970, 390 ff.), the limits of all closed theories cannot be determined with certainty. Therefore, statements regarding phenomena acquire a hypothetical character, which relates to Heisenberg's *historical conception of knowledge*, i. e. to his conviction that the validity of certain aspects of knowledge are subject to historical change. Knowledge yielded by closed theories does not expand without repercussions for its already existing elements. The degree of their certainty grows with the increasing determination of their limits without being required to reach final exactness. Consequently, the finality of the theories does not rule out that their statements are of a hypothetical nature – whether provisionally or in principle.

Against this background Heisenberg establishes that:

> The closed theory does not contain any statements that are entirely reliable of the world of experiences. It remains – strictly speaking – doubtful and simply a question of success up to what extent the phenomena can be dealt with by the concepts of this theory ... Despite this uncertainty, the closed theory remains a part of our scientific language (Heisenberg 1948, 339).[20]

In Heisenberg's conception there are two more aspects of a hypothetization of scientific knowledge which, albeit to a different extent, are likewise attributed to the historicization of scientific knowledge. While the aforementioned aspect concerns the objects of experience that were wrongly counted as lying within a field of application, the second aspect is about the *relation between experience and theory* within the

20 "Die abgeschlossene Theorie enthält keine völlig sichere Aussage über die Welt der Erfahrungen. Denn wie weit man mit den Begriffen dieser Theorie die Erscheinungen greifen kann, bleibt im strengen Sinne unsicher und einfach eine Frage des Erfolgs ... Trotz dieser Unsicherheit bleibt die geschlossene Theorie ein Teil unserer naturwissenschaftlichen Sprache."

boundaries of a field of application. According to Heisenberg, the axiomatization of theories guarantees their consistency and determines certain meanings of the concepts. He assumes, however, the experience in the particular field of application to be changeable. This transformability is covered by the meanings of the concepts only to a limited degree (Heisenberg 1948, 338 f.; Heisenberg 1973, 418).

This aspect of the hypotheticity of closed theories is associated with Heisenberg's *romantic reference to Plato's theory of forms*. In his speech "On the History of the Physical Interpretation of Nature," given in 1933, he differentiates with Plato "four levels of knowledge": knowledge of essence (episteme), insight (dianoia), belief (pistis) and conjecture (eikasia).[21] Whereas Plato relates episteme only to the world of ideas, Heisenberg understands it as a form of knowledge of nature separate from dianoia (Heisenberg 1933, 54). According to him, episteme means an understanding of nature that is immediate, clear and qualitative in character, and is therefore directly connected to experience; in contrast to this, dianoia signifies a quantitative description of nature, which is accomplished through increasing axiomatization. He states that natural science has augmented the amount of dianoia and increasingly drifted away from episteme (Heisenberg 1933, 56). The immediate understanding of the nature of episteme, of which Goethe's conception of nature is paradigmatic in Heisenberg (Heisenberg 1967, 405), allows an awareness of the change of the concrete diversity of phenomena and thus forms a critical instance against the claim to truth of the mathematical knowledge of nature. Heisenberg's Platonism therefore allows a justification not only of absolute claims to validity, but also of the diversity of phenomena.

Like the first one, also the third aspect of the hypothetical in Heisenberg's conception concerns the relations between closed theories. New theories emerge, because old ones fail when expanding their fields of application. Putative areas of application of an old theory turn out to be those of a new theory. Consistent relations between the concepts of the old and the new theory are not necessary. Yet the laws of the old theory can emerge as borderline cases from the laws of a new theory. As borderline cases, the phenomena of an old theory can be understood by means of the concepts of the new theory. The emergence of new theories leads therefore to the possibility of empirically equivalent descriptions of objects by theories that might be conceptually incompati-

21 Plato, Pol. XI 509d–511e.

ble. The *empirical underdetermination* of closed theories not discussed by Heisenberg is expressed in this feature. As long as the unity of knowledge remains a part of the definition of truth, underdetermination results in the hypotheticity of scientific knowledge.

To summarize, I wish to claim that, with the concept of closed theories, Heisenberg took a step towards a conception of science that recognized the hypothetical character of scientific knowledge. Paradoxically, with this step he tried to save the classical claim to the final nature of knowledge. He abandoned the necessary classical conditions of the universality and exclusivity of truth and conceded that there were uncertainties in the relations between closed theories as well as between one theory and its corresponding realm of experience. In terms of the historical development sketched in the first section, Heisenberg stands at the transition from an early modern claim to truth to a hypothetical conception of science.[22]

3. The Reception of Heisenberg's Conception

Despite its plausibility, Heisenberg's conception has not received significant attention in the philosophy of science up to now. It has mainly been reflected in the works by Carl Friedrich von Weizsäcker (1974) and in the circle of his former colleagues (Scheibe 1993, Böhme et al. 1973, Böhme 1970 f.). Today, his conception attracts interest above all because of its historical significance for the understanding of quantum mechanics (Beller 1999, Chevalley 1988, Bokulich 2006) and sometimes also in the philosophy of science (cp. the aforementioned Hacking 1992). Up to now, little attention has been paid to the fact that closed theories are a suitable object to study the process of transformation of claims to truth within the sciences.

I have already mentioned Popper's falsificationism and the thesis – attributed to Duhem and Quine – of empirical underdetermination as paradigms of the hypothetical in the *theory of science*. In the *history of science,* it was Thomas S. Kuhn who laid some of the groundwork on a hypothetical conception of science. To conclude, I want briefly to outline the relation of Heisenberg's conception to these paradigms of the hypothetical.

22 In this classification there is a similarity with Hermann von Helmholtz's conception of science, which is analyzed in Schiemann 1997.

In order to characterize the relation to Popper's philosophy of science in one sentence one could say that Heisenberg's conception of closed theories keeps a clear distance from *falsificationism*, because the claim to finality excludes the possibility of refutation. In his later writings, however, Heisenberg retracts his proposition that closed theories are irrefutable (Heisenberg 1973, 418). He is able to refer to his understanding of finality, which he conceives as not being absolute and timeless, but rather as extending over a relatively long period of time. The non-holistic character of closed theories, in which no concept "in general" is changed "without the whole system being destroyed" (Heisenberg 1959, 81, see above), also weakens any immunity to refutation.

There are different versions of *Duhem's and Quine's underdetermination thesis*. I choose one that appears to me to be the most appropriate to be compared with Heisenberg's conception. Accordingly, a theory is underdetermined if its empirical evidence is not sufficient to confirm or invalidate it. If empirical evidence were the only criterion for assuming or refuting a theory, no decision could be made to decide between logically incompatible theories that relate to the same object. Similarly, Heisenberg's conception leads to the possibility of logically incompatible closed theories in a certain field. He does not, however, reduce the criterion of theory selection to empirical evidence. The concepts of closed theories remain more appropriate to their fields of application than the concepts of those theories whose borderline case can be calculated.

The domain of a closed theory can also lose any relevance. In his first discussion of the concept of a closed theory in 1934, Heisenberg compares the relation of closed classical theories to quantum mechanics with the relation of disc and sphere theories of the earth. The disc theory was replaced by another conceptual system, where parts of its domain as well as related questions no longer occurred (Heisenberg 1934, 98 and 100).

The emergence of new theories, separated by a conceptual gap from old ones, shows *similarities to Thomas S. Kuhn's theory* of the development of science. Heisenberg's conception has frequently been discussed as a precursor of that theory.[23] However, the succession of Kuhn's paradigms does not necessarily lead to progress in knowledge. In contrast, according to Heisenberg, new theories expand knowledge since they

23 On the relationship of Heisenberg and Kuhn cf. also: Beller 1999, Bokulich 2006, Van Dyck 2003.

deal with phenomena hitherto not yet investigated, or not correctly investigated, that differ from the phenomena of previous theories. While, according to Kuhn, the selection of theories depends considerably on non-scientific influences, Heisenberg believes that new closed theories emerge from interdisciplinary contexts. With respect to the conditions of the origin of quantum mechanics, he partly emphasizes the significance of the discussions held among physicists and of their intuition (Heisenberg 1969, 86), and partly claims that the new theory has been "imposed by nature" (Heisenberg 1934, 96).

A comparison of the three hypothetical conceptions of science with the conception of closed theories confirms that Heisenberg continues to orientate himself towards unconditional claims of truth. He (mostly) contests the possibility of any fundamental revision of scientific knowledge, the possibility of its equivalent representations and its historical relativity. The development of some established theories reflects advances in an improvement in knowledge which leads to knowledge within limited fields of application. The concepts of these theories are so well-adapted to experience that they are valid forever.

4. Conclusion

In conclusion I summarize my claims: according to Heisenberg, some established theories of physics function as so-called *closed theories*. Closed theories have a limited realm of application. Their concepts are particularly well adapted to the pattern of experience of their realm of application, within which they are valid for all conceivable circumstances. On the one hand, Heisenberg endorses the claim to final knowledge with this conception as it was typical of physics at the beginning of the early modern age. On the other hand, he relativizes claims to truth within the scope of his conception. The final certainty of physical knowledge does not go beyond closed theories and, as a consequence, ceases to be necessarily directed at the target of a uniform description of nature. There is then uncertainty about validity, *firstly* regarding the limits of realms of application, *secondly* regarding the concepts which, being fixed by axiomatized theories, only conditionally relate to the changing experience they refer to, and *thirdly*, regarding those realms of application that are covered by several closed theories at the same time.

Heisenberg's conception possesses *considerable plausibility* and does justice to the stability of established physical theories better than Popper's falsificationism. In systematic terms it displays similarities with the thesis of the empirical underdetermination of theories, and in historical terms with Kuhn's conception of the development of theories.

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