Between manifold and completeness – Wilhelm Ostwald on mathematics and form

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Abstract

For the chemist and Nobel laureate Wilhelm Ostwald, mathematics became something like an overall concept for his philosophy of science. Mathematics as a basis of his pyramid of sciences and for the unity of all sciences led him to aim, typical for a chemist, for an “elementary table of concepts”. Ostwald applied mathematical thinking and here especially combinatorics in areas like his philosophy of nature, like creativity as well as like his theory of colors and forms. In addition this paper discusses the use of the term 'manifold' which was very popular also outside mathematics around 1900. František Wald used this term in the sense of a model whose dimensions had to fit the dimensions of described phenomena. Wilhelm Ostwald took over this notion in his lecture at the 1904 St. Louis Congress. Another term, especially used by Ostwald when discussing stoichiometric laws, 'Restlosigkeit' – its English translation 'completeness' is also used in mathematics – played an important role within another of Ostwald’s activities: the foundation of an "International Institute for the Organization of Intellectual Work", "Die Brücke [The Bridge]", also called "World Brain" by Ostwald. This institute tried to build a comprehensive encyclopedia on sheets of standardized formats so to improve and organize scholarly information and communication. All this may contribute to explain a hidden tradition of “in-formation” in chemistry (trans-formation) which is also visible in the fact that so many information pioneers in the 20th century were educated as chemists.

1. INTRODUCTION: OSTWALD, MATHEMATICS AND CHEMISTRY

When spending a holiday on the island of Rügen in north-east Germany, one may come across a book containing paintings with beautiful views of this island (Ostwald 1992). These paintings were made by the chemist Wilhelm Ostwald (1853-1932) who „was first attracted to chemistry through the fabrication of his own oil paints, pastels, and fireworks and later contributed fundamental insights into the ways in which ions contribute color to solutions ...“ (Root-Bernstein 2003, cf. also Root-Bernstein 2006). So art was one of the starting points of Ostwald's 'chemical' life. Ostwald, who was one of the founders and organizers of physical chemistry in the last part of the 19th century, worked from 1887 until 1906 in Leipzig as a professor, and was awarded the Nobel prize for chemistry in 1909, especially for his work on catalysis. After his retirement Ostwald was increasingly engaged in philosophy and his further multi-faceted and broad interests.[1]

The search for harmony and order in combination with his energetic imperative ("Do not waste energy, but convert it into a more useful form") was a foundation of Ostwald’s activities in the organization of scholarly communication, in the system of scholarly disciplines itself as well as in the theory of colors and forms. He proposed a "science of order" as a basis of his "pyramid of science". The need for standardization, especially expressed in his ideas about paper formats, as well as the need for a synthetic auxiliary language to facilitate international communication of science were outcomes of his philosophical concept of order.

In his later life in the 1920s, art was an important issue for Ostwald when dealing with a theory of forms to explain beauty and harmony. The search for beauty and harmony is often also viewed as part of mathematics as well as other subjects (Schummer & Spector 2003; Schummer et al. 2009). The question of form has been a long ranging activity in art, chemistry, and mathematics. The use of mathematics in chemistry has had a long tradition reaching back at least to J.B. Richter’s “Stoechiometria” (Ruthenberg 1996, Dmitriev & Romanovskaya 1994). All these subjects – like other sciences – tried to describe the manifoldness of the world as completely as possible.

This paper concentrates on the use of some mathematical concepts like manifold, combinatorics, and completeness in the thinking of Ostwald, sometimes also including crosslinks to the thinking of the Czech chemist František Wald (1861-1930) who was in contact with Ostwald for many years and who used mathematical concepts when describing his chemical ideas (Ruthenberg 2007) and even wrote a paper with the title “Chemistry and mathematics” (Wald 1909a). In addition, this introduction deals with Ostwald’s use of mathematics in general. Finally, the paper takes a view to common grounds in the development of chemistry and information science.[2]

In 1914 the Russian chemist Nikolai S. Kurnakov (1860-1941) - also citing Ostwald and Wald

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1 For more biographical details on Ostwald see (Kim 2006), (Deltete 2008), and (Ertl 2009).

2 When studying chemistry and mathematics the author of this paper was most attracted by “ab initio” methods in quantum chemistry. In his later life as a library and information professional he came across the use of mathematics in chemistry when creating and using topological tables while searching for structural formulas in the database Chemical Abstracts.

in his article - wrote that the “concept of the chemical compound has become a mathematical one” (Kurnakov 1914, 112). Kurnakov also mentioned the German mathematician Ernst Eduard Kummer (1810-1893) who compared the multiplication of complex numbers with the chemical compound. According to Kummer, “the elements, or actually the atomic weights of them, correspond to prime factors; and the chemical formulae for the decomposition of compounds [Zerlegung der Körper] are the same as the formulae for the decomposition of numbers” (Kummer 1847, 360). For him this analogy and connection between number theory and chemistry had its conceptual foundation in a common basic concept (or element), the concept of composition (Zusammensetzung, in English also: formation).[3] Later the mathematician Arthur Cayley (1821-1895) used methods of graph theory to model e.g. isomers in structural chemistry, and James J. Sylvester (1814-1897) applied algebraic theory to modeling valence theory (Dmitriev & Romanovskaya 1994).

An Ostwald biographer referred to Ostwald's foreignness as pure mathematics (Günther 1953, 497): “Pure mathematics was alien to him; an attempt to arrive at it, led him instead to positivistic philosophy.”[4] The last part of this sentence may be right, but the first is to be questioned: Surprisingly, Ostwald was engaged in mathematics and mathematical thinking all his life. In Ostwald's subject of physical chemistry, which he founded in cooperation with Jacobus Henricus Van't Hoff (1852-1911), Svante Arrhenius (1859-1927) and others and which he also called “general chemistry”, mathematics was prevalent. This can be seen e. g. in the case of the American physicist Josiah W. Gibbs (1839-1903), whose work, published in a small journal accessible only with difficulty, Ostwald translated into German, which helped it become known in a larger scientific community.

According to his autobiography, Ostwald learnt mathematics from a book from the philosophizing mathematician Karl Snell (1806-1886) from Jena (Snell 1846-1851): “This was not the usual sort of dry textbook but instead went into epistemological and methodical questions which in a study of calculus push themselves to the forefront and demand attention. These were happy hours that I spent with this brilliant book which not only provided me with the major part of my modest mathematical abilities but also stimulated me to think for the first time about philosophical questions..” (Ostwald 2017, 60)

For Ostwald philosophy had the task to find the “general” issues of the specific sciences – like his physical chemistry within the overall field of chemistry: He also viewed this as necessary because of the “flood of new scholarly work and publications [Hochflut neuer wissenschaftlicher Arbeit]” (Ostwald 1912b, 107).[5] Ziche pointed out that Ostwald's use of the term “generality” suffered from the problematic contrast of its two areas of meaning: as a mathematical and logical “general” statement on the one hand and as general applicability in all areas of life on the other hand (Ziche 2009, 62).

Mathematics as ideal science became something like an overall concept for Ostwald's

3 This gives a first connection to part 5 of this paper about the hidden tradition of in-formation in chemistry.

4 Translations of original German texts in this paper were made by the author.

5 This gives a second connection to part 5 of this paper about the hidden tradition of in-formation in chemistry.

“Philosophy of Nature” which viewed from today can be seen as a philosophy of science. Here he also looked for an empiric foundation of mathematics and was aware of the attempts to identify the most general principles in mathematics, e.g. through David Hilbert (1862-1943). But Ostwald was not very consistent when using mathematical vocabulary: In 1907 for example he cited Peano's set theory and used the term “set [Menge]” as a basis for his discussion (Ostwald 1907), in his “Grundriß” (Ostwald 1908; Ostwald 1911a) he used the concept of the „group [Gruppe]“ instead (Ziche 2009, 61) and this not in the correct mathematical sense. In the foreword of his book “The fundamental principles of chemistry” Ostwald wrote: “Mathematics, Geometry, and Mechanics began an examination of their fundamental principles years ago, and a firm foundation has now been set up for each of these sciences.” (Ostwald 1909a, V-VI) These sciences were for Ostwald a model for chemistry. The aim of his “General or physical chemistry” was “the search for general laws” (Ostwald 1907, 160). The efforts of the Czech chemist František Wald went in the same direction with a narrower emphasis on chemistry.

Mathematics as a “basis for scientific unity” (Schmidt 2009, 154) led Ostwald to aim for an “elementary table of concepts”. According to Ostwald already Gottfried Wilhelm Leibniz (1646-1716) said that the “foundational problem of logic and philosophy of science [Fundamentalproblem aller Logik und Wissenschaftslehre]” is a “table of a theory of concepts [Tabelle der Begriffskunde] (Ostwald 1911b). Ostwald’s claim for being one of the discoverers of logics (Ziche 2009) has to be mentioned here.

2. MANIFOLDS

The mathematical term ‘Mannigfaltigkeit’ was very modern and popular around 1900 (cf. Ziche 2008, 211-252) and corresponded to the 'zeitgeist' in philosophy as well as in chemistry. A translation of the German term 'Mannigfaltigkeit' into English offers many possibilities: diversification, diversity, manifold (and also manifoldness), miscellaneousness, multifariousness, multiplicity, omnifariousness, plurality, or variety. The situation in chemistry, especially in the last part of the 19th century, was very complex and chaotic and so was in line with the term “Mannigfaltigkeit”. The number of chemical substances grew enormously. Each substance had a dozen of different names. To cope with this variety and diversity there was a need for standardization and systematization (Bensaude-Vincent 2009). These efforts led, for example, to the periodical table of elements introduced by Dmitri Ivanovich Mendeleev (1834-1907).

In the writings of Ostwald, and also Wald, the term was most often used as a general one for variety, plurality, complexity or diversity. Nevertheless, connections to the mathematical term can be shown. As a mathematical term, the English translation 'manifold' is used in this paper. But even mathematicians used the term with different definitions. For the German mathematician Lothar Heffter a manifold was a synonym for “domain or world [Gebiet oder Welt]” (Heffter 1912). The philosopher Edmund Husserl also used the term manifold very generally as “a set, a linear ordering, a group, a field, etc., defined by a set of axioms” (Hartimo 2007, 294).

The term manifold came into use in mathematics during the 19th century evolution of linear algebra, matrix algebra and multidimensional geometry, especially through Johann Carl Friedrich Gauss (1777-1855), through Bernhard Riemann (1826-1866) – here cf. his paper “On the hypotheses which lie at the bases of geometry” (Riemann 1873) - with thinking about the frontiers of Euclidian geometry and the development of concepts like vectors and spaces with more than three dimensions as well as through Hermann Grassmann's (1809-1877) algebra of geometrical “extensions” (Grassmann 1844). N-fold extensive quantities were created to cope with phenomena which have n parameters. Another goal was illustration and geometrical visualization through n-dimensional spaces and vector analysis. Following Leibniz, Grassmann wanted to enhance the application of arithmetic and algebra in geometry by exceeding two-dimensional and three-dimensional spaces (Otte 1994, 362-363). The term manifold can be viewed as a bridge between algebraic and geometrical thinking.

Today in contemporary mathematics a manifold is “a geometric object which locally has the structure (topological, smooth, homological, etc.) of R^n or some other vector space. This fundamental idea in mathematics refines and generalizes, to an arbitrary dimension, the notions of a line and a surface.” (Chernavskii 1990, 78) The concept of a manifold allows the handling of complicated structures by using simpler ones which are better understood.

Wald’s attempts to describe chemical processes on the most general level led him to use the term ‘manifold’. In his paper with the title “On the manifold of chemical phenomena” (Wald 1903), which may be one of the most general and philosophical ones by Wald, he wrote: “For a given problem of experimental research, it seems to be the first task to get clarity about the manifold, that means the nature and quantity of the independent and variable pieces, which determines the phenomena being found” (Wald 1903, 110). So for Wald a manifold was something like a mathematical model or theory whose dimensions had to fit the dimensions of the described phenomenon or can perhaps better be viewed as a property of a model or theory.

Wald discussed the question how to describe a phenomenon as completely as possible and the impact of whether too few or too many parameters for the description of experimental observations are considered.[6] For Wald a theory which attributes a larger manifold to the phenomena than they really possess is in danger of having the “character of an apodictic dogma” (Wald 1903, 112), because no single phenomenon can be found which directly contradicted the theory. Clearly, here Wald had the atomic theory in mind.

Ostwald took over what he might have learnt from Wald's 1903 paper in his lecture “On the theory of science” at the 1904 St. Louis Congress. After discussing the connection between algebra and geometry, he wrote “This again characterizes an extremely important scientific procedure which consists, namely, in constructing a formal manifold for the content of experience of a certain field, to which one attributes the same manifold character which the former possesses. Every science reaches by this means a sort of formal language of corresponding completeness,[7] which depends upon how accurately the manifold character of

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6 For this see the following German sentences: “Setzt man eine zu kleine Mannigfaltigkeit der möglichen, willkürlichen Erscheinungen voraus, so treten entweder zufällig oder doch bei aufmerksameren Studium neue Erscheinungen auf, welche man nicht erwartet, vielleicht sogar für unmöglich gehalten hatte, und solche Entdeckungen haben dann oft das Gepräge des Sensationellen; ...” (Wald 1903, 111) “Wesentlich anders liegt die Sache, wenn man in Vornhinein eine zu große Mannigfaltigkeit der Erscheinungen voraussetzt. Die Grundauffassung zeigt hier allerdings die Möglichkeit von Erscheinungen an, welche nie zur Beobachtung gelangen, allein dabei bleibt immer der Hinweis auf die Zukunft offen, welche die erforderliche Combination jener Umstände kennen lehren soll, durch welche die noch fehlenden Erscheinungen zur Verwirklichung kommen werden.” (Wald 1903, 112)

7 For the term 'completeness' see also section 4 of this paper.

the object is recognized and how judiciously the formulae have been chosen" (Ostwald 1904, 31).

For Ostwald a manifold was also a very general concept, the "entirety of any ordered - or related to each other - entities or objects [Gesamtheit irgend welcher geordneter oder mit einander in Beziehung gebrachter Dinge]" (Ostwald 1905, 79) In his writings the term had to do with the formation of concepts out of experience. Later he wrote "But we can easily make manifold arbitrary combinations of concepts from different experiences, since our memory freely places them at our disposal, and from such a combination we can form a new concept[8]" (Ostwald 1911a, 18). For Ostwald logic and the science of the manifold were the same (Ostwald 1911a, 57). But in explanatory notes added to the third edition of his lectures on the philosophy of nature Ostwald acknowledged his use of the concept of manifold as "extremely incomplete and imperfect" (Ostwald 1905, 462) and pointed to the mathematical research of his time.

Wald used for the explanation of the concept manifold also spatial pictures (Wald 1903, 116) when illustrating the modifications of an old theory through a new theory.[9] Using such pictures might have led Wald to his geometrical approaches when describing chemical reactions. For the "mathematical description of chemical processes" Wald (1909b) looked for the degrees of freedom of a chemical process with n participating substances, precursors and products. Then Wald assigned to it a linear space of n dimensions. So n degrees of freedom span a (vector) space of n dimensions. The use of spatial pictures for building concepts to explain observations was also highlighted by Ostwald in a biographical sketch on Michael Faraday. When creating his theory of electricity Faraday used a new type of concept formation: Concepts are not defined by words or mathematical characters but "by spatial assumptions" which give relations to Wald's geometric approach (Ostwald 1909b, 27).

The development in chemistry can perhaps be viewed similar to mathematics: In the 19th century, mathematicians were increasingly becoming aware that objects and quantities were not its subject, but these were relations and proportions between objects which led to "structural mathematics" (Otte 1994, 363).

3. Ostwald Applying Combinatorics: Philosophy of Nature, Creativity, Theory of Colors and Forms

The notion of combination of concepts from the last section gives a first idea of Ostwald's combinatorial thinking.[10] It was influenced by his chemical experience as a catalytic chemist and led him to use this mathematical tool "combinatorics" in his work far beyond chemistry. He

[8] See the next part of this paper about the combination of concepts.

[9] "... der Schlußeffect ist in allen solchen Fällen derartig, als wenn man z.B. auf einer gegebenen Fläche durch eine andere eine bestimmte Schnittlinie abgrenzt. Die alte Theorie erscheint durch die eine Fläche abgebildet; indem sie behauptet, die Erscheinung sei durch die Fläche dargestellt, hat sie zwar Recht, doch sagt sie zu wenig. Die neue Erfahrung behauptet, daß die Erscheinung auch an die andere Fläche oder sonst ein geometrisches Gebilde gebunden sei, und ist, allein genommen, ebenfalls ungenügend; beide Behauptungen zusammengenommen können dann die ganze Wahrheit sagen. Kleidet man also die neu erkannten Beziehungen in die Form neuer Gesetze, welche neben der alten Auffassung zur Geltung zu bringen sind, so kann die Uebersicht wiedergewonnen und die alte Lehre beibehalten werden" (Wald 1903, 114).

[10] See also a text by the author which complements this section of this article (Hapke 2012).

also often used combinatorics in a metaphorical way or as an educational tool, as a form of representation and teaching of knowledge (Hapke 2009, 79-81).[11] His teachers in Riga and Dorpat, Karl Schmidt and Arthur von Oettingen, introduced Ostwald to combinatorial thinking. Early he was impressed by the fact that it was possible to predict the number of isometric substances through combinatorics even before they could be synthesized. Recently chemistry has even been described "as a combinatorial art" (Laszlo 1999, 234). The same author wrote: "It is not the role of philosophers of science to point out that such a phrase 'combinatorial chemistry' is redundant, because chemistry is combinatorial by essence." (Laszlo 2001, 270)

After describing how concepts or terms could be combined, Ostwald noted in his book "Modern philosophy of nature": "The laws of combinatorics even allow it to decompose an area of research formally and exhaustively in its branches and fields of research - by initially locating empirically the elements of the domain and then by exhaustively combining them [...] The application of combinatorics in scholarship is far from being widespread, as it should be." (Ostwald 1914b, 262-263) The thinking about ordering concepts by Ostwald in his philosophy of nature had its roots in a long philosophical tradition and can be traced back to Plato.[12] In Plato's later dialogues a method to order concepts through division was described (Gill 2009).[13]

Ostwald's method of scholarly research can be described in the following steps: Defining the problem (1), exploring the problem by going back to the basic concepts of it (2), and combining these basic concepts in a combinatorical way to explain the diversity or manifoldness (sic!) of the complex world (3). The diverse objects created through combination had to be held together by a holistic framework (4) like Ostwald's monistic world view, scientism and energetics (see Table 1 which shows the Ostwald's application of the method in different contexts). The search for elements when using his 'combinatorial method' was in contrast to Ostwald's position to the atomic concept which he rejected until 1908. Ostwald didn't bother.

Table 1: Ostwald's method of scholarly research

1	**Chemistry**	**Information organization**	**Color theory**	**Theory of forms**	**Sciences**
2	Chemical Elements	Fragmentation to unique thoughts	Pure colors, white and black	Basic forms	Defining basic sciences
3	Combined within periodical system	Combined within a classification	Combined within a double-cone	Combined in diverse ways	Combined within a pyramid
4	Physical Chemistry as General Chemistry	Central agency, World Brain	Harmony of colors	Harmony of forms	Energetic imperative, Monism

11 Ostwald never contributed to the mathematical sub-discipline „combinatorics" itself.

12 Comment of Nikos Psarros after the author's talk in Prague.

13 See also the entries „Ordnung der Begriffe" in (Ritter 1971-2007, 1310-1312) and „Dihairesis" in (Ritter 1971-2007, 242-244).

Ostwald also used combinatorics as a tool for heuristics and systematics (Luther 1933, 61), a method to get new relations and analogies, a method for creativity. This is visible for example in the presentation of combinatorics in Ostwald's „Grundriß der Naturphilosophie“ (1908), translated as “Natural Philosophy” (1911), where combinatorics was viewed as a method to generate new knowledge: „Thus combinatory schematisation serves not only to bring the existing content of science into such order that each single thing has its assigned place, but the groups which have thereby been found to be vacant, to which as yet nothing of experience corresponds, also point to the places in which science can be completed by new discoveries.” (Ostwald 1911, 73; Ostwald 1908, 82)

As early as in the work of Ramon Llull (1232-1315) and of Leibniz’ combinatorics was a part of logics. Leibniz named logics as “ars inveniendi”. For Ostwald creativity also contained "combinatorics". He wrote: “Combinatorics does not replace productive imagination only, but is superior to it!” (Ostwald, 1929b, 29). Ideas and discoveries were often only "a novel combination of existing components". „What is performed by fantasy, by creation out of the core, is limited to a novel combination of existing components, also in case of the most brilliant idea” (Ostwald, 1929b, 29). New facts in research also had to be combined with diverse existing ones to create new insights. His idea on creativity corresponds to modern alternative views of copyright and intellectual property within the "Creative Commons" licenses: "Share, reuse, and remix – legally".[14]

Ostwald's activities in education showed a sense for individuality and its development combined with systematic treatment. He believed that “the art of discovery” should become “a part of the intellectual inventory of every one” (Ostwald 1910a, 124). Ostwald was aware that teaching research skills combined with enabling effective use of libraries was important. He suggested that teaching centers should be created at technical universities to improve techniques for the presentation of engineering knowledge and that these should be integrated into engineering education (Hapke 2008, 318).

Applying combinatorics Ostwald also explained the diversity of colors. The origin of Ostwald's theory of colors may be seen in the fascination that chemical combinatorics appealed to him (Pohlmann 2003, 38; Pohlmann 2002). In the first volume of one of his many books about the theory of colors with the title “Mathetische Farbenlehre“[15] Ostwald mentioned explicitly his „Moderne Naturphilosophie“ (Ostwald 1914b) and wrote: “I may well say that without this preparative work I would not have been able to carry out the present one.” (Ostwald 1924, VII). For Ostwald his theory of colors was quasi a practical testing and application of his theoretic scientific principles. His theory of colors was a kind of proof for his assumption that creativity can be arranged (Ostwald 2017, 579).

At the beginning of his theory of color Ostwald looked for the fundamental elements, here for the fundamental colors. He differentiated between „achromatic [unbunte]“ (white, different values of grey, black) and colorful colors with eight primary colors. „All occurring colors in nature contain in addition to the primary color an achromatic fraction, namely white and black.“ (Ostwald 1930, 12). After introducing a grey scale into color and mapping the color space

14 https://creativecommons.org , visited January 20, 2010.

15 „Mathetics [Mathetik]“ was Ostwald’s name for his theory of order, the basis of his pyramid of the sciences (Ostwald 1929c).

following the American Albert Henry Munsell (1858–1918), he arranged the colors in a circle, extending it to a circle with 24 colors. According to Ostwald the diversity of colors is produced through the combination of 24 hues with different fractions of white and black. In the so-called color cone, a double-cone, color and the opposite color face each other. Together with the particular fraction of white and black they form a triangle.

His imperative order = “legality = harmony" (Ostwald 1923, 158) and his color theory marginally influenced the activities of such movements in art like the German Werkbund, the Dutch De Stijl, and the Bauhaus (cf. Gage 1993, 247-263). In 1912 Ostwald joined the Werkbund which aimed at standardizing industrial design. He published a paper on "standards" in the yearbook of the Werkbund in which he called art a "social product" which made it necessary to standardize it (Ostwald 1914c). His ideas for color composition from a scientific viewpoint were combated by most contemporary artists. Nevertheless in the first volume of the journal De Stijl a review on Ostwald’s "Color Primer [Farbenfibel]" was published. Two years later this journal of the Dutch art movement published Ostwald's paper on the "Harmony of colors” (Ostwald 1920). In the Twenties Ostwald came into contact with members of the Bauhaus, e.g. to Walter Gropius. He gave talks at the Bauhaus in Dessau in 1927. The same year he was invited to join the Bauhaus board of trustees (Ball 2004). Nevertheless most of the Bauhaus members remained offish to his ideas. Ostwald was also mentioned by the Swiss artist and Bauhaus follower Max Bill in the afterword of the German edition of Kandinsky‘s “Point and line to plane” (Kandinsky 1973, 210).

In connection with his color theory Ostwald was engaged in the "harmony of forms" using his “combinatorial method”. In the “Companion encyclopedia of the history and philosophy of the mathematical sciences” Ostwald was mentioned only once, with his theory of forms in a chapter on “Art and architecture” (Schreiber 1994, 1607). Using the rules he developed Ostwald created ornaments and new forms "according to the laws of combinatorics" which were "all beautiful, without any exception!” (Ostwald 1922a) The Swiss graphic artist and designer Karl Gerstner dedicated a whole chapter of his book “The forms of color” to Ostwald's theory of forms. The chapter was titled „The harmony of forms : an (almost forgotten) form system by Wilhelm Ostwald“. Gerstner wrote about Ostwald's theory of forms: „It was produced late, 1922, as a complement to the theory of colors, but unlike the latter it has survived the intervening period intact. [...] Like Kandinsky a few years later, Ostwald starts from the Euclidean elements of points, line, and plane. But unlike Kandinsky he does not develop his theory on the basis of metaphysical speculations but in a rational and systematic manner. Starting from the elements, he proceeds via operations of steadily increasing complexity to results that are value-free and of universal validity.” (Gerstner 1986b, 76) After these sentences in the German edition of the book, the words “Programming before the computer [Programmierung vor dem Computer] appeared” (Gerstner 1986a, 76). To create new forms Ostwald looked first for basic elements of form, the triangle, the square and the hexagon, and then filled out the plane leaving no space when juxtaposed with three basic operations of symmetry, as there were translation, rotation, and reflection (Ostwald 1922b) (Fig. 1).

Fig. 1: The world of forms (Ostwald 1922b)

4. The Concept of 'Completeness' ("Restlosigkeit") in Chemistry and Knowledge Organization

The term 'Restlosigkeit' (completeness, cf. Krajewski 2006), which Ostwald especially used when discussing stoichiometric laws, had to do with the laws of invariants [Erhaltungsgesetze].[16] Nothing gets lost! This term also had to do with having a "big picture", something like a holistic framework. The term played an important role within another of Ostwald's activities, the organization of scholarly information and communication. The English term „restless" has another meaning than the German term „restlos". It means "uneasy" or "wakeful" and was for example also used by Wald for the state of equilibrium (Wald 1931).

When discussing the law of equivalent proportions in a biographical article on J.B. Richter Ostwald mentioned the term "Restlosigkeit". For Ostwald the proof of this law "was based on the experience of the completeness of ordinary chemical processes." (Ostwald 1929a, 376)[17] Already in 1909, Ostwald had stated: "This fact of experience [through which the atomic theory became useful to derive the stoichiometric laws] holds that during all of its conversions every

[16] In the works on „Theory of science [Wissenschaftslehre]" of the German psychologist Kurt Lewin (1890-1947) one can also find the term „Restlosigkeit" in connection with principles of invariance and with the concept of "genidentity [Genidentität]", an identity through development. In this sense two objects were viewed as identical when one object has been developed from the other (Lewin 1983, 60 and 81).

[17] And further: "Wenn ein Stoff A mit einem chemisch zusammengesetzten Stoff BC in Verbindung tritt, so finden sich die Elemente B und C in der enstandenen Verbindung ABC in genau demselben Gewichtsverhältnis vor, in welchem sie die binäre Verbindung BC gebildet hatten, denn es ist nach der Reaktion kein Rest, weder von B, noch von C nachzuweisen.Verbindungen verhalten sich also in dieser Beziehung ebenso, als wären sie unzerlegbare Elemente. Das ist auch der Grund, weshalb man unzerlegte Verbindungen solange als Elemente ansehen darf, bis ihre Zusammengesetztheit nachgewiesen wird."

pure substance passes into its new forms (states of aggregation) completely and without any different remainder" (Ostwald 1909c, 507).[18]

Also the French philosopher of science Gaston Bachelard (1884-1962) noted that the concept of completeness - in the German translation of his book "The philosophy of no" one can find the term "Vollständigkeit (complétude)" (Bachelard 1980, 73), in the English translation "the need to fill out the picture" - "appeared in the doctrine of chemical substances" (Bachelard 1968, 49). And further on: "Realism, by its very nature, sets objects before knowledge and thus relies upon what opportunity offers, upon the given fact which is always unsolicited, always potential, never completed. But a doctrine which, to the contrary, relies upon an internal systematization then provokes the opportunity, constructs what is not given, fills in and boldly completes the disjunctions of experience. Henceforward what is not known is formulated. This is the inspiration which dominates the work of organic chemistry; it too knew the chain before it knew all the links, it knew the series before the substances, the order before the objects. The substances were then dethroned, as it were, by the vigor of the method. They were concretions of circumstances selected in the application of a general law. A powerful a priori force guides the experiment. The real is now nothing but a realization." (Bachelard 1968, 49-50)[19]

Different notions can be observed in German language between the terms "Restlosigkeit" and "Vollständigkeit [completeness]" (Krajewski 2006, 295-296). "Vollständigkeit" includes something like a heuristic method where redundant conclusions were not important. In this case the term is connected to the concept of completeness in mathematics, especially to Hilbert's axiom of completeness as a property of his geometric theory or of a logical system. His axiom stated that all propositions, statements or formulas which can be formulated and which are valid in the system or theory are theorems of the theory. "Restlosigkeit" embraces a view on richness, plentifulness (or manifoldness) and an attention to every last detail (Krajewski 2006, 296). In the first decade of the last century the relevance of the notion 'completeness' was already being discussed concerning the difference between the sciences and the humanities. Completeness was criticized as a goal to reach when doing scholarly research (Meyer 1907; cf. Krajewski 2006, 297-299).

The term 'Restlosigkeit' also played an important role within another of Ostwald's activities. In 1911 Ostwald founded with others "Die Brücke [The Bridge]", an "International Institute for the Organization of Intellectual Work", also called "World Brain" by Ostwald. This institution tried to build a comprehensive, illustrated encyclopedia on sheets of standardized formats and to improve and organize scholarly information and communication. Such a utopian handbook of the future was intended to be "completely up-to-date at all times" (Ostwald 1919, 93).

18 Also Wald used the term implicitly when discussing the law of constant proportions: "Finden eines endlichen gemeinsamen Maßes. Bleibt beim Teilen durch kleineres Maß kein Rest, ist dieses das Maß" (Wald 1897, 257).

19 The relation between the thinking of Ostwald and Bachelard seems to be very interesting and further research is necessary. More on Bachelard and the philosophy of chemistry can be found in (Nordmann 2006) and (Bensaude-Vincent 2005).

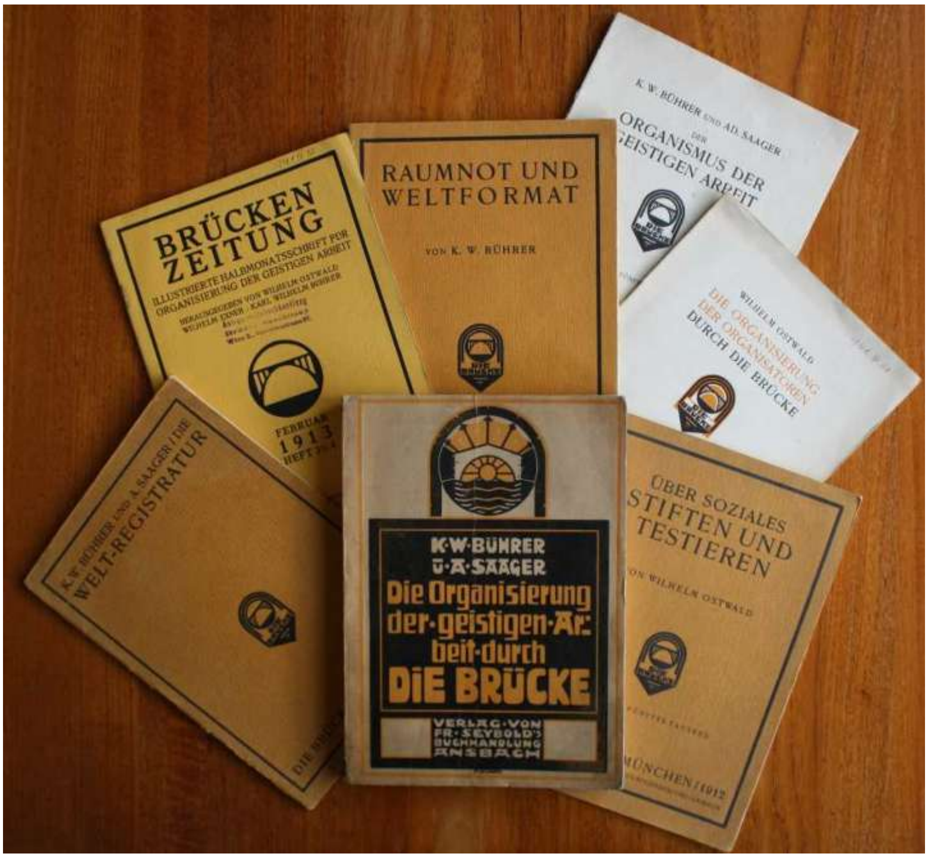

Fig. 2: Leaflets of the "Bridge"

In the propagandistic main work of the Bridge (Fig. 2), which was not written by Ostwald but by the two co-founders of the Bridge, "the completeness of scholarly thinking has no limitation and is related to everything, including the work of the scholar, regardless [...] of the kind of work, as long as it is carried out exactly: So completeness concerns the work itself, the matter of work, the space in which the matter it is located, and the time in which it exists" (Bührer & Saager 1911, 17-18). Here Restlosigkeit is used as "thoroughness [Gründlichkeit] and "accuracy [Exaktheit] as the opposite to "superficiality [Oberflächlichkeit]".

The principles of the Bridge (Satoh 1987, Hapke 1999) seemed to correspond to the thinking of a chemist, which might be one reason for Ostwald to support this enterprise enthusiastically after first reading the main work of the Bridge. So the first principle, the monographic principle, looked for elements of thinking.[20] In a book about chemical literature Ostwald (1919) summarized many of his efforts to organize scholarly communication and predicted new publication formats. He developed ideas to disassemble the contents of printed journals and disseminate single papers separately (monographic principle). He proposed to split the periodical into separate papers because no scientist wants to read the whole periodical. As early

[20] A further philosopher dealing with elements of being in chemistry and looking for the application of chemical methods of thinking in philosophy and other domains was the Neo-Kantian Friedrich Kuntze who mentioned in connection with chemical elements also the decimal classification as well as Bührer and Saager (Kuntze 1927, 65). He also wrote a book about the "technique of intellectual work" where he also mentioned Ostwald's activities for organization of scholarly work (Kuntze 1921, 2).

as 1889 he was applying his "principle of the independent use of the individual piece", or "Monographieprinzip", in the publication of his "Classics of the exact sciences [Klassiker der exakten Wissenschaften]" where he republished original scientific works for easy access as separate volumes. For the Bridge founders, from the property of mobility, which is characteristic for ideas, the monographic principles followed directly. Comparable to the invention of printing through Gutenberg which made letters move - which could be combined in any order - the monographic principle would allow the same for the fragments of knowledge (Bührer & Saager 1911, 122).

When predicting the transformation of the book into the card index, Ostwald used his combinatorial thinking again: „In case you pay attention [when transforming the book into the card index] that every sheet contains only one topic, you are at once aware that you can reach an infinite combinability of the elements obtained with this way, and that you can express if necessary - depending on what purpose you want to follow - any optional relation of the described facts through the spatial order of these sheets" (Ostwald 1919, 96). This "one-sheet-one-topic" principle also originated from one of the co-founders of the Bridge, the Swiss Karl Bührer (Hapke 2008, 311), and can also be found as a research principle e.g. in the work of sociologists, contemporaries of Ostwald, like Beatrice and Sidney Webb, who "established the rule that each sheet of paper must contain notes pertaining to only one single event occurring at a definite time and place" (Lepenies 1992, 127-128).[21]

The necessity to arrange the separates, monographs or index cards led back to the problem of ordering. Thus the "technical" fragmentation of knowledge - Ostwald observed and wanted to promote - enhanced combinatorial thinking and had to be kept together through a uniform standardized system of knowledge organization in form of a classification. The Bridge used the decimal classification which Ostwald mentioned in his book „The pyramid of sciences" (Ostwald 1929c, 76-82) as well as in his „Moderne Naturphilosophie" (Ostwald 1914b, 293-297). The decimal classification was developed in 1876 by the American librarian Melvil Dewey as a shelf classification and is still used today. It divides the domains of knowledge into 10 sub-divisions named by the digits 0 to 9, repeating this process again and again (Fig. 3).

21 See also (Webb 1926).

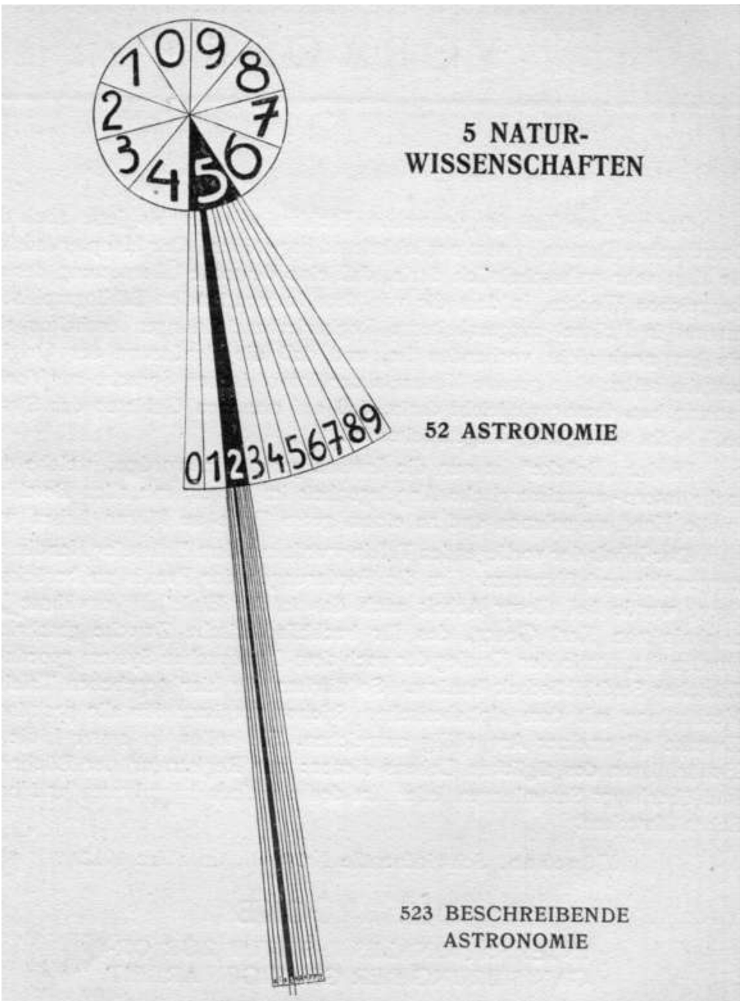

Fig. 3: Illustration of the decimal classification in a Bridge leaflet, see also Fig. 2 (Bührer & Saager 1912, 4)

The second principle of the Bridge was organization, which was defined as using the principle of dividing and combining,[22] in analogical chemical the terminology “analyzing and synthesizing” was used. The third principle was the already mentioned principle of completeness. The fourth principle was the concept of standardization. For Ostwald the standardization of paper sheets was a practical application of his energetic imperative. For the Bridge this was necessary for putting into practice the monographic principle.

Ostwald also developed the idea of an International Institute of Chemistry (Ostwald 1914a), something like a 'small' Bridge. Here Ostwald applied the principles of the Bridge to his special subject chemistry. The Institute was planned with a "Chemical World Library", where the principle of completeness should rule: all documents in the field of chemistry, a complete index of all chemical materials and concepts, a registry of all chemists, as well as a collection of specimen of all chemical materials should be collected and included in the Institute. Ostwald made his proposal to the Belgian industrialist Ernest Solvay who named his own institute

[22] See also the footnotes 11 and 12.

“Institut international de chimie Solvay” (Van Tiggelin 1999). The memorial on the International Institute by Ostwald, which had appeared in German language before 1914 (Ostwald 1912a), was published in French as late as in 1932 (Hapke 2005, 132).

In the twenties Ostwald gave a very critical view on the efforts for “Restlosigkeit” by the Brücke and its co-founder Bührer in his autobiography (Ostwald 2017, 539)[23]. The principle of completeness was pushed too hard in the hands of Bührer in collecting everything, for example all postcards of the town Ansbach or advertising picture cards or other ephemera like advertising stamps. It became the reason for the failure of the Bridge in 1914.

Years later the Hungarian composer Jospeh Szigeti mentioned Ostwald's principle of completeness with a very thoughtful note: “His organization had some such name as ‘Die Brücke’ (The Bridge) and it was the epitome of German thoroughness if anything ever was. […] This German worship of methodicalness, of thoroughness, of 'completeness' (I think Ostwald uses the word Restlosigkeit in describing one of his efforts in methodology) came to my mind lately in a macabre association of ideas. I had been reading about the death factory of Maidanek […] The word 'Restlosigkeit means 'total' … total war, total extermination, total domination […] This sense of total orderliness in the conservation of things [...] has its counterpart in a similarly total orderliness in the destruction of human beings [...]” (Szigeti 1967, 25-27).

This section demonstrated how many of the organizational principles of the Bridge were based in chemical thinking (cf. Table 2). Chemistry, as well as knowledge and information organization, aim at describing and coping with the manifoldness and diversity of the world completely, or at least as complete as possible!

Table 2: Principles of knowledge organization and chemistry

Bridge principles	**Chemical principles**
Monographic principle: Elements of scholarly work	Chemical elements
Organizing: dividing and combining	Analyzing and synthesizing
„Restlosigkeit“ (Completeness)	Laws of conservation
Standardization	Standardization
Decimal classification	Periodical system

5. Conclusion: The Hidden Tradition of 'In-formation' in Chemistry (Trans-formation)

In line with the last part of this paper, the American-British philosopher of science Steve Fuller also saw a strong connection between information science and chemistry which implicitly drew on combinatorics. He characterized chemistry as a “closed science” around 1900, “a field whose ontological boundaries are sufficiently secure that chemists need not worry that fundamental theoretical disputes in physics might affect the legitimacy of new chemical discoveries, or vice versa.” (Fuller 2008, 64) or “whose growth was limited to pursuing implications and applications of known fundamental principles” (Fuller 2007, 71). He

[23] This English edition of Ostwald’s autobiography translates „Restlosigkeit“ with „totality“.

connected this “epistemic decline” of chemistry with a link to the history of library and information science, adding here an idea of combinatorics by using a model of “chemical combination”, which is “'combinatorial' in the sense of presupposing a reality in which complexes are constructed out of simples” (Fuller 2008, 63). “On the one hand, it [the decline of chemistry as well as a vision of library and information science] suggests that fields of inquiry can be understood quite deeply through the metaphor of bounded spaces, thus gesturing to a point when all that is knowable will be known. All the shelf space will come to be filled, so to speak. This is the scientific realist's utopia. On the other hand, chemistry in its 'closed' state remained unattractive to the vast majority of researchers (...). They harkened to the pre-twentieth-century vision of chemistry of open frontiers, where genuine novelty might emerge from combination of familiar elements.”(Fuller 2008, 64) Here we have again combinatorics, combinatorics as a way out of the “closed shop”!

All this may contribute to explain a hidden tradition of “in-formation” in chemistry (trans-formation) which is also visible in the fact that so many information pioneers in the 20th century such as Ostwald, Erich Pietsch (1902-1979), head of the Gmelin Institute for Inorganic Chemistry and a leading figure of documentation in Germany (Hapke 2004) or Eugene Garfield, the developer of the Science Citation Index and promoter of bibliometrics,[24] were educated as chemists. As well as many philosophers of science were educated as chemists, in addition Ostwald and Pietsch had historical and philosophical interests. A further connection between chemistry and information can be observed in the thinking of a contemporary, more successful competitor of Ostwald's bibliographical efforts, the founder of the Institut Internationale de Bibliographie in Brussels, Paul Otlet (1868-1944), who incorporated “within the trope of the book generalizations of scientific laws and facts” (Day 2001, 13).[25] Otlet wrote: “The law of conservation of energy: never lost, never created, all is transformation. In the book also: books conserve mental energy, what is contained in books passes to other books when they themselves have been destroyed; and all bibliological creation, no matter how original and how powerful, implies redistribution, combination and new amalgamations from what is previously given” (cited by Day 2001, 15). The similarity between the bibliographic efforts of the first information pioneers like Ostwald and Otlet and the subject chemistry may also be due to their positivistic attitudes, which saw science as a model for all other subjects. A further connection between chemistry and information science might be seen in the use of the term “library”, especially in “combinatorial chemistry”: “Central to modern combinatorial practice is the generation at some intermediate stage of a large set of molecules” (Hoffmann 2001, 3337) which is called a “library”. For the Nobel laureate Roald Hoffmann the terms “portfolio” or the German “Sortiment” would be better alternatives.

What have chemistry and information science in common beneath a sense of completeness? One important aspect may also have been the need for standardization and structuring in chemistry and in the handling of information (documents) as well as the need for concepts[26] and naming. Common activities like “identifying, naming, and classifying” (Bensaude-Vincent 2009, 171) were main activities of chemists to cope with millions of new molecules they produced each year. This strong connection of chemistry to language (cf. Bensaude-Vincent

24 See (Cronin & Atkins 2000).

25 For more see (Day 2001, 13-20). For more on Otlet see (Levie 2006).

26 The importance of a „concept theory“ for information science has been emphasized by (Hjoerland 2009).

2003 and Laszlo 1993), which chemistry also has in common with mathematics (Mehrtens 1990), might also have led to activities of Ostwald when striving for a synthetic auxiliary language to facilitate international communication of science. Ostwald's paper in the anthology with the title “International language and science; considerations on the introduction of an international language into science” (Ostwald 1910b) started by mentioning mathematics as a language whose formulae can understood internationally.

The imagery of the metaphor “chemistry” was used recently when describing the information revolution of the Internet and of the social media. The fragmentation of knowledge today is enhanced through new media formats; remixing single fragments becomes easier and a feature writer wrote: “We are located in the middle of the largest and most complex chemical reaction of cultural history. [...] Folks, forge new molecules! Let the digital Bunsen burner glow”(Glaser 2009). Wald’s efforts to establish phases as a fundamental concept in chemistry mirrored modern thoughts to describe media or information revolutions. The “phase change” which accompanied the technological innovations in media culture (book printing, photography, index cards, computer media, networks) “gave the ability to see things that had never been seen before” (Robertson 2003). Wald might have been able to have the same experience.

Thinking about the basic concepts of chemistry and science led Wald as well as Ostwald to use mathematical concepts. It is of interest that this formalism and formalization in chemistry can also be observed within parallel developments of formalization in art (cf. Ostwald’s activities within Werkbund). In addition to these connections between chemistry and information science, today more and more connections between "in-formation" on the one hand and education (“Bildung”, formation) and advertising (Hapke 2008) as well as art and design on the other hand are visible in domains like information literacy, information design and knowledge media design.

The German sociologist of science Helga Nowotny wrote on innovation relating combinatorics and diversity, respectively manifoldness (compare section 2 of this paper): “Innovation creates ... the impression that it is the new, state-of-the-art navigation map that offers orientation on the uncertain journey into a fragile future. ... It strives to increase the diversity of new forms because that is the only way the new can arise outside an already determined space of possibilities, the only way that, without wanting to predetermine the new, it can extend its effect beyond the process of arising by leading further innovations. The new combination of already known or existing components, which Joseph Schumpeter said determines the process of innovation, points in the direction of a diversity with the potential to become ever greater. For the more innovations there are, the greater is the number of components from which new combinations can be produced in a rapidly growing process of combinatorics, without the contents being foreseeable and without categories for their description already existing. But the contexts of application must also multiply to offer the diversity of new forms the space of possibilities in which innovations not only arise but can also stabilize, solidify, and materialize.” (Nowotny 2008, 9-10) This paper concludes with a sentence taken from an article which characterized Ostwald in the combinatorial sense of this text as “[...] as a phenomenal combination, not only of the scientist and the philosopher, also of artist, linguist, and writer, who squandering no energy, but conserving it, applied his major interests to one another.” (Wall 1948, 118)

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