Foundation of Science (2007) 12:223–234
DOI 10.1007/s10699-006-9105-0

ORIGINAL PAPER

Philosophy of chemistry and the image of science

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Published online: 23 January 2007

Abstract The philosophical analysis of chemistry has advanced at such a pace during the last dozen years that the existence of philosophy of chemistry as an autonomous discipline cannot be doubted any more. The present paper will attempt to analyse the experience of philosophy of chemistry at the, so to say, meta-level. Philosophers of chemistry have especially stressed that all sciences need not be similar to physics. They have tried to argue for chemistry as its own type of science and for a pluralistic understanding of science in general. However, when stressing the specific character of chemistry, philosophers do not always analyse the question 'What is science?' theoretically. It is obvious that a 'monistic' understanding of science should not be based simply on physics as the epitome of science, regarding it as a historical accident that physics has obtained this status. The author's point is that the philosophical and methodological image of science should not be chosen arbitrarily; instead, it should be theoretically elaborated as an idealization (theoretical model) substantiated on the historical practice of science. It is argued that although physics has, in a sense, justifiably obtained the status of a paradigm of science, chemistry, which is not simply a physical science, but a discipline with a dual character, is also relevant for elaborating a theoretical model of science. The theoretical model of science is a good tool for examining various issues in philosophy of chemistry as well as in philosophy of science or science studies generally.

Previous versions of this paper were read at the 12th International Congress of Logic, Methodology and Philosophy of Science, Oviedo (Spain), 7–13 August 2003, and at the 7th Summer Symposium of the International Society for the Philosophy of Chemistry, Tartu (Estonia), 16–20 August 2003; its Sect. 3–5 are partially a revised version of the section 'φ-Science, Non-φ-Science, and Chemistry' of my earlier paper (Vihalemm, 2001). Thanks are due to Kluwer Academic Publishers (now Springer) for the kind permission to reproduce a few paragraphs from it here.

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Keywords Philosophy of chemistry · Theoretical model of science · Demarcation problems · φ-Science · The dual character of chemistry

1 Introduction

The philosophical analysis of chemistry has advanced at such a pace during the last dozen years that the existence of philosophy of chemistry as an autonomous discipline cannot be doubted any more.[1] The purpose of the present paper, however, is neither to give an overview of the main topics and problems investigated in this new branch of philosophy of science nor to treat some of them in detail. My paper will attempt to analyse the experience of philosophy of chemistry at the, so to say, meta-level. It is asked what philosophy of chemistry as an autonomous discipline really aims at and what the rationale for these aims is. How is the specificity of chemistry construed in philosophy of science, so that it is thought that chemistry should be considered separately, not within the framework of the philosophy of physical sciences?

Due to different insights as to why chemistry and philosophy are mutually interested in each other, quite different approaches have emerged in philosophy of chemistry. First of all, interpreting chemistry as a physical science has become unpopular, since this implies, in one way or another, that chemistry can be reduced to physics — an idea which has come to be seriously questioned.[2] So, one often tries to argue for chemistry as its own type of science (see, e.g. Schummer, 1997a). Also, it is found that, due to its more empirical nature, chemistry is even a more typical science than '(the philosophical image of) physics' (Schummer, 1997b, p. 91) which has been the traditional paradigm of science for philosophers (cf. van Brakel, 1999, p. 111, 141).

When stressing the specific character of chemistry, philosophers of chemistry do not always thematize the question 'What is science?'. Usually, chemistry is taken to be a science simply as a, so to say, sociological fact: contemporary chemistry is 'normally' called science. So it is assumed that, while analysing chemistry, one is somehow dealing with philosophical reflection upon science as well. Chemistry is relevant to such reflection because without this specific field of science the reflection would be incomplete: some aspects of science would be unrepresented. Philosophers of chemistry have especially stressed that all sciences need not be similar to physics. They have argued for a pluralistic understanding of science.

In this paper, I will discuss why it is important to thematize the notion of science in philosophy of chemistry as well as in philosophy of science generally.[3] It is not obvious that philosophy of chemistry should be regarded as a sub-discipline of philosophy of

[1] It seems right to say that philosophy of chemistry was born in 1994 (van Brakel, 1999, p. 112, 2000, p. 38; Scerri, 1999, p. 107). Since 1990 more than 500 papers and about 40 monographs and collections have been published on philosophy of chemistry (Schummer, 2006). A regularly updated online bibliography maintained by J. Schummer is available at: http://www.hyle.org/service/biblio.htm. However, if we do not limit ourselves to the English-speaking world of philosophy, we shall have to say that in fact philosophy of chemistry began to emerge as early as in the 1960s in the Soviet Union and Eastern Europe (see: van Brakel, 1999, pp. 122–129; 2000, pp. 22–34; Vihalemm, 2004b, pp. 6–9).

[2] It should be mentioned that actually the very meaning of the theses that chemistry can (or cannot) be reduced to physics is not clear (see, e.g. van Brakel, 2003). This issue, however, is not the topic of the present paper.

[3] Perhaps it should be noted more specifically that although in writings on philosophy of science their authors presumably eventually are seeking better elucidation of the question 'What is science?', it makes a difference whether this question is taken as a special theme of consideration or not.

science. Chemistry might also be analysed as something which is interesting in its own right, not necessarily as just a science. But if the question concerning the status of chemistry as science is not considered, one should also not expect to gain from chemistry some kind of new knowledge or corrections to the philosophy of science, e.g. the peculiarities of chemistry could not be used then as arguments for the pluralistic character of science.

On the other hand, a 'monistic' understanding of science should not be based simply on physics as the epitome of science, regarding it as a historical accident that physics has obtained this status. If this were the case, one would have good reason to believe that the image of science in philosophy and methodology of science would be different if chemistry (or biology, or any other discipline) rather than physics was taken as a paradigm. My point is that the philosophical and methodological image of science[4] should not be chosen arbitrarily; instead, it should be theoretically elaborated as an idealization (theoretical model) substantiated on the historical practice of science.

In my earlier works (Vihalemm, 1999, 2001, 2003a, 2004a, 2005), I have argued that, although physics has, in a sense, justifiably obtained the status of the general paradigm or philosophical image of science, it should be elucidate in what sense exactly. Speaking about physics in the status just mentioned we are not speaking about physics simply but actually about it as a model of science. Thus, the question whether and to what extent speaking about physics in that role is justified depends on whether and to what extent physics can be understood as the model of science. In philosophy (or theory) of science this model should be elaborated theoretically. So a theoretical model of science as idealized physics-like science can be elaborated. For elaborating of such a model chemistry is also relevant. I have proposed that this theoretical model of science be called φ-*science*. Thus, I would like to emphasize that I have not proposed, of course, to simply rename physical sciences or exact sciences φ-sciences but have introduced under the name of φ-*science* the concept of an idealized physics-like science as the theoretical model of science. This model offers a key for examining the issues concerning the status of chemistry and various other topics considered in philosophy of chemistry (and beyond).

2 What kind of question is 'What is science?'

From an unsophisticated point of view, this question may be seen as an empirical, theoretical, or normative question. So, for example, in history and sociology of science, including the contemporary Sociology of Scientific Knowledge (SSK), with its Empirical Relativist (and Social Constructivist) Programmes,[5] this question is treated as an empirical one, i.e. as a factual issue in sociology and history. Science is a socially

[4] The expression 'image of science' would seem to be adjacent to Wilfred Sellars's phrase 'the scientific image' used by van Fraassen in the title of his well-known book *The Scientific Image* (van Fraassen, 1980). In the present paper, however, unlike of van Fraassen's book, it is not the scientific image meant as the image of the world in science which is analysed (not to mention that the aim of van Fraasssen's book is, actually, to develop an empiricist alternative to scientific realism), but here the topic is the image of science meant as the general idea of what is science, what is seen to be a typical science or a paradigmatic scientific discipline. A classic work in which the expression 'the image of science' was used is *The Structure of Scientific Revolutions* (Kuhn, 1970, p. 1), criticizing ahistorical image of science.

[5] See (Collins, 1983). It is claimed that in an explicit relativism 'the natural world has a small or non-existent role in the construction of scientific knowledge' (Collins, 1981, p. 3).

and historically constructed cognitive field which embraces everything that is 'normally' called science, or has ever been called science. This cognitive field is given to the researcher, historically and socially, as a field for various case studies, and the task of the scholar is to describe these cases as they are, or have been.

In 'theory of science', the question 'What is science?' has been treated as a theoretical issue. Traditionally, it is philosophy of science which has presented theories of science. The contemporary movement towards naturalized philosophy of science, or 'philosophy of science without philosophy', can also be regarded as a movement towards a theory of science. Of course, one should then realize that it is not enough to use the term 'theory of science' in the sense of 'non-philosophical theory of science', which in turn means simply scientific study of science.[6] 'Scientific (non-philosophical) study of science' in a broader sense includes history and sociology of science as well. Theory of science—and this is my main interest in the analysis of this approach—presupposes that the scientific study of science itself (i.e. the study on the meta-level) is in its theoretical nature analogous to 'normal' (object-level) scientific theories in natural sciences.

In traditional, classical (i.e. non-naturalistic) philosophy and methodology of science the question 'What is science?' is treated mainly as a normative one: what a science ought to be, how should one rationally reconstruct it? It is presupposed that philosophy of science should be regarded as a part of epistemology and that it has connections with metaphysics as well. The question 'What is science?' can be analysed in a sense 'a priori' (i.e. on an extra-scientific basis; it is presupposed that science has such a philosophical foundation). Following Alexander Bird, this traditional philosophy of science may be called the *Old Rationalism*. It is the pre-Kuhnian, mainly logical empiricist philosophy of science whose 'main players' were Rudolph Carnap, Carl Hempel, Karl Popper and Imre Lakatos (Bird, 2000).

Closer examination has shown that none of these three approaches has ever been consistently carried through; each of them has sometimes applied the ideas and arguments of an approach which is rejected or avoided. In addition to the fact that the question 'What is science' is construed differently from different viewpoints, one also interprets differently the questions 'What is philosophy' and 'What is a (non-philosophical or empirical) theory of science'. Then it is unclear what a post-Kuhnian *theoretical* understanding of science might really mean — and whether any such understanding is possible at all. It is only clear that such an understanding cannot be a priori and, in this sense, philosophical; instead, it should be empirical and non-philosophical; or, to put it differently, it should be scientific and naturalistic.

At least since the works of T. Kuhn and I. Lakatos we are familiar with the following dilemma of 'aprioristic rationality' and 'historiographical positivism': if the principles of the rational reconstruction of history of science are given a priori by some normative methodological conception, then the actual history of science cannot have any effect on the principles of rationality. If, however, it is claimed that the very understanding of rationality should be derived from the actual history of science, then it is unclear how it will be possible to avoid 'historiographical positivism', i.e. a simple description or a, so to speak, 'theoretical' justification of everything that takes place in the actual history of science.[7] As Lakatos has also written: 'It is a special case of *normative positivism,* of the theory that sets up might as the criterion of right …

[6] See, e.g. (Giere, 1988); cf. (Vihalemm, 1995).

[7] (Kuhn, 1971, 1980), (Lakatos, 1971). See also (Vihalemm, 1982).

Reactionary Hegelian obscurantism pushes values back completely into the world of facts; thus reversing their separation by Kantian philosophical enlightenment' (Lakatos, 1971, pp. 132–133). The programme of a 'naturalized philosophy of science' has been proposed exactly by those who endorse Kuhn's approach and try to avoid aprioristic rationalism. However, for resolving the dilemma, the scientific study of science should be not only descriptive (empirical), but theoretical and normative as well. The question then arises, what kind of knowledge is offered by the relatively autonomous theoretical part of the history of science—theory of science? Can a theory of science be, for example, something like theoretical physics? This latter question is important, because physics has gained the status of a standard of theoretical science, and scientificity in general.

3 φ-Science: a theoretical model of science

As was said in introduction to the present paper, I would like to defend a theoretical view of science that uses the concept of an idealized science, I have called φ-*science*, as the theoretical model of science. It has proved possible to elaborate this model on the basis of physics. The model can be used for explaining why physics has gained the status of paradigmatic science. Naturally, we should keep in mind that, as with all models, the real object (in the present case the 'thing called science' (Chalmers, 1986, pp. 165–166), which is hardly identifiable) is not identical with its model. The model is an idealization, an abstract, non-linguistic entity, which resembles the real object in certain respects and to a certain degree. Here I make use of Ronald Giere's treatment of the relation between model-based scientific theory and reality (Giere, 1988, pp. 62–110), applying it to science itself.

The general situation around the question 'What is science?' contains more than one demarcation problem. The cognitive field which is called science (or has ever been called science) is huge and includes paradigms of thinking which are surely not genuine science, but are treated by any philosophy of science as pseudo-science. However, what remains, after we have excluded pseudo-science, is not φ-science, but science in a broader sense—including non-φ-science. For instance, philosophy is also a science in this broader sense, although a non-φ-science. Let me try to show it on a scheme (see Fig. 1).

This scheme describes demarcations between pure types. Of course, there are intermediate types as well. Chemistry, for example, belongs to an intermediate type between φ-science and non-φ-science, although it is usually regarded as an instance of φ-science.

Traditionally, in the so-called general methodology of science (which is actually general epistemology), the demarcation issue is analysed as a problem of demarcating between science in a broader sense, on the one hand, and unproblematically identifiable non-science (magic, religion), on the other hand; or as demarcating between science and pseudo-science (in its paradigmatic cases, such as astrology).[8] This methodological tradition characterizes science as the production of reliable knowledge. According to this approach scientific knowledge is not a special kind of knowledge—which it actually is, as I believe—but simply knowledge of high quality. Exact science

[8] Alchemy is sometimes incorrectly classified as pseudo-science. Instead, one should say that it is simply non-science, because it belongs to the specific cultural phenomena of the Middle Ages. One may of course interpret alchemy as pseudo-science, but such an interpretation would be anachronistic.

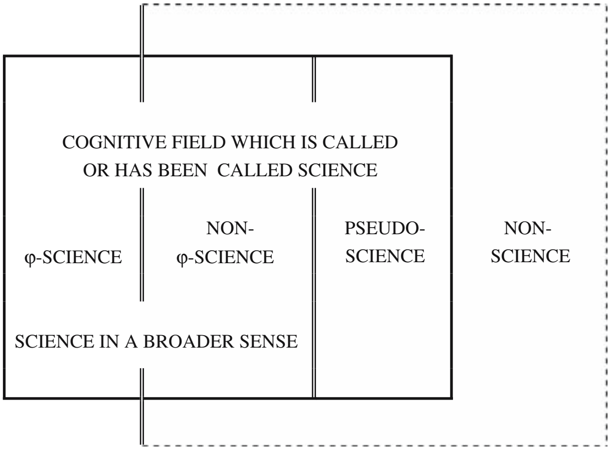

Fig. 1 Question 'What is science?' contains more than one demarcation problem

is supposed to be an ideal of the quality of knowledge. This ideal is usually presented in the form of mere rhetorical declaration. It is quite difficult to say what the scientific method consists in if science is taken in this broader sense and, therefore, the characterization of science will inevitably include social features of the so-called scientific activity.

I agree with authors who stress—like Alan Chalmers in his book 'What is this thing called Science?'—that the question stated in this title

> is a misleading and presumptuous one. It presumes that there is a single category "science", and implies that various areas of knowledge, physics, biology, history, sociology and so on, either come under that category or do not. I do not know how such a general characterization of science can be established or defended. Philosophers do not have resources that enable them to legislate on the criteria that must be satisfied in an area of knowledge if it is to be deemed acceptable or "scientific". Each area of knowledge can be analysed for what it is (Chalmers, 1986 p. 166).

In other words, science in this broader sense is not a natural kind. The issue of science as a natural kind was raised by Richard Rorty:

> One of the principal reasons for the development of a subarea within philosophy called "philosophy of science" was the belief that 'science' (or at least 'natural science') named a natural kind, an area of culture which could be demarcated by one or both of two features: a special method, or a special relation to reality (Rorty, 1991, p. 46).

He finds that science, even 'natural science', is not a natural kind. However, this conclusion, as well as the position advocated by Chalmers, holds true of science only if the latter is not regarded as a theoretical model. As with natural kinds in general, one must here also keep in mind that natural kinds are not simply 'given' to us by reality, but tell us something about nature only through theories we have constructed, whose idealized models are similar to real systems in specified respects and to specified degrees. [9]

A general methodological characterization of science in the broad sense cannot be given. Philosophers lack the resources for such a task, as emphasized by A. Chalmers in the aforementioned quotation. However, I think that philosophers and theorists of science do have the resources for identifying an area of knowledge and research which constitutes science in the narrower sense—i.e. physics-like science, or φ-science as some kind of theoretical object (an idealization). The theoretical study of science in the narrow sense can, indeed, identify its object on the basis of the relevant aims and methods, and it does not depend on the peculiarities of objects or spheres of reality; when the aims, methods and principles of inquiry are very different, the descriptive studies have to differ accordingly, and, consequently, no unified general theory can be proposed.

4 A monistic or a pluralistic view of science?

Whereas no unified general theory of science can be proposed, one might wonder why bother with theoretical study of science at all? What is the benefit of the theoretical concept of science if it does not concern the science in general, but only the idealized physics-like science as a theoretical model? Why not to reconcile to a pluralistic view of science accepting that 'Science, construed simply as the set of knowledge-claiming practices that are accorded to that title, is a mixed bag' and 'should be seen as a [Wittgensteinian] family resemblance concept' (Dupré, 1993, p. 242)?

Let us recall that in the present paper just the question 'What is science?' has been thematized and the alternative—a monistic or a pluralistic view of science—was raised as the question whether it is possible or not to elaborate the theoretical conception of science. We have seen that in the context of the relationship between chemistry and physics it was referred to the peculiarities of chemistry and to the failure of reduction of chemistry to physics and argued that all sciences need not be similar to physics let alone reducible to physics. The above-mentioned Dupré argues, drawing on biology, analogously against the possibility of a unified science and in favour of pluralism. Dupré emphasizes that his thesis is 'that the disunity of science is not merely an unfortunate consequence of our limited computational or other cognitive capacities, but rather reflects accurately the underlying ontological complexity of the world, the disorder of things' (Dupré, 1993, p. 5). However, as it was emphasized already, if we are interested in the possibility of proposing a theoretical conception of science then we should look the question from another angle, i.e. not from the angle of the ontological complexity of the world and of 'science, construed simply as the set of knowledge-claiming practices' in that complex world, but from the analysis of the scientific practices which have gained the status of the paradigms in producing perfect theoretical knowledge. One should acknowledge the fact that physics has gained that status. The question is: why? What kind of knowledge the scientific-theoretical knowledge actually is?

It is essential to realize what are the premises and limits for knowledge and research in a field that has the status of a perfect exact science, like physics. Scientific cognition is paradoxical, in the sense that in science theoretical knowledge presupposes

9 See also my paper (Vihalemm, 2003b).

empirical knowledge, but the latter, in turn, presupposes the former. This paradox will not cause great difficulties only if we deal, as in physics, with an experimental-theoretical research which, operating with experimentally substantiated idealizations, constructs itself its object of research (physical reality, physical phenomena). I would like to stress the fact that the subject matter of modern physics (i.e. physics since Galileo) is not determined by any definite objects of nature, or any fundamental level of nature itself, but only through theories we have constructed and experimentally substantiated. The structure, objects, facts, etc. of the natural world are not self-identified by the nature.[10] *In this sense*, the social constructivists are right when they say that the natural world has a small, or non-existent, role in the construction of scientific knowledge (Collins, 1981, p. 3). Nature is the subject matter of physics only on the basis of those of its characteristics, aspects and phenomena which can be expressed mathematically, which can be measured, exposed and reproduced experimentally. So, physics itself constructs its object of investigation, considering nature only through idealized and mathematically projected situations. Therefore, physics represents an experimental exact science in general, in its purest form, making it possible to study the methodological structure and functions of the exact science theoretically.

I think that the premises and limits of a science which is, actually or in principle, an exact science, were distinctly recognized by Immanuel Kant already. I mean his famous ‘Copernican revolution’. I would like to interpret these Kantian ideas in my own context.[11] For instance, I don’t agree with Kant’s apriorism presupposing fixed and immutable prior principles. All prior knowledge is historico-culturally conditioned and can be questioned and changed; on the other hand, there is no knowledge without some kind of prior assumptions. In the case of φ-science, there are very specific prior assumptions. Exact science is possible only on condition that the object of investigation is defined by the cognitive process itself, by the very principles of exact science (as is the case with physics). If, however, we have the opposite situation—our cognitive aim is to acquire knowledge about an object that is already ‘given’ to the researcher by some kind of pre- or non-scientific practises, before and independently of its investigation—then purely scientific knowledge as regards this object, or knowledge following the pattern of exact sciences, is impossible. Of course there are no objects and subjects of cognition ‘ready-made’ or ‘given’ by nature itself, since they both have a historico-cultural character as well. Nevertheless, we can differentiate between objects of φ-science and non-φ-science. The research of the ‘given’ objects cannot be φ-scientific in its nature, it cannot search for the laws of nature; rather, it has to be like natural history, classifying-descriptive-historical, where ‘laws’ occur in quotation marks only, having the character of non-justifiable ‘universal generalizations’ (these are in quotation marks, too). So, in the field of empirical knowledge (‘empirical’ in the sense of ‘non-philosophical’ and/or ‘non-formal/mathematical’) there are two main types of cognition:

(1) scientific (more precisely φ–scientific) cognition, being of a constructive–hypothetico–deductive character;
(2) non-φ-scientific (or natural historical) cognition, being of a classifying–historico–descriptive character (ranging from classical biology to the humanities).

[10] Cf. (Niiniluoto, 1999, Sects. 7.3, 3.1.).

[11] I have referred to Kant only because some ideas concerning exact science in the present paper can be found in his works already. For a special analysis of Kant’s views on a proper science and on chemistry see van Brakel (2006).

It should be emphasized that (a) both types of cognition embodied also philosophical and formal-mathematical cognition as their aspects or integral parts (these last types of cognition exist, of course, separately of empirical knowledge as well), (b) laws of nature and scientific theories are possible only in the first type of cognition, (c) in the second type of cognition theoretical part of knowledge can actually be only philosophical or methodological.

One should not broaden the notion of science in order to cover all research fields and types of knowledge or value systems. One should rather understand clearly that the scientific treatment has certain premises and limits within the framework in which it is effective, but cannot pretend to have the status of ideal cognition and knowledge in general.

The study of science, if its goal is in fact to obtain knowledge about real science, not to construct a presumably ideal rational science, is without doubt also a field of inquiry that belongs to the second type of cognition. Therefore, it seems that the study of science cannot be pursued by a purely scientific method, i.e. following the pattern of φ-sciences. And the scientific theory of science in the strict sense, i.e. as an analogue of an idealized physical theory, seems to be impossible. The question is, however, a bit tricky. φ-Science as a theoretical model, or an idealized object, for theory of science is constructed on the basis of a real science—physics. The scientific theory of science is indeed impossible if we set ourselves the aim of taking into account the peculiarities of all the fields of research that are known under the name of science. I think that to set ourselves such an aim is not a good idea; however, the theoretical model of φ-science is a good tool for examining various issues in philosophy of science and science studies in general.

5 The dual character of chemistry

Chemistry investigates particular kinds of substances (stuffs) and their transformations. Then the primary tasks of chemistry are the identification and classification of substances and of their modes of transformation. From the point of view of these tasks chemistry belongs to the classifying-historico-descriptive type of knowledge and inquiry (as I have called it), or to *natural history* (as it has been called by Toulmin (1967)). This type of inquiry is radically different from the constructive-hypothetico-deductive inquiry characteristic of φ-science.

The aim of φ-science is to examine reality from the viewpoint of laws of nature. Examining reality from such a viewpoint presupposes the construction of models as experimentally substantiated idealizations. Modern chemistry is a mixture of constructive-hypothetico-deductive inquiry (i.e. φ-science) and classifying-historico-descriptive inquiry (i.e. non-φ-science).

Chemistry as a φ-science has to construct, or to 'design', its objects of investigation through φ-scientific instrumentation. The, so to say, final aim of chemistry, however, is neither the creation of an instrument, or a machine, nor the discovery of universal laws of nature; instead, it aims at producing substances with certain properties by means of transforming them, and discovering some laws of nature concerning these substances. If a pure φ-science can really be defined by means of the laws of nature, then chemistry has to be defined through substance (or stuff), and only thereafter as a research field that studies how and to what extent substances can be treated φ-scientifically from the viewpoint of the laws of nature.[12] The latter means that it should be possible to model and construct substances φ-scientifically. It is obvious that substances and their properties cannot be constructed from scratch, although substances with certain properties can be created by transforming one stuff into another, or, more exactly, by creating the conditions for such transformations. Therefore, the φ-scientific character of chemistry depends on the extent to which this transformation of substances can be controlled, or carried out in a predetermined way. We might also say that the problem is: *what* in the substances, their properties and transformations can be grasped by, treated (modelled) from the viewpoint of the laws of nature? This *'what'* is not the substance 'as it is' but the aspect of the substance that is φ-scientifically projectable, challengeable, or calculable.

I have argued that it is incorrect to claim that chemistry *as a science* has a specific character. But I would like to add that chemistry as a research field is not an ordinary scientific discipline either. From the viewpoint of philosophy and methodology of science, *chemistry as a science* can be identified with physics-like science (called *φ-science*). This is not to say that the peculiarities of chemistry can be ignored. Chemistry is not a pure science (φ-science) as it has a non-scientific (i.e. non-φ-scientific) origin. My point is that the peculiarities of chemistry do not concern chemistry as a science (i.e. φ-science), but indicate in which way and how far the scientific approach, having certain premises and limits, can be introduced into a particular field of non-scientific origin, such as chemistry. One should also not confuse the methodological identification of chemistry with φ-science and the reduction of chemistry to physics. Physics as a special scientific discipline is merely an empirical example of φ-science, the latter being the theoretical model of science. As to chemistry, it has an intermediate character between φ-science and non-φ-science.

A typical example of the dual character of chemistry is the discovery of the Periodic Law and the Table of chemical elements by D. Mendeleev. If we interpret the Periodic Table merely as a classification of empirically known elements, and a law of nature as a 'universal generalization'—or in the context of the reduction of chemistry to physics—then one may conclude that the term *law*, which is sometimes used for describing the periodic system, is here being applied loosely. Still, it can be shown that Mendeleev discovered a proper law of nature (not a law of physics, but a φ-scientific law of nature) in chemistry. It ought to be realized that the classification of chemical elements was achieved through the construction of an idealized system of idealized elements. The fundamental idealization substantiated by experimental chemistry was the *chemical element* as the *place in the periodic system* (Vihalemm, 2003a).

I find that it is exactly this dual character of chemistry that gives an interesting opportunity to explore φ-science, because it shows clearly what the difference between physics and physics-like science (i.e. the theoretical model of science). Chemistry is not simply a physical science whose theoretical foundations presumably are given by physics. However, neither is chemistry so different from physics—from the perspective of the theoretical model of science—that one should start to protest against the 'domination' of the image of science inspired by physics and aim at a pluralistic understanding of science.

Acknowledgements The author thanks the reviewers for helpful criticisms and suggestions to the earlier version of this paper. This research was partially supported by the grant of Estonian Foundation of Science no. 5804.

[12] On the laws of nature in chemistry—on the so-called 'actionist' account—see also (Psarros, 1999).

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