arXiv:1308.4015v7 [physics.hist-ph] 12 Oct 2014

Jacob's Ladder and Scientific Ontologies

Julio Michael Stern*

Final and corrected version† published at:
Cybernetics & Human Knowing, 2014, v.21, 3, p.9-43.

Abstract

The main goal of this article is to use the epistemological framework of a specific version of Cognitive Constructivism to address Piaget's central problem of knowledge construction, namely, the re-equilibration of cognitive structures. The distinctive objective character of this constructivist framework is supported by formal inference methods of Bayesian statistics, and is based on Heinz von Foerster's fundamental metaphor of *objects as tokens for eigen-solutions.* This epistemological perspective is illustrated using some episodes in the history of chemistry concerning the definition or identification of chemical elements. Some of von Foerster's epistemological imperatives provide general guidelines of development and argumentation.

Keywords: Bayesian statistics; Chemical element; Cognitive constructivism; Development of cognitive structures; Eigen-solution; Objectivity; Ontology alignment; Symbol grounding.

*e-mail: *jstern_at_ime.usp.br* ulr: *http://www.ime.usp.br/∼jstern*
IME-USP – Institute of Mathematics and Statistics of the University of São Paulo, Brazil.
Slide presentation at *http://www.ime.usp.br/∼jstern/miscellanea/jmsslide/moebs.pdf*

†Submitted on January 17, 2013; rev.1 June 02, 2013; rev.2 June 24, 2013; rev.3 September 12, 2014.
Former Appendix B published as Stern,J.M.; Nakano,F. (2014). Optimization Models for Reaction Networks: Information Divergence, Quadratic Programming and Kirchhoff's Laws. *Axioms*, 3, 109-118.

An adequate model of knowledge construction must comply with two conditions that are difficult to conciliate: To be open to indefinite new possibilities while conserving already constructed cycles of mutual implications destined to be converted into sub-systems of an expanded system: The issue is therefore to conciliate openness and closure.
Jean Piaget (1976, p.91), commenting von Foerster contribution.

When a sage points to the moon, only a fool looks at the finger.
Zen Buddhist proverb.

1 Introduction

Cognitive Constructivism is based in the general theory of autopoietic (autonomous, self-producing) systems developed by the philosophers Humberto Maturana, Francisco Varela, Heinz von Foerster, Niklas Luhmann, and several others, see Foerster (2003), Maturana and Varela (1980), and Varela (1978). Nevertheless, the specific version of cognitive constructivism I use as the epistemological framework at the core of this article has a very distinctive objective character that, I believe, makes it more suitable for scientific applications. The objective character of this epistemological framework is supported by formal inference methods of Bayesian statistics, and is based on Heinz von Foerster's fundamental metaphor of *objects as tokens for eigen-solutions*[2].

The main goal of this article is to address, according to the cognitive constructivism perspective, some issues related to Piaget's central problem of knowledge construction, as stated at the opening quotations. I will also illustrate this perspective using some episodes in the history of chemistry; Figure 8, at the end of this paper, gives approximate timelines

[2] The concept of eigen-solution is the key for an autopoietic system to distinguish specific objects in a cognitive domain. This critical point is further clarified in the following quotations of Heinz von Foerster:

"Objects are tokens for eigen-behaviors. Tokens stand for something else. In exchange for money (a token itself for gold held by one's government, but unfortunately no longer redeemable), tokens are used to gain admittance to the subway or to play pinball machines. In the cognitive realm, objects are the token names we give to our eigen-behavior. This is the constructivist's insight into what takes place when we talk about our experience with objects." Segal (2001, p.127).

"The meaning of recursion is to run through one's own path again. One of its results is that under certain conditions there exist indeed solutions which, when reentered into the formalism, produce again the same solution. These are called eigen-values, eigen-functions, eigen-behaviors, etc., depending on which domain this formation is applied — in the domain of numbers, in functions, in behaviors, etc. The expression 'eigen-something' comes from the German word 'self'. It was coined by David Hilbert in the late 19th century for solutions of problems with a structure very similar to the ones we are talking about." Segal (2001, p.145).

In fact, the expression coined by Hilbert was not eigen-something but rather, eigen-solution (*Eigenlösung*). Since its inception, Hilbert's expression has been widely used in mathematics and physics. Since the early days of quantum mechanics, the concept of eigen-solution has acquired paramount importance in philosophy of science, where it has been associated to a variety of epistemological metaphors. This explains my formulation of the metaphor *objects are tokens for eigen-solutions* as a generalization directly derived from von Foerster's original formulation *objects are tokens for eigen-behaviors*.

for the work of some involved scientists. All these episodes concern the discovery, characterization or identification of chemical elements, as they were defined after Lavoisier's chemical revolution. I am afraid that, in doing these exercises, I play the role of the fool alluded in the Zen Buddhist aphorism at the opening quotations. Yet, analyzing how objects of scientific knowledge come to be and how it is possible to objectively point at them, that is, understanding scientific understanding, is an unavoidable role that must be played by those interested in history and philosophy of science.

The way I present these episodes is certainly not the only way to tell the story. However, the versions I present are, I hope, well grounded in the literature of history of science and its original sources. In order to establish this point, I made a conscious effort to provide a good assortment of short, clear and pertinent quotations from historical documents and influential commentators. Some of these quotations are even self-referential, giving a clear view of how key authors see or evaluate their own work. For example, I use an "anonymous" review by Lavoisier of his own work, and also some opinions of Kirchhoff and Balmer concerning the foundations and evolution of spectral analysis, including their own work on the field. These historical examples have been chosen for didactic reasons: They are, I hope, clear and simple, using concepts that are already familiar or easily grasped by a wide audience. All examples pertinent to our discussion must involve mathematization, which is necessary for the formulation of invariant quantities of interest. However, the examples at hand only use pedestrian mathematics.

It is important to realize that virtually all key foci of natural sciences involve eigen-behaviors, fixed points, invariant quantities, or similar eigen-forms, represented as the most fundamental objects of the pertinent ontology. For example, in Stern (2011b) I present a formal comparative analysis of the role played by Noether-type theorems in Physics and deFinetti-type theorems in Probability and Statistics. Furthermore, the concept of eigen-solution is amply used in social sciences, ethology, psychology, and many other areas. For example, in economics, prices are often regarded as eigen-values or fixed-points expressing supply and demand equilibria, see Border (1989), Shashkin (1991) and Zangwill and Garcia (1981). For an historical perspective of the *invisible hand* responsible for building and maintaining these eigen-solutions, see Ingrao and Israel (1990) and Cerezetti (2013).

Figures 1ab: Strongly objective economic tokens; 1cde: Weakly objective economic tokens.

Figures 1ab display economic tokens that are strengthen by a chaining process in which they inherit stability and invariance properties of secondary backup tokens. The US 8-dollar note was issued under the Mint Act of 1792, establishing a dual (alternative) conversion policy at fixed ratios of 24.75 grains of gold per dollar, and 15 grains of silver per grain of gold. The US 100-dollar note was issued under the Gold Standard Act of 1900, and was still a convertible (to gold only) currency. After 1971, the US dollar became a free-floating *fiat money*. Figures 1cde display some emergency-money cards *(Notgeld)*, weakly objective tokens used at the hyper-inflation period in Germany. The 75-pfennig card displays a picture about the inflation process that destabilizes and devaluates economic tokens, plunging the economic system into chaos. The 5-mark card brings the legend "The most frightful of frights is man in his delusion", from *The Song of the Bell* by Friedrich Schiller, a reminder of the terrible consequences that may result from the collapse of equilibria and stability conditions that sustain the social fabric of any human civilization.

Jean Piaget makes his statement at the opening quotations commenting von Foerster contribution in Inhelder (1976, p.91). I will reverse this position using some aphorisms formulated by Heinz von Foerster in search for answers to Piaget's problem.

The following ordered list of five imperatives suggests a logical concatenation of sequential steps in the ontogenesis of an autopoietic system: From the incapacity to effectively handle some relevant but not yet understandable or even clearly perceived aspect of the systems environment; To the struggle to transcend this blindness or limitation; To the construction of an expanded reality incorporating new objects and semantic links; Culminating with re-equilibrations of cognitive structures necessary to maintain functional coherence and systemic integrity. Of course, several cycles of this five-step dance can or should be repeated during the system's life or development.

1. Metaphysical (implicit, negative) imperative:
   Something that cannot be explained cannot be seen.
   (derived from von Foerster, 2003, p. 284)

2. Therapeutic Imperative: *If you want to be yourself, change!*
   (as stated in von Foerster, 2003, p. 303)

3. Aesthetical imperative: *If you desire to see, learn how to act!*
   (as stated in von Foerster, 2003, p. 227)

4. Ethical imperative: *Act so as to increase the number of choices!*
   (as stated in von Foerster, 2003, p. 227)

5. Organic imperative: *Maintain structural and functional integrity!*
   (derived from von Foerster, 2003, p. 175)

Von Foerster's aphorisms condense essential characteristics of the life of autonomous organisms or the evolution of abstract autopoietic systems. Some of those he designated as *imperatives*, also giving them distinctive titles. I took the liberty of using the term *imperative* to designate all five of von Foerster's aphorisms above, also choosing a distinctive title for those that originally did not receive this honor. In this way, I have chosen the expressions

metaphysical (negative) imperative and *organic imperative* as labels for von Foerster's aphorisms of, respectively, "something that cannot be explained cannot be seen" and "maintain structural and functional integrity".

The (positive) imperatives appearing in this article should not be interpreted as impositive commands. Rather, depending on context or disposition, they can be interpreted as general guidelines for conduct, directions for systemic development, or just as pointers to the natural flow of life. In the same way as the consecrated expression *forbidden state* is used in contemporary physics, a negative imperative should not be interpreted as an arbitrary prohibition, but rather as an indication of existential constraints, excluded states, or impossible pathways[3].

Jacob's Ladder, a classical visual metaphor for evolutionary processes, is depicted in Figures 2a and 2b as a spiral ladder or helical stairway. These two beautiful images will be used in figurative analogies that, I hope, may help to convey the meaning of some ideas or arguments presented in the text in more abstract format or dryer style.

Section 2 presents the key concept of eigen-solution and its aesthetical characterization, that is, it explains how we perceive objects in the practice of science. This section illustrates these concepts studying the importance of the scientific equipment developed by Lavoisier and their use in analytical procedures of the new chemistry. I shall also try to understand why these new procedures are perceived as so powerful, why the objects of the "new" chemistry are perceived as so real, and why some commentators perceive Lavoisier's revolution as a point of transition, from pre-scientific alchemy to scientific chemistry.

Many traditions consider ethics as conformity to an externally produced (allopoietic) normative regulation, legal code, and so forth. However, there is also a long standing autopoietic tradition in which ethics relates to the effort, endeavor or struggle of an individual, living organism or abstract autopoietic system[4], to develop and coherently maintain a basic

[3] In this way, the Metaphysical (implicit, negative) imperative, namely, Something that cannot be explained cannot be seen!, does not indicate a desire or conscious preference not to see something, but rather the incapacity so to do. Von Foerster (2003, p. 212) illustrates this state of mind with his famous Blind Spot optical effect. Similar blinding effects, known as ambigrams, have been studied by Joseph Jastrow (1899) and Ludwig Wittgenstein (1953). In all these examples, the blinding effect is neither grounded on conscious preferences, nor is it rooted on fundamental physiological limitations, being instead an obstacle that is a consequence of the observers current point of view or prior mindset, see Kihlstrom (2006) and Stern (2008b) for further commentaries. Overcoming such a blind spot always requires the opportunity to have a transcending point of view, acquiring an innovative insight, or even deeper modifications in the observers cognitive structure.

[4] The definition of autopoietic system used in this article can be found in Maturana and Valela (1980, Page 78): "An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network."

This definition aims to capture the essential characteristics of a living system and, I believe, was extremely successful in achieving its goal. At the same time, this definition is highly abstract: It focus on the organizational structure of systems perceived as living organisms circumventing, however, the production networks' details of implementation; for example, it does not mention organic chemistry. Hence, the definition of autopoiesis opens the possibility of considering artificial life, social systems, scientific disciplines, and other abstract systems, as sharing some (but not all) of the characteristics of the living organisms of conventional biology, see for example Luhmann (1989) and Krohn et al. (1990).

set of behavioral patterns or core operations, to assemble and stay consistent with kernel procedures, to learn and remember some central concepts or cognitive traits that characterize its (actual, potential or ideal) *modus vivendi*, that is, its form of being or way of existence. Arguably, the most influential work in such an ethics of autonomy in mainstream philosophy is that of Baruch Spinoza (1677, see Ch.III, Prop.6-11); DeBrander (2007) links this tradition to the Stoics.

The ethical imperative states that a given autopoietic system should always try to increase the number of available choices, diversify the possible ways and means it has to survive. However, the necessary innovation processes should not be shortsighted or improvident: Time honored idioms teach us not to be penny-wise and pound-foolish, not to throw the baby out with the bathwater. In order to increase its musical repertoire one has to learn new songs, retaining however the melodies one already knows how to sing. A viable path of evolution avoids unnecessary breaks in continuity recycling already developed solutions, keeping them alive even if as adjusted versions or in revised form.

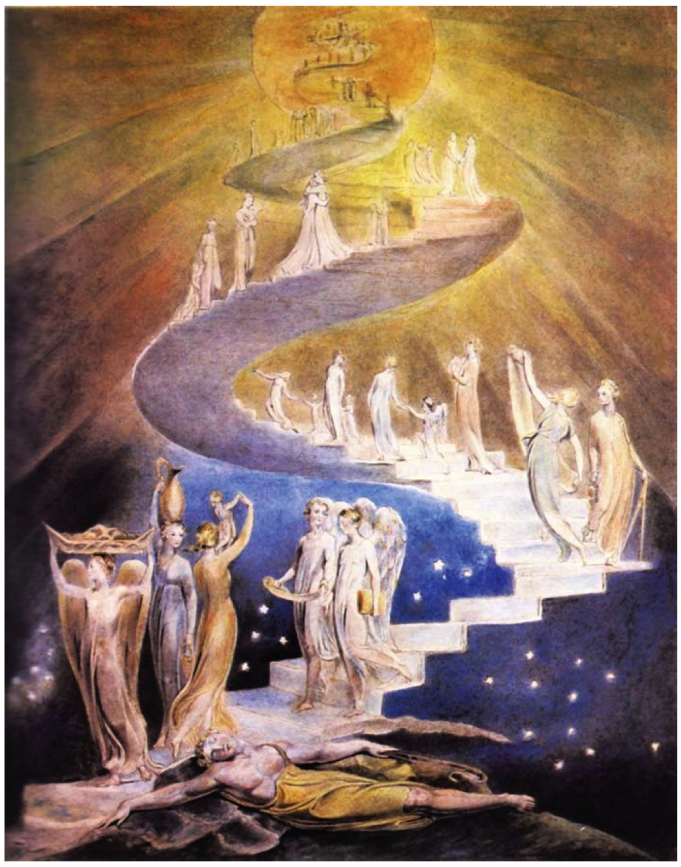
Alongside all the innovations of Lavoisier's revolution, there is also a tremendous effort to preserve the objects of knowledge of the old (Stahlian) chemistry. Using this perspective, in Section 3 I analyze the ethical dimension of the new chemical nomenclature system devised by Lavoisier and Moerveau. Furthermore, I discuss the evolution, during this period, of the concept of chemical affinity, focusing on its algebraic additive structure and its capability (or lack thereof) of working as the main organizing principle of chemical science.

Figure 2b displays a beautiful example of spiral staircase as it is used in architecture. The stairway from a given level to the next may represent the theoretical and technological developments that allow the new level to be reached. Meanwhile, the building's floors linked by the staircase may be considered as figurative analogs representing successive levels or

Autonomous living-like systems can be ranked by abstraction, as in the following list: Actually known DNA / RNA living organisms; Possible or potentially existing DNA / RNA organisms; Systems based on wet organic chemistry; Systems based on carbon or silicon substrates; Computer simulation of the previous systems; Physically implemented artificial life (AL) systems; Computational AL systems; Social systems; Legal systems. Of course, pertinence and order in this list is somewhat arbitrary.

Maturana and Varela (1980, p.107-109) consider a beehive to be a natural example of higher order autopoietic system, suggesting perhaps that social systems should be moved cloaser to the head of list above. Even considering someone's favorite ranking order, how far down the list is it appropriate to apply the concept of autopoiesis has been the subject of vivid debate. Francisco Varela, Humberto Maturana, and Ricardo Uribe (1974) where among the first to study cellular automata as autopoietic systems. However, only a few years later, Varela (1978) expressed serious concerns about using the term Autopoiesis for abstract systems, suggesting the word Autonomy to be used instead in non-biological contexts. Nevertheless, McMullin and Varela (1997) seem to have found a way of reconciliation with at least some of the more general applications of autopoiesis, rediscovering computational autopoiesis; see also McMullin (2004).

Personally, I think that trying to get the genie back in the bottle is an unnecessary and even counterproductive effort. In fact, I believe that the case at hand only shows how the best ideas quickly outgrow the limits of their originally perceived scope, and how the most powerful concepts soon find their way far beyond their first intended applications. Moreover, it has been my personal experience that the integrated study of abstract or artificial systems can greatly benefit our understanding of biological systems, specially so when investigating difficult questions concerning the always intertwined topics of autopoiesis, evolution and self-organization; see for example Inhasz and Stern (2010) and the references herein for a concrete example concerning the role of genetic introns. Nevertheless, this semantic distinction is not among the core topics of the present paper, and the reader should feel free to replace the words autopoiesis / autopoietic by autonomy / autonomous whenever he or she finds it to be appropriate.



Figures 2a: Jacob's Ladder by Willam's Blake; 2b: Spiral staircase by Nils Eisfeld.

stages in the historical development of a scientific discipline. At each one of such levels, the objects recognized by the scientific discipline at that stage have to be organized in a coherent fashion. This organization may be represented by the checkered or mosaic pavement patterns at each floor of the building.

A *scientific ontology* consists of a structured vocabulary for the formal definition of the collection of objects of knowledge of a given scientific discipline and its organization, that is, the semantic relations that exist between these objects. Moreover, for the sake of continuity, it is important to compile translation dictionaries or to establish valid (even if approximate) correspondences relating objects of the present ontology of a scientific discipline to objects of ontologies used in the immediate past or, if possible, even to ontologies of much older times. Employing our architectonic analogies, we must be able to map positions in the current floor to corresponding positions in the preceding or other previous floors. Such maps are known in computer science as *ontology alignments*, these are briefly discussed Sections 2, 3 and 6. A good representation of successive ontologies of an evolving science has them displayed in optimal alignment. For straight stairways, a regular pitch or raising slope implies successive shifts of relative horizontal position or changes in orientation at the stair's landing points from floor to floor, hence the preference for displaying Jacob's Ladder in spiral or helical shape.

Metaphysics concerns causal explanations telling why things are the way they do; these are the narratives, metaphors, and abstracts symbolic statements used to build a system's understanding or intuition about the world and the way it works, see Stern (2008b, Ch.4). Von Foerster's (2003, p.284) alternative formulation of the metaphysical (negative) imperative is: "For which we cannot show a cause or for which we do not have a reason, we do not wish to see." Section 4 illustrates the metaphysical (negative) imperative in the (arguably somewhat retarded) development of spectroscopy.

Science must evolve, acquiring valid knowledge over new objects, or better (more objective) knowledge over its old domains. However, as a consequence of the metaphysical imperative, in order to be ready to see some*thing* we must already have some way of thinking about *it*, we must already have some concepts able to assimilate the structure of these ideas, and we must have already crafted some terms in our language that can be used to communicate these concepts. Hence, the paradox: How can we name or better describe what we do not yet see, if we cannot see what we cannot yet explain?

The metaphysical imperative was formulated in negative form, and that is the way it ought to be. One cannot naively flip its orientation, stating it in positive form: *Explain that which you want to see!* — is just wishful thinking! (Like in a Möbius band, in order to obtain a flip in orientation, one has to travel all the way around it). In order to introduce new objects in a (upgraded) scientific ontology, one has to reach a higher level of theoretical understanding, developing new ideas and acquiring more powerful insights. Using once again the visual metaphor of Jacobs Ladder, one has to climb up all the way around an helical stairway, reaching the next floor of the building, even if the building, the next floor, or the stair itself, is still under construction. Section 5 illustrates how such creative change is possible, using, as historical examples, Lavoisier's early ideas of air-like substances and Balmer's geometrical models. In Section 6 I present my final remarks, and describe some topics to be discussed in following articles.

1.1 Heavy Anchors and Fine Points

As in many representations of Jacob's Ladder, the images at Figures 2a and 2b have the ladder's base firmly anchored to the ground. In our epistemological context, such heavy anchors are provided by formal methods of Bayesian statistics developed with the specific purpose of measuring the credibility of statements declaring the existence of an eigen-solution — technically, computing an e-value, the epistemic value of a sharp statistical hypothesis. None of these formal methods will be directly used in the present article. However, the reader should be aware of their existence, for they provide the nexus for application of the epistemological framework under consideration to the practice of science and technology. Without having these heavy methodological anchors readily available and implemented as statistical tools for data analysis, all the angels in William Blake's painting at Figure 2a would remain in heaven, never reaching earthly realms or, at least, not being able to reach empirical science's daily life. The following sub-sections (1.1.1 – 1.1.3) can be skipped on first reading without loss of continuity; they contain some remarks on statistical inference, observations on the interpretation of eigen-solutions, and also some warnings on historiographical methodology[5].

1.1.1 Bayesian Epistemic Value of a Sharp Hypothesis

The essential properties of an eigen-solution, studied in Section 2, dictate that these statements have the special form of *sharp* or *precise* statistical hypotheses, implying many important and non-trivial consequent requirements for appropriate methods of statistical inference. In the last 15 years, the Bayesian Statistics research group of IME-USP, the Institute of Mathematics and Statistics of the University of São Paulo, has been developing a significance measure known as the e-value — the epistemic value of a sharp or precise statistical hypotheses, H, given the observational data, X; see Madruga (2001), Pereira and Stern (1999) and Pereira et al. (2008). At the same time, we have been exploring the strong algebraic structure of the compositional properties of e-values, that are characteristic of abstract belief calculi or logical inferential systems, see Borges and Stern (2007), Stern (2004, 2011a) and Stern and Pereira (2014). These algebraic or logical properties further reflect the essential compositional properties of the eigen-solutions the corresponding statistical hypotheses stand for, as discussed in Section 2. Furthermore, I have been developing a specific version of cognitive constructivism as a suitable epistemological counterpart for this novel statistical theory, and vice-versa, see Stern (2003, 2007a,b, 2008a,b, 2011a,b, 2012).

The relationship between Bayesian e-values and the epistemological framework of cognitive constructivism, together with its fundamental metaphor of *objects as tokens for eigen-solutions* runs parallel to the relationship between p-values of frequentist (classical) statistics and the epistemological framework of Popperian falsificationism, together with its fundamental metaphor of *the scientific tribunal* where hypotheses are judged and proven (or not) to be false. These associations, in turn, run parallel to the relationship between Bayes factors of

[5] In order to give firm foundations to the discussions in this paper, there are many details about the chemistry of reaction networks that must be carefully described. In particular, I should clearly define several alternative conceptions of a reaction network I am using, and how they relate to each other. In order to do that, I also have to describe their (sometimes implicit) algebraic representations, the compositional properties of their quantities of interest, like (algebraic) rules for handling stoichiometric and affinity values, etc. The interested reader can find this material in Stern and Nakano (2014).

decision-theoretic statistics and the epistemological framework of von Neumann-Morgenstern utility theory, together with its fundamental metaphor of *the scientific casino and rational betting systems.* These parallel associations of inference systems and epistemological frameworks are carefully compared in Stern (2011a) and Stern and Pereira (2014).

1.1.2 Polysemy, Significance and Nature of Eigen-Forms

1.1.2.1 Metaphorical meaning vs. formal structure of eigen-forms:

Each one of the aforementioned statistical frameworks, or just their corresponding fundamental metaphors, can be used as ways of thinking about and understanding the world we live, far beyond of hard empirical science.

Game theory, originally developed by Morgenstern and von Neumann (1947) in the context of economy, was soon adapted for a new role in foundations of Bayesian statistics, see Blackwell and Girshick (1954), Dubins and Savage (1965) and Finetti (1972, 1974). Afterwards, the scope of game theory was extended to ethology, psychology, epistemology, and even foundations of mathematics, see Jech (1973, Sec.12.3 – The Axiom of Determinateness) and Shafer and Vovk (2001, Sec.4.6). However, as the scope of possible applications of game theory expands, it is unavoidable that the word *game* becomes increasingly polysemic. Nevertheless, reasonable applications of game theory share strong formal properties captured by well defined mathematical structures, preserving a methodological integrity in the field and allowing coherent interpretations in different applications. This issue is strongly connected to the theme of ontology alignment, that is commented throughout the text, and to von Foerster's organic imperative, briefly commented on in Section 6.

Moreover, examining the literature of utility / game / decision theory, we can attest undeniable positive-feedback, reinforcement and synergy effects between (1) the development of mathematical formulation of these theories; (2) the development of the corresponding epistemological frameworks; (3) the development of Bayes Factors and other analytical tools based on decision-theoretic Bayesian Statistics; and (4) a coherent generalization of the underlying game or gambling metaphors.

I believe that similar synergy effects are possible between (1) the use of an already vast and ever expanding literature on mathematical models for or based on functional eigen-solutions; (2) the development of the epistemological framework of cognitive constructivism; (3) the development of analytical tools based on Bayesian measures of epistemic significance for sharp statistical hypotheses and their compositional properties (logical rules); and (4) a coherent generalization of the underlying metaphor of *objects as eigen-solutions.* One of the main goals of our research group is to study and foster this synergy, hence our emphasis on formal and quantitative analyses for characterizing empirical eigen-solutions.

1.1.2.2 Constructive vs. objective nature of eigen-solutions:

In the epistemological framework of cognitive constructivism, eigen-solutions emerge from the recursive interactions of an autopoietic system with its environment. Hence, any object known by an organism or abstract autopoietic system has an undeniable constructive character. Better said, as products of an interaction process, objects must depend on the interacting parts: The observer and the observed; The actor and what it acts upon; Some*thing* out there and the one manipulating *it*. This delicate theme concerns the *self-reference paradox*, studied

at Stern (2007b, 2008b Sec.6.4), see also Brier (2001, 2005) and Rasch (2000, Ch.3,4).

In our framework, *objectivity* refers to the truth-value of the known object, that is, the degree in which it exhibits the essential properties of the underlying eigen-solution, namely, precision, stability, separability and composability. Moreover, in scientific applications, such (statistical) *significance measures* are essential for the discovery, calibration, and standardization of the interactive processes in which an object emerges. It is through this fine-tuning that the entities in a scientific ontology are ultimately defined. The historical examples presented in this paper should help to make it clear how this process takes place.

The constructive character of eigen-solutions can be illustrated by several examples in Cerezetti (2013). The author develops algorithms for automatic detection of *arbitrage opportunities* — events recognized by specific failures in equilibrium conditions that characterize *efficient markets*. These algorithms have been used and tested at the BM&F-Bovespa derivative markets. The (statistical) detection of an arbitrage opportunity can, in turn, have two interesting applications: On the one hand, it can be used for speculative trading; On the other hand, it can be used by market regulators, preventing fraudulent trading, activating circuit breakers or taking other pertinent exception handling procedures. In either of these two roles, speculator or regulator, the agents using such algorithms act as fingers of the *invisible hand*, effectively building the efficient markets in which eigen-values known as *prices* can emerge having the desired meaning and operational properties.

Players and regulators of finacial markets, small communities issuing complementary currencies, as in Figure 1, and birds singing and synchronizing their songs, as in Figure 4, are all actively *trying* to build stable eigen-forms. Alas, using variational principles, we can give teleological explanations even to the movements of infinitesimal particles, see Stern (2011b). Nevertheless, the level of conscience or self-awareness of the role played by *agents* participating in each one of these construction projects / processes varies greatly. Symbolic meaning, cognition and communication of eigen-forms at different levels of complex hierarchical structures are topics examined in Brier (2001, 2005).

1.1.3 Historiographic Remarks

Before ending this section, it is only fair to post a *caveat emptor* about the illustrative use made in this article of some examples in the history of science. If establishing a single fact may be a challenging task, interpreting a dynamical processes is inevitably a lot harder, especially so at times where concepts are in rapid flux and language undergoes great transformations. Nevertheless, the best examples to illustrate the epistemological ideas presented in this paper are offered exactly by processes taking place in such eyes of the storm. I have chosen examples from the turn of the 18th to the 19th century. Choosing more recent alternatives could, perhaps, alleviate some historiographical difficulties, but would also impose heavier overheads of mathematical formalism and specialized scientific knowledge.

Furthermore, a word of caution must be given about the references in the literature of history of science listed in the text. The cited authors often come from very different backgrounds, use incongruent methods of analysis, and may produce divergent general conclusions. Hence, one should not expect the aforementioned references to provide an overall harmonious and coherent perspective. Nevertheless, in each of such references I could find a specific point of view or an interesting comment that (in my opinion) is somehow supportive

Figures 3abcd: Scientific aesthetics: Nice colors, sharp images, and beautiful tokens.

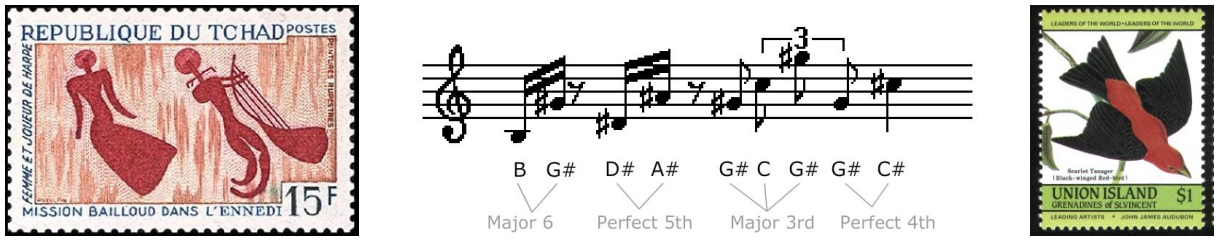
or pertinent to the epistemological ideas being developed in this article. Furthermore, the fact that two or more authors, coming from diverse schools of thought and different academic traditions, can agree to distinguish certain characteristic in a specific thread of historical process or indicate a distinctive aspect of a given event, may be taken as corroborative evidence in favor of these common factors or shared interpretations. Finally, I hope that this article motivates further and far more technical inquires in history of science.

2 Objective Aesthetics and Eigen-Solutions

Eigen-solution is the key concept of the objective version of cognitive constructivism used in this article. Eigen-solutions emerge as operational fixed-points or equilibria, as invariants for a system interacting with its environment. A fundamental insight for the constructivist framework is expressed in my re-interpretation of von Foersters well-known metaphor as: Objects are tokens for eigen-solutions. In other words, objects, and the names we use to call them, stand for and point at the eigen-solutions that emerge in our eigen-behaviors, that is, in the stable recurrent interactions we have in our environment. Figure 3 displays some postage stamps; these are tokens (that can be exchanged) for a specific and well defined postal service. The themata depicted in these stamps are also related to matters discussed in this article.

When a musician plucks a string of his or her guitar, he or she produces very definite musical notes. In modern physical language, these notes emerge as eigen-solutions of the (small amplitude) wave-equation for the (homogeneous) string. For mathematical, graphical and artistic representations of these eigen-solutions, the fundamental and higher harmonic standing-waves, see Stern (2008a, p.50-53) and Figure 3d. Nevertheless, humans have been playing guitars, harps and similar instruments long before anyone knew how to solve a differential equation, see Figure 4a. That is, humans have perceived the existence of *objects* they called musical notes, and used them as the key elements for playing or composing music, long before they had the abstract mathematical notion of a functional eigen-solution.

Figure 4b presents a short song using modern musical notation. However, this is not a human song, but an archetypal form from the Plain-tailed Wren's four-part chorus, see Mann (2006). Speciation is a biological evolutionary process in which such eigen-forms emerge as stable organizational patterns. According to some schools of neo-Jungian psychiatry, evolutionary eigen-behaviors known as *archetypes* play a primary role in human psychology, see Stevens (1999, 2003) and Stevens and Price (2000). Figure 4c displays the beautiful plumage of the Scarlet Tanager (Ramphocelus bresilius) in a painting by John James Audubon. The Tiê Sangue is in Brazil a symbol of freedom, for the vivid colors that a healthy bird displays



Figures 4abc: Archetypal forms in music and biological speciation.

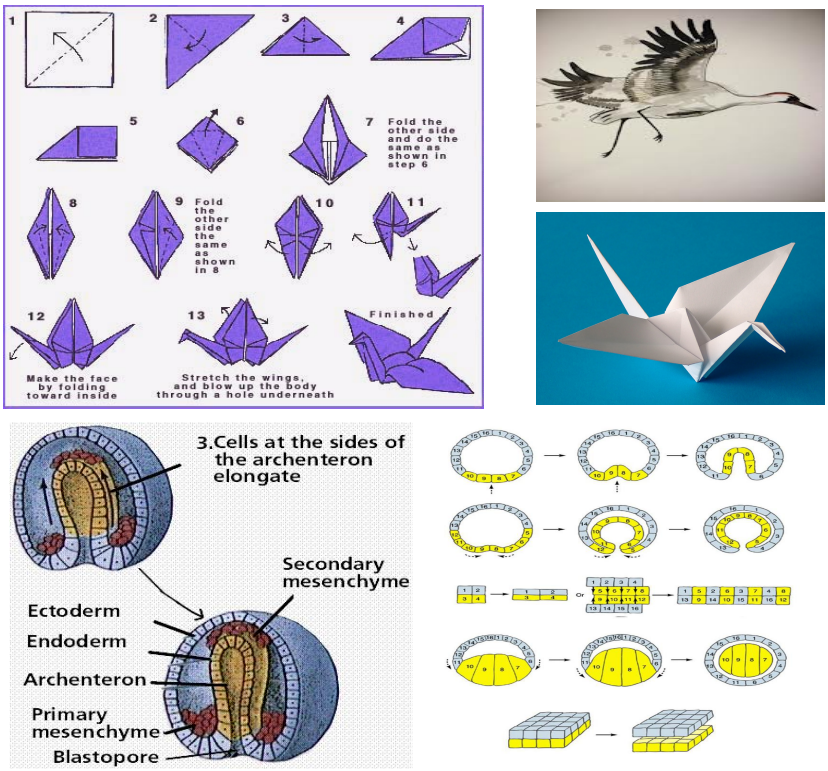
in the wild quickly fade away when it is held in captivity. This bird is also displayed at the back cover of Ber van Perlo's *A Field Guide to the Birds of Brazil*, a catalog of archetypal forms used by bird watchers for taxonomic identification.

Musical notes are the *atoms* of Western music: In the most basic form, they constitute a *discrete* set of (fundamental) frequencies available for musical performance. The (relative) frequency of each of these notes is exactly defined. *Precision*, that is, having an *exact* or *sharp* definition, is the first essential property of eigen-solutions. The guitar is a musical instrument that is carefully designed in order to make it easy to produce these musical notes. Small variations in the way the player plucks a string will not substantially change (the fundamental frequency of) a musical note, neither will reasonable variations in the atmospheric conditions, and so forth. This property is called *stability*, the second essential property of eigen-solutions. It is also possible to produce singular tones separately, or to produce simultaneously several notes without distorting each of the singular tones. Eigen-solutions are *separable* and *composable*. These essential properties allow the artist to use musical notes as building blocks in the construction of harmonious chords and beautiful melodies.

To Summarize: The four essential properties of eigen-solutions are to be discrete (or sharp, exact or precise), stable, separable and composable. In the constructivist framework, these four essential properties define the possible forms of perception of an eigen-solution, that is, the aesthetical attributes of the corresponding scientific object, the objectivity of the same science and, perhaps, also the nicety of related experiments or the beauty of pertinent demonstrations; see Foerster (2003c, p.266), Golinski (1995), Segal (2001, p.145, 127-128), Stern (2007a, 2008a, 20011a), and Szabó (1978, p.240).

Eigen-solutions can also be tagged or labeled by words, and these words can be articulated in language. Of course, the articulation rules defined for a given language, its grammar and semantics, only make the language useful if they somehow correspond to the composition rules for the objects the words stand for. Ontologies are carefully controlled languages used in the practice of science[6]. They are developed as tools for scientific communication.

[6] Nowadays, the development of some areas of empirical science would be impossible without powerful computational tools for ontology management. For example, current research in genomics requires well structured and carefully controlled vocabularies for identification of biological genes, and subsequent annotation concerning: sequencing alternatives; proteomic translation; biochemical, cellular and extra-cellular function; and so forth. Moreover, a good ontology management framework should provide ontology alignment and other statistical analysis tools capable of tracing evolutionary relations, following biochemical pathways, identifying similarities in function across biological species, and searching for other meaningful correspondences. Furthermore, such a computational framework should enable the integration of large, distributed and diverse databases, facilitating collaborative work of independent research groups.

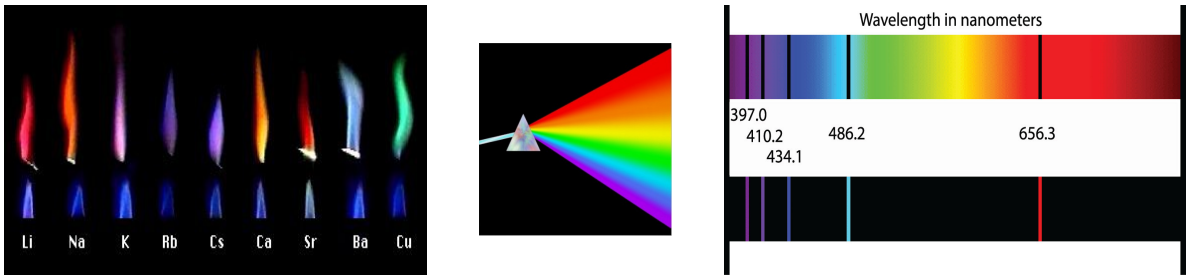


Figures 5abcde: Geometrical foldings, origamic and organic.

According to the constructivist perspective, the key words in scientific ontologies are labels for eigen-solutions. This is the constructivist approach to the classic problems of external symbol grounding and alignment of scientific ontologies, as briefly discussed in Section 6.

The importance of working with eigen-solutions is illustrated by the elegant origami example, presented by Richard Dawkins in Blackmore (1999, p.x-xii). Dawkins compares two instances of the Chinese whispers game. In this game, an object is shown to the first child in a line of children, that must copy the object the best he can, and then show the copy he made to the second child in the line, and so on. The fidelity of the copy mechanism can be estimated by the difference between the original object shown to the first child, and the copy produced by the last child in the line. Dawkins than compares the results obtained when copying two very distinct objects: A freehand drawing and an origami, both representing a Chinese junk. The result is easy to foresee: Except for the rare occurrence of a spurious mutation, the successive copies of the origami are all identical, that is, most of the time, despite small differences in craftsmanship, all copies follow the exact same folding scheme. Meanwhile, the final copy of the freehand drawing has little resemblance to its original. These results are similar to the progressive degradation afflicting successive copies of an analogous tape recording, in contrast to the high-fidelity copying process for digital discs.

An origami is produced by a successive folding process. The small number of basic folds used in the traditional art of origami have the same essential characteristics of eigen-solutions: They are defined as exact geometric operations, that can be produced with great precision and stability. Furthermore, many successive folds can be easily superposed in order to produce complex compositions. Even larger and more intricate structures can be assembled by modular composition of individual origami objects. Figure 5a shows the



Figures 6a: Blowpipe colors; 6b: Dispersion by refracting prism; 6c: Spectral lines.

instruction sheet for the *tsuru*, the classical origami for a crane. Real (biological) cranes are self-assembled by organic morphogenesis. Figure 5e depicts tissue foldings used in this process: invagination, involution, convergent extension, epiboly and delamination. Of course, analyzing eigen-solutions of complex biological processes demands sophisticated tools, like stochastic processes, statistical models, fractal geometry, catastrophe theory, and so forth.

2.1 Blowpipe and Spectral Analysis

Let me now present some examples of eigen-solutions in the field of chemistry, comparing two techniques used to identify chemical substances, namely, blowpipe and spectral analysis.

A typical blowpipe consists of a small curved brass tube having at its ends a mouthpiece and a fine nozzle. Blowing through this tool, an experienced operator can direct a jet of air through a gas burner, obtaining a flame with special characteristics (oxidizing or reducing) and high temperatures at specific spots. Taking small samples of chemical substances into this flame produces light with characteristic colors, as displayed in Figure 6a, that can be used to identify the presence of known chemical elements.

In 1751, Axel Fredrik Cronstedt used blowpipe analysis to identify a new chemical element, the metal nickel. Carl Wilhelm Scheele and his coworkers used blowpipe analysis to identify the new elements manganese, 1774, molybdenum, 1781, and tungsten, 1783. From that point on, this tool contributed for the discovery of several new chemical elements, see Jensen (1986). Nevertheless, standard blowpipe analysis also has some drawbacks. Among them, is the somewhat subjective nature of the specific color tones and hues that can be seen at a flame, the recognition of which requires extensive training of the analyst and, even then, is a task prone to error.

Spectroscopy is a technique that overcomes many shortcomings of blowpipe analysis. Since ancient times it is known that a prism can decompose light into its constituent colors, making it possible to analyze the resulting spectrum. Isaac Newton describes several spectroscopic experiments in his book Optics of 1704. In 1785 David Rittenhouse was able to manufacture diffraction gratings with approximately 100 lines per inch, a better alternative for spectroscopy than prisms. In 1802 William Hyde Wollaston reported dark lines in the spectrum of solar light. Between 1814 and 1821 Joseph von Fraunhofer build the first reliable spectroscopes, first using prisms, and later replacing them by diffraction gratings. Fraunhofer analyzed the spectra of natural sun light and also alternative sources like a variety of combustion flames, observing with great accuracy absorption and emission spectra. Emission spectra are composed by a discrete set of bright lines, each one defined by a pre-

cise position that corresponds, in contemporary physical theory, to an exact frequency or wave-length. Absorption spectra exhibit a complementary picture, that is, an continuous color composition except for a finite set of dark lines. Figure 3b shows Fraunhofer's solar absorption spectrum and Figure 6c shows the emission and absorption lines of hydrogen.

In 1859, Gustav Robert Kirchhoff, see Figure 3c, and Robert Wilhelm Eberhard Bunsen realized that spectroscopy analysis could be a highly efficient method for analytical chemistry, starting a revolution in the field, see Kirchhoff (1860a) and Kirchhoff and Bunsen (1860). Many historians have wondered why this revolution took so long, because, as one can infer from the aforementioned chronologies, see Figure 8, all necessary the technology was available for quite some time. I will analyse this question in great detail in section 4. For now, I just want to call the reader's attention for the possibility of a parallel correspondence between, on the one hand, the blowpipe and spectral analysis methods described in this section and, on the other hand, the freehand drawing and the origami instances of the Chinese whispers game described in the last section.

In 1885, Johann Jakob Balmer was the first to achieve an explanation for the relative position of the emission lines of hydrogen, the simplest of all atoms. The frequencies, ν, or wavelengths, λ, of these spectral lines are related by an integer algebraic expression:

$$\frac{\nu_{n,m}}{c} = \frac{1}{\lambda_{n,m}} = R\left(\frac{1}{n^2} - \frac{1}{m^2}\right) \ ,$$

where $R = 1.0973731568525(73)E7 \ m^{-1}$ is Rydberg's constant (this notation includes a standard deviation for the last significant digits, 525±73). In Balmer's formula, distinct combinations of integer numbers, $0 < n < m$, give wavelengths of distinct spectral lines, see Balmer (1885, 1897), Banet (1966, 1970) and Enge (1972). Further comments on Balmer's intuition for arriving at his formula are given in Section 5.

Many times, when great scientists face fundamental eigen-solutions, they are taken by a marvelous sense of wonder or find themselves in a state of ecstatic admiration, as expressed by Balmer in the following quotations.

> *Extending the calculations based on the last estimated constants to the following (spectral) lines, resulted in an average deviation from the measured wave-lengths of only about 1/4 of a unit. Obtaining such a closely correct result in the first trial of this formula - using only round integer numbers for the first and second constants, was for me a great surprise, that strengthened to the highest degree my conviction that this formula is the most adequate expression for a physical truth.* Balmer. (1897, p.383)

> *The final impression, involuntarily imposed on our spirit by contemplating such a basic and fundamental relationship, is the existence of an inexhaustible wisdom established in nature that fulfills its function with infallible certainty, a wisdom that a thinking spirit can only perceive in incompleteness, following it with humbling and arduous efforts.* Balmer. (1897, p.391).

Perhaps, these strong feelings could be taken as a helpful hint, suggesting that the constructivist approach to objectivity provides sensible intuitions. Maybe, these strong subjective impressions reveal an a priori conception indicating that the constructivist notion of reality offers powerful insights.

2.2 Stoichiometry, Conservation Laws and Invariant Elements

The example of scientific eigen-solutions seen in the last sub-section is expressed by Balmer's formula, a mathematical equation. That is exactly the case for the most fundamental scientific statements. Well known examples of deterministic statements are Newton or Einstein's laws of gravitation or Maxwell's equations for electrodynamics; good examples of probabilistic statements can be found in statistical physics, stochastic equations of population genetics or in formulas for state transition probabilities in quantum mechanics. In all these examples, the equality sign of the law, formula or equation, expresses the first essential quality of an eigen-solution, namely, precision.

Even considering that any actual experiment aiming to verify a scientific statement expressed as a mathematical equation has its design flaws and is plagued by a variety of operational imprecisions and measurement errors, there is an underlying equality relation the experiment aims to access. Modern technology is living proof that, to a great extent, science has been very successful at this task. As a trivial example, the Intel CPU powering the gadget I am using to write this article is a complex composition of about 200 million transistors, designed to implement sophisticated Boolean logic algorithms. Furthermore, it operates at a clock rate over 3 GHz, so that all and every single one of these transistors must operate in time synchrony of less than half a part per billion of a human heart-beat!

In this sub-section, I make some remarks about the perceived value in Lavoisier's work of von Foerster's essential characteristics of eigen-solutions, starting with precision. I argue that the new standard of precision introduced by Lavoisier was an important factor in the public (and his own) perception of these changes as a revolution that brought chemistry into science, see also Donovan (1988, 1990, p.270-272) and Perrin (1990, p.260).

In 1774, the *Académie Royale des Sciences* invited Lavoisier to write an anonymous review of his own work, the *Opuscules Physiques et Chimiques.* According to Perrin (1984), at that time, such an invitation was considered acceptable practice. Moreover, this self-referential "anonymous" review give us a rare opportunity to get a sincere assessment of what the author most appreciated in his own work. The next two quotations give the first and last paragraphs of this precious review. The third quotation is also from Lavoisier; it is not anonymous but it is meta-theoretical, in the sense that it brings the author's opinion about the goals, means and methods of general science.

> *Mr. Lavoisier has published, at the beginning of 1774, a book entitled Physical and Chemical Essays. The subject of this work was to examine the nature and properties of these air-like fluids that flow out from or combine with the body. These fluids have been hardly noticed by scientists until recently, when they become, for the last few years, one of the main objects of their research.* Lavoisier (1774, p.89).

> *Those are the main experiments contained in the work of Mr. Lavoisier: he applies to chemistry, not only the equipment and the methods of experimental physics, but also the spirit of calculation and precision that characterizes this science. The union that appears to be in the making between these two branches of knowledge will lead to a brilliant era of progress for both of them, and Mr. Lavoisier is one of those that most contributed for this desired reunion we so long awaited.* Lavoisier (1774, p.96).

> *I have already observed in preceding memories that the way of reasoning is the same*

for all sciences; that chemists, like geometers, can only proceed from what is known to the unknown by true mathematical analysis, and that all reasoning in matters of science implicitly contain true equations. Lavoisier. (1788, p.777-778).

The value Lavoisier gives for the precision of his experiments takes him (perhaps unconsciously) to even exaggerate the exactitude of his work, for example, showing calculated results with more than the appropriate number of significant digits. On the one hand, we must recognize that a good error analysis theory was not available at that time. On the other hand, Lavoisier clearly makes a rhetorical use of this exaggeration, for it is clear to him that the more exact are the results that he can show, the more scientific will be the perception of his new chemistry. Lavoisier's friends and adversaries alike were well aware of the potential and also of the liabilities of precision as a rhetorical device, see Golinski (1995) and Levere (2001, p.93). Nevertheless, according to the constructivist perspective, honest reports of high-precision experiments is exactly what one should expect from good (objective) science.

According to the constructivist perspective, not only precision, but also stability, separability and compositionality are essential characteristics of good scientific objects. Explicitly seeking these properties, Lavoisier suggests a new list of chemical elements. Moreover, Lavoisier gives this list a provisional status, because more powerful analytical methods could always be developed, showing how to reduce "substances that had so far resisted analysis into simpler building blocks", see Levere (2001, p.69). Furthermore, Lavoisier is careful not to tie his operational definition of chemical element to any other unnecessary hypothesis about their "true nature". The following quotation should make these points clear.

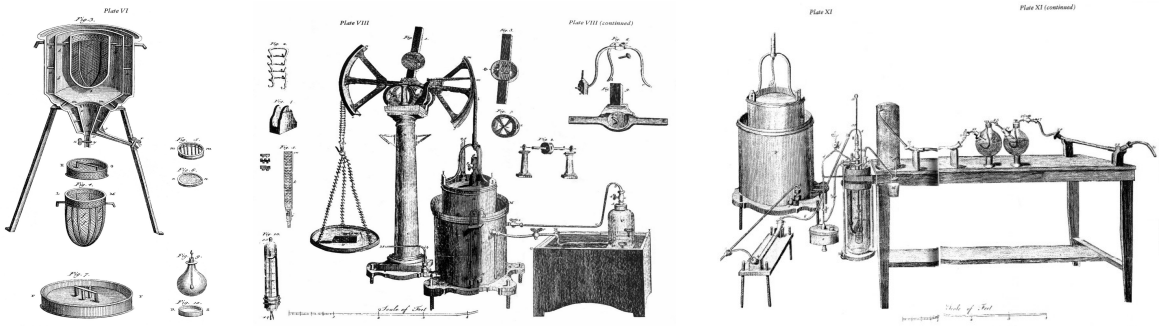
If, by the term elements, we mean to express those simple and indivisible atoms of which matter is composed, it is extremely probable that we know nothing about them; but, if we apply the term elements, or principles of bodies, to express our idea of the last point which analysis is capable of reaching, we must admit, as elements, all the substances into which we are capable, by any means, to reduce bodies by decomposition. Lavoisier (1789,v.1, p.xvii), as quoted in Levere (2001, p.80).

Jeremias Benjamin Richter coined the term *Stoichiometry* to designate chemical balance equations giving the exact proportions in which the involved substances interact.

Because the mathematical part of chemistry is constituted mainly by such bodies, which are indivisible substances or elements, and because this science discusses the volume proportions between them, I could not find a shorter and more appropriate name for it than the word Stöchyometria, of the Greek στοιχειον, which means something like indivisible, and the word μετρειν, which means the search for volume proportions. Richter (1792, v.1, p.xxix), as quoted in Szabadváry (1966, p.102).

These equations express compositional rules and mass conservation laws for reagents and products that can be written as simple linear equations, see Leicester and Klickstein (1963, p.205-208), Muir (1907, p.269-276), and Szabadváry (1966, p.97-113).

The invariance properties and the conservation laws expressed by stoichiometric balance equations mutually support each other. Their validity can be jointly checked and confirmed by empirical experiments based on careful mass measurements, made with the aid of gravimetric (or, for gases, volumetric) instruments, see Figure 7. The relation between invariant



Figures 7abc: Lavoisier (1789, Plates VI, VIII and XI).

elements of a theory and its conservation laws is a very rich area of research, that I cannot further explore in this paper. I will return to this topic in following articles, see Stern (2011b) for a more formal and detailed analysis.

Chemistry can rely on stoichiometric rules, mass conservation laws, and the associated invariant elements to achieve an orderly structure. However, chemical theory will not be very useful if it does not allow a practitioner to foresee, among all the stoichiometrically well balanced equations, which ones correspond to chemical reactions that actually occur. These predictive powers concern the topic of chemical affinity, to be addressed in the next section.

3 Ethics, Recycling and Affinity

The ethical imperative, as discussed in Section 1, requires innovation, that must however be conciliated with the need of an autonomous system to preserve its kernel identity. New and better opportunities must to be created, conserving however the system's essential form and attributes, preserving core mechanisms of its fundamental way of life. Theoretical models and hypothesis, technological devices, laboratory apparatus, data analysis algorithms and others means and methods involved in the life of an autonomous scientific system can all be replaced, as long as they are substituted by compatible analogs, that is, by functional equivalents or succedanea that allow the system to recycle its *modus operandi* (to maintain its autopoiesis). Of course, accomplishing all that is no easy task. Conflicting demands and inconsistent conditions must be dealt with, difficult (ethical) choices need to be made. This task always involves non-trivial, and sometimes profound, systemic re-organizations or, using Piaget's nomenclature, the re-equilibration of cognitive structures. In this section I study some ethical aspects of the chemical revolution.

The European corpus of chemical knowledge in the Middle Ages is known as alchemy, inheriting traditions having their roots in several ancient civilizations, that were collected, reorganized and consolidated mostly by Arab sages. Its language sounds strange to a modern scientist. Alchemical texts explain how substances live and die (or even, sometimes, resurrect). Alchemy explains the way chemical substances interact telling stories about their passions and desires, how they love and hate each other; wherefrom the origin of the term *chemical affinity* can be traced. Alchemical practice may call for intervention of the supernatural or manipulation of hidden or occult forces. Its texts often employ arcane symbology to convey its mysteries, and are intentionally written so to be obscure, because the secrets

they contain are not supposed to become widely known. Finally, it seems that the magical-vitalistic nature of alchemical explanation is essentially qualitative, having for a long time precluded, or at least strongly discouraged, the development and application of quantitative research methods, see Alfonso-Goldfarb (2001, Ch.5), Crosland (1962, Ch.I-III), Hansen (1978, p.484-490) and Sevcenko (2000).

At the beginning on the XVI century, the alchemical and related literature had expanded to incorporate practical knowledge of many areas, including: mining and metallurgy; extraction and distillation of essences; preparation of cosmetics and medicines; and production of a great variety of materials, from glass to gunpowder. Nevertheless, all these applications employed a basic set of chemical substances, sharing common means and methods of preparation. The term *Stahlian chemistry* is often used referring to pre-Lavoisier chemistry, due to the influence of Georg Ernst Stahl (1659-1734). However, notwithstanding all the practical progress attained at this period, the old concepts of alchemical theory were still very much alive, see Bensaude-Vincent (1991, p.419), Leicester and Klickstein (1963, p.58-63), and Lewowicz (2011, p.438).

Inevitably, those working or otherwise interested in the field, started to search for principles of rational explanation that could help them to effectively organize and more easily understand the subject of chemistry. According to several researchers in history of chemistry, the first satisfactory of such organizing principles was chemical affinity, see Chalmers (2012), Goupil (1991, L.I-II), Klein (1996) and Duncan (1996, p.27-29, 156-159, 223-225).

In 1718, Étienne François Geoffroy published his *Table of Chemical Affinities*, see Leicester and Klickstein (1963, p.67-75) and Figure 9 in Appendix A. Each column in this table is organized as a list, having at the head an important chemical substance. The list's tail contains substances able to combine with the one at the head, ordered by decreasing chemical affinity. Affinities, or tendencies to combine, are ranked according to displacement reactions. Geoffroy explicitly chooses the word *affinity* (rapport) for its neutral character, trying to stay away from vitalistic interpretations and convey objective empirical information.

The reception of Geoffroy work in 1718 was enthusiastic, as one can tell from the first quotation that follows, a contemporary report from Fontenelle, the historian of the French Academy. As one can see from the second quotation, three decades later (1749), M.Clausier saw Geoffroy work as the major organizing principle of chemical science, and was ready to elevate affinity relations to the status of *axioms of chemistry*. Nevertheless, before the end of the century Lavoisier expressed a much somber view, as one can see from the third and forth quotations. It seems that, in Lavoisier's melancholic judgment, chemical affinity could become an important scientific concept but, so far, it stood on very shaky grounds.

> *It is here that the sympathies and attractions would come very much to the point, if they meant anything. But in the end, leaving as unknown that which is unknown, and keeping to certain facts, all the experiments of Chemistry prove that a particular Substance has more disposition to unite with one Substance than another, and that this disposition has different degrees... This Table becomes in some sort prophetic, because if substances are mixed together, it can foretell the effect and result of the mixture... If Physics could not reach the certainty of Mathematics, at least it cannot do better than imitate its order. A Chemical Table is by itself a spectacle agreeable to the Spirit, as would be a Table of Numbers ordered according to certain relations*

or certain properties. Fontenelle (1718), as quoted in Duncan(1996, p.157).

The affinities as we give them here are only an assemblage of experiments which having been repeated many times on the same materials, are as good as axioms in Chemistry... Clausier (1749, p.5), as quoted in Duncan(1996, p.157).

The part of Chemistry most susceptible, perhaps, of becoming one day an exact science, is that which deals with affinities or elective attractions. M.Geoffroy, M.Gellert, M.Bergman, M.Scheele, M.de Morveau, M.Kirwan and many others have already assembled a multitude of particular facts, which now await only the place which has to be assigned to them; but the principal data are lacking, or at least those which we have are not yet either precise enough or certain enough to become the fundamental basis on which must rest so important a part of Chemistry. Lavoisier (1789, v.I, p.xiii-xiv), as quoted in Duncan(1996, p.158).

This science of affinities, or elective attractions, holds the same place with regard to the other branches of chemistry, as the higher or transcendental geometry does with respect to the simpler and elementary part; and I thought it improper to involve those simple and plain elements, which I flatter myself the greatest part of my readers will easily understand, in the obscurities and difficulties which still attend that other very useful and necessary branch of chemical science.

Perhaps a sentiment of self-love may, without my perceiving it, have given additional force to these reflections. M.de Morveau is at present engaged in publishing the article Affinity *in the Methodical Encyclopedia; and I had more reasons than one to decline entering upon a work in which he is employed.* Lavoisier (1790, p.xiv,xxxvii).

In light of the previous sections of this article, one can explain the decline of prestige or decay in scientific status suffered by the concept of chemical affinity as a consequence of the weak aesthetical properties of its object of study, relative to the new objects of stoichiometric analysis. Geoffroy's affinity tables encode ranking relations that can be translated as inequalities, not equations. The article of Morveau cited by Lavoisier wraps affinity relations in an elegant additive algebraic structure, see Morveau et al. (1803, p.399-401), Goupil (1991, p.179-189) and Appendix A. Nevertheless, even using Morveau's formalism, experimental data in the form of occurrence or non-occurrence of displacement reactions can only render mathematical inequalities. Hence, this setting cannot define precise values for chemical affinities, but only enforce finite interval bounds.

Morveau may have been way ahead of his time, see Figure 8. Modern approaches to these issues describe equilibrium points in networks of reversible reactions, not irreversible displacements, see Stern and Nakano (2014). In this context, Théophile Ernest de Donder (1936) could derive, in 1923, affinity related eigen-solutions exhibiting the exact additive structure foreseen by Moereau, see Goupil (1991, L.III, Ch.4, Sec.4, p.297-305). However, the notions of reaction velocity and state equilibrium were only introduced by the work of Guldberg and Waage (1879) in the late 19th century, see Leicester and Klickstein (1963, p.468-471) and Muir (1907, Ch.XIV, p.402-405). It is interesting to note that Guldberg and Waage had the sense of being on a mission to rescue the notion of chemical affinity from its steady decline, stating that

Although we have not solved the problem of chemical affinities, we think that we

have indicated a general theory of chemical reactions, namely, those wherein a state of equilibrium is produced between opposing forces...

All our wishes would be accomplished if we could succeed in drawing the serious attention of chemists, by means of this work, to a branch of chemistry which has undoubtedly been much neglected since the beginning of the century.

Guldberg and Waage (1879), as quoted in Muir (1907, p.405).

Once we understand the reasons for the decline of affinity at the time of Lavoisier, an ethical question arises: What should have been the destiny given to all the knowledge accumulated by Sthalian chemistry, a corpus that had been organized around the decaying concept of chemical affinity? Should all that knowledge have been scraped? According to the notion of ethics formulated in Section 1 and in the first paragraph of the current section, such a wasteful attitude should be considered profoundly unethical!

In 1787, an elite group of French chemists, including Guyton de Morveau, Antoine-Laurent de Lavoisier, Claude-Louis Berthollet and Antoine Fourcroy, introduced a new method of chemical nomenclature; see Lavoisier et al. (1787) and Leicester and Klickstein (1963, p.180-192).

Many researchers have investigated how the new language they carefully crafted faithfully expresses and reliably encodes the analytical mechanisms of Lavoisier's new chemistry, see for example Beretta (1993, p.200), Crosland (1962, p.177-180), Donovan (1993, p.70-71,308), Levere (2001, p.69-71), and Poirier (1993, p.197). Perhaps willing to transmit the accuracy of the new system, the aforementioned authors of the new method of chemical nomenclature simply stated, as one of its basic principles, that:

Denominations should, as far as possible, conform to the nature of things.

Leicester and Klickstein (1963, p.182).

Such a blunt statement may bring the danger of *reification*, the naïve tendency, typical of strong-realistic epistemological frameworks, to assume that a given object in a cognitive domain concretely exists out-there as a *Ding an sich* (a thing in itself). From the way *objects* are constructed and *objectivity* is characterized, the epistemological framework of cognitive constructivism automatically shields the scientist from this kind of misunderstanding; for a more detailed discussion of this issue, see Stern (2007b, 2011a,b).

In contrast to examples possibly perceived as reification statements, the aforementioned statements of Lavoisier (1790, p.xiii-xxxvii) exemplify a process of de-reification. Affinity, the central concept of Stahlian chemistry, is qualified with the adjectives (im)*precise*, (un)*certain*, *obscure* and *transcendental*. Such reification and de-reification movements are typical of paradigm shifts in the historical development of scientific disciplines.

In light of our discussion, it should be clear how the perceived strength or weakness of general aesthetical properties of objects of knowledge, that is, the relative precision of invariance relations and the power of compositional rules of the eigen-solutions they stand for, are eventually translated into reification or de-reification statements.

Many fewer researchers have investigated the success of Lavoisier's new language in efficiently recycling an important inventory of chemical substances and preparation methods used in Stahlian chemistry, see for example Donovan (1993, Ch.4) and Holmes (1989, p.i-ii,55,122). As noted by J.L. Heilbron,

[Holmes'] prime example is the chemistry of salts formed from mineral acids and various bases. He shows that Lavoisier `took over this body of knowledge virtually intact`*: it had* `its own principles and logic`*; and did not require dephlogistication to be useful.* Holmes, (1989 p.i-ii, emphasis mine).

Eklund (1975) compiles a dictionary that re-presents old objects using the new nomenclature. I should stress that, in such a dictionary, translation assumes some form of functional equivalence or compatibility, it does not imply identity. I will return to these issues in Section 6 and following articles, studying the possibility and meaning of diachronic ontological alignments.

4 Metaphysical Blind-Spots

Spectroscopy and the Chemists: A Neglected Opportunity?

'It is remarkable for how long chemists neglected the precious mean of discrimination at their hands in the use of the prism — a striking example of how much may be lost by a too exclusive devotion to one branch of science to the neglect of others.'

This observation, made by George Stokes (1885, p.34-35), echoes a number of earlier remarks on the delayed acceptance of spectrum analysis by chemists.

An opinion similar to that held by Stokes was expressed by Herschel in a letter to John Tyndall, in which he stated that the work he had done in the 1820's 'might have led an enquiring person at an earlier period than the present to much that in now strikingly brought out.' Sutton (1976, p.16).

This is how M.A. Sutton starts his article about spectroscopy as a long *neglected opportunity* in chemical analysis. The starting quotation by George Stokes highlights the lost opportunity of (once again) interconnecting two well established systems of human knowledge, namely, chemistry and physics. As for the usefulness or even the need of this new technology, Sutton (1978, p.19) quotes William Huggins (1899, p.5-7), who compared it to "the coming upon a spring of water in a dry and thirsty land". Sutton (1976, p.17) speculates on the factors that could have prevented an earlier adoption of spectroscopic methods in chemical analysis, suggesting, among the possible reasons, the "unavailability of the necessary apparatus" and "suspicion of the consistency of the effect in the absence of any adequate theory of its cause", see also Pearson and Ihde (1951) and Koirtyohann (1980).

A brief examination of the selected landmarks in the succinct time-line of spectroscopy in Section 2, summarized in Figure 8, should be enough to dismiss the unavailability of good equipment as a possible reason. In fact, it is possible to completely invert this argument! According to McGucken (1969, p.9,28-29), the greatest obstacle hindering the development of spectral analysis was the complexity of observed spectra. Fortunately for Kirchhoff and Bunsen, the limitations of the equipment they were using compelled them to work with over-simplified data, containing "only the more conspicuous characteristics of a spectrum". On the one hand, such an over-simplified description was still sufficient to distinguish chemical elements and, on the other hand, allowed them to escape the complexity conundrum.

The second reason stated by Sutton as an impediment for the development of spectroscopic analysis, namely, "suspicion of the consistency of the effect in the absence of any adequate theory of its cause", must also be false, because the first acceptable physical model

for the line spectra of hydrogen, the simples of all atoms, was only given in 1913 by Niels Henrik David Bohr (Figure 3a), see Bohr (1913, 1987, 1998), Einstein (1905), Enge et al. (1972, Sec.4.7, p.99-104), Stern(2008b, Ch5) and Tomonaga (1962, v.I, Sec.3.18, p.97-106). However, I believe it is possible to uphold a relaxed version of this statement. Before giving my own version, let us hear the opinion of Gustav Robert Kirchhoff, who is universally acknowledged as the sole responsible for the final breakthrough that triggered the spectroscopy revolution.

> *I also have a few points to mention concerning the history of the chemical analysis of the solar atmosphere. The core of the theory of solar chemistry that I have developed consists of a proposition that, shortly stated, says: For each kind of (heath or light) rays, the relation between the emission power and absorption power is the same* (das gleiche) *for all bodies at the same temperature. From this proposition it easily follows that a glowing body that only emits light rays of certain wavelengths, also only absorbs light rays of the same wavelengths; wherefore it is revealed how it is possible to know the constituents of the solar atmosphere from the dark lines of the solar spectrum.* Kirchhoff (1863, p.102-103).

What makes this historical example so interesting is that Kirchhoff did not provide an adequate theory for the cause of spectral emission and absorption. As stated in Section 1, Balmer's formula was the first available explanation for the relative positions of (some) lines in atomic spectra. Kirchhoff did not even provide such an empirical recipe, explaining nothing of the structural order found in spectra. Instead, it seems that Kirchhoff provided the bare minimum for the breakthrough, namely, a firm handle to grasp new objects, an anchor securing a fixed point of view and allowing one to stare straight into the phenomena at hand, see Kirchhoff (1860b). This anchor had the form of a simple law of equilibrium, having nothing to do with specific models for atomic or spectral structure. Instead, it took the form of a general thermodynamic equality (*Gleichheit*) constraint. This opinion is supported by James (1983, p.42), Rosenberger (1890,v.3, p.691-692) and Schirmmacher (2003, p.299-301).

The minimality of Kirchhoff's explanation and the intensity of the following revolution highlights a *seeding effect* that seems to be characteristic of the metaphysical imperative. The presence of tiny particles in a dense cloud or in a saturated solution have the power of triggering phase-transitions in the form of wide spread condensation, precipitation or crystallization. In the same way, Kirchhoff's minimalist explanation sparked an abrupt and radical transformation in its cognitive field. Nevertheless, before the seeding, nothing happens, the world stands still, see Jastrow (1899). Heinz von Foerster (1995) used to convey this idea with his

> *Principle of the Double Blind: The blind spot: One does not see what one does not see.*

5 Therapy: Curing the Blind

The therapeutic imperative seeks cure for systemic blindness, revealing what is concealed, displaying what is occult. However, as noted in Section 1, in order to introduce new objects in a (upgraded) scientific ontology, one has to reach a higher level in the scientific disci-

pline (under construction), revisiting the aesthetical, ethical and metaphysical imperatives. The therapeutic imperative points to evolution, seeking sharper images of an expanded reality, looking for better scientific understanding of new phenomena, by (typically, but not necessarily in that exact order) speculating on alternative approaches and investigating innovative hypotheses, developing conventional means and methods and coherently incorporating unconventional ones, searching for new or sharper (eigen) solutions and, if necessary, integrating all of the above in better theoretical frameworks. This section shows how authentic therapeutic change is possible, using two historical examples to illustrate this process.

5.1 From Vapor-Ware to Material States

The first historical example in this section is centered on Lavoisier's new theory of the gaseous state, the equipment he developed to check mass conservation in chemical reactions, see Figure 7, and the emergence of the modern notion of chemical element. The path followed by Lavoisier in the critical years of this revolution constitute a complex story[7]. Many research topics and treads of development are intertwined in this path including, among others: Discussion of several conceptions of the classical five, four (or even two) alchemical elements (a.k.a substantial principles or natural instruments); study of boiling or evaporation of liquids, in open air or in evacuated chamber and expansibility properties of several substances; study of fixation and release of water in formation of salts and crystallization phenomena; study of fixation and release of airs in combustion and calcination phenomena; development of special balances, densimeters, pneumatic equipment and other measurement devices; development of a new theory of chemical combustion reactions, new notion of physical states of matter, and new definition of chemical elements.

In spite of all the inherent complexities of any real historical process and the many works of Lavoisier, Gough (1988, p.31) gives the following simplified outline of Lavoisier's core steps for the (Gough disapproves of the term *revolution*) momentous development of chemistry:

> *I should like to propose that Lavoisier brought into [a] basically Stahlian framework three important and interrelated ideas.*
>
> - *First of all (both historically and logically), Lavoisier formulated a theory of the gaseous state of matter that allowed him to conceive of numerous chemically distinct substances in an aëriform state as gases rather than airs.*
> - *Second, the realization that invisible aeriform fluids could leave and enter substances during the course of chemical reactions necessitated a gravimetric accounting to determine chemical composition. It was the systematic application of an unarticulated gravimetric criterion of composition that allowed Lavoisier to determine the proper order of chemical simplicity.*
> - *Finally, the fact that many aëriform substances existed in physical states that were nearly identical, but in chemical states that were quite divergent, prompted Lavoisier to apply the Stahlian reactive criteria of chemical identity in a more thorough, rigid, and systematic fashion than ever before.*

[7] For a lively account of this story, see Donovan (1993, Ch.4, p.74-109); for interesting details on the evolution of measurement techniques and devices, see Holmes and Levere (2002).

These three steps in Gough's outline are a perfect match to our metaphysical, aesthetical and ethical concerns. Speculating on several ideas about the nature of aëriform (air-like) substances, Lavoisier could acknowledge the new variables that he needed to incorporate in his measurements even if, at the beginning, he could only faintly notice or distinguish the corresponding entities. Developing and building the necessary equipment, including some adapted devices borrowed from the physics laboratory, he could take accurate measurements, showing the nice aesthetical properties (precision and compositional rules) of the newly found invariant objects and conservation laws. Using (informally) the (implicit) relation between conservation laws and invariants of a theory, he used these invariant objects to give a new characteriztion of chemical elements.

Finally, if Lavoisier was a revolutionary, his revolution was a very ethical one. Lavoisier (1772) may even have said, as quoted in Donovan (1993, p.104),

I have felt no obligation to consider anything done before me as more than a hint.

Nevertheless, from the metaphysical imperative, we know very well how valuable a good hint can be. Furthermore, the newly developed chemical theory was able to efficiently recycle the important inventory of Stahlian chemistry, doing so in a way that was consistent and coherent with the basic organizing principles of the old framework. I will further explore possible interpretations of the last statement in following articles, as indicated at Section 1.

5.2 The Strange Case of Balmer's Formula

As a second historical example in this section let us examine Balmers formula, a case that exhibits some aspects often perceived as strange, exotic, or at least as contrasting with the first historical example. We use the following descriptive labels for future reference.

Exogenous aspect: Balmer's intuition, allowing him to see the patterns he then described using his celebrated empirical formula, was based on models written in the language of projective and descriptive geometry and embedded in the context of classical architecture, see Banet (1966, p.503). Such language and context are considered disconnected from chemistry, hence perceived as exogenous, extraneous or exotic.

Asynchronous aspect: The models used by Balmer, based on ancient geometry, and the target application in spectroscopy, seem to be unrelated in time, that is, there is no apparent connection in the event chronology of the two fields.

Disengagement aspect: Lavoisier's work instantly triggered a revolution in chemistry, as did Kirchhoff's work in spectroscopy, see Section 2. Meanwhile, the most important consequences of Balmer's work had to wait for 30 years when, reinterpreted through the work of Niels Bohr, it had a large impact in the quantum mechanics revolution.

I am intrigued by these strange aspects, and tempted to ask the following questions:

- Did I choose *fair* descriptive labels for of these aspects?
- What are their conceivable causes, interconnections and possible consequences?

- Could Balmer's formula have been discovered before the statement of Kirchhoff's law?
- If so, would Balmer's formula be able to replace Kirchhoff's law as a trigger for the spectroscopy revolution?

Any definitive answer to these question is in danger of being a *nunc pro tunc* (now for then) conclusion, composing an ill-conceived, goal-directed, trans-historical or whiggish narrative. Nevertheless, I still dare to propose these questions for discussion in the spirit of a Talmudic *pilpul*, that is, a dialectical disputation aiming to examine the strength and weaknesses of possible arguments or their constituent parts.

6 Future Research and Final Remarks

The present article explores the construction and evolution of scientific ontologies. One of the main objectives of future articles is to use the epistemological framework of cognitive constructivism to further study ontology alignments, focusing the question: How is it possible to coherently relate concepts and communicate between different worlds? This is a recurrent problem in history and philosophy of science referring to the possibility or impossibility of identifying (or, in some reasonable sense, just matching) entities belonging to two distinct theoretical frameworks. Diachronic alignments concern specifically the case of two theories developed at different epochs that, nevertheless, aim to understand the "same" things. This issue is closely connected to other classical philosophical problems, including,

- The problem of (in)commensurability of scientific theories;
- The problem of *objective symbol grounding* in scientific ontologies.

The consecrated expression *external symbol grounding* can still be used as long as we understand it as a reference strictly external to language, because a symbol points to an objective eigen-solution, but not as a reference to a completely independent *Ding an sich*[8].

A second objective of following articles is to use the epistemological framework of cognitive constructivism to study the organization of science as a higher-order system having autonomous disciplines as sub-systems. This form of organization assumes the necessary and non-conflicting features of operational closure and cognitive openness. Such features can be enabled by coherent and harmonious communication among distinct autonomous sub-systems based on synchronic ontology alignments. These issues concern the last of von Foerster aphorisms in Section 1, the *organic imperative*.

Acknowledgments: The author is grateful for the support of IME-USP (The Institute of Mathematics and Statistics of the University of São Paulo), FAPESP (The State of São Paulo Research Foundation; grant CEPID 2013/07375-0), and CNPq (The Brazilian National Counsel of Technological and Scientific Development; grant PQ 301206/2011-2). The author is thankful for having had the opportunity to access the personal library of

[8] For influential philosophical discussions, see Feyerabend (1999) and Kuhn (2000); for computer science and systems theory approaches that will be instrumental in pursuing our goals, see Feng et al. (2004), Goldstone and Rogosky (2002), and Harnad (1990).

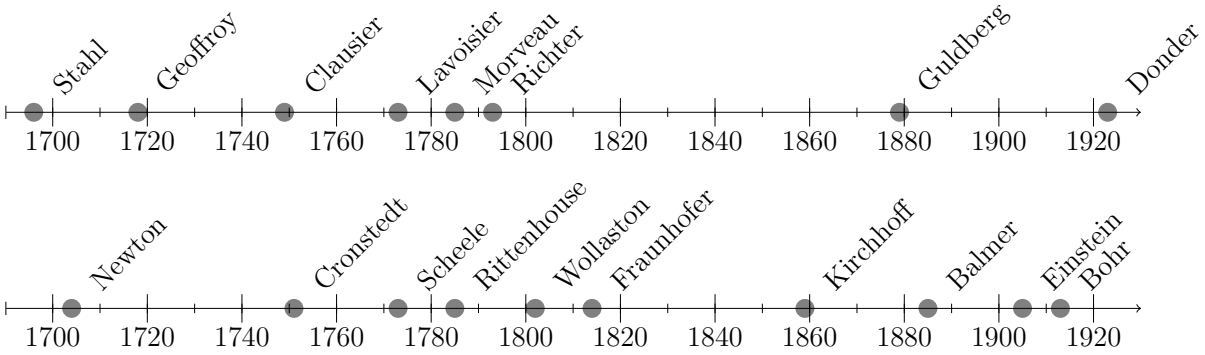
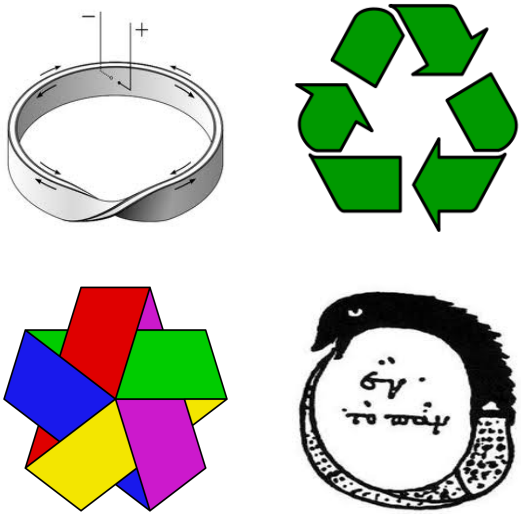


Figure 8: Scientists' timelines (approximate, by first work cited or published).

Prof. Haim Jurist, the special library of History of Chemistry at PUC-SP (The Pontifical Catholic University of São Paulo), and the rare books and special collections section of the library of IQ-USP (The Institute of Chemistry of the University of São Paulo). The author is also grateful for the organizers and the constructive criticism received from the following discussion fora: UniLog-2013 (The 4th World Congress and School on Universal Logic); ISPC-SS2013 (The Summer Symposium of the International Society for the Philosophy of Chemistry); and SIF-2013 (The XVII Congress of the Inter-American Society of Philosophy). Finally, the author is grateful to Rafael Bassi Stern for his critique of the first draft of this paper, to Jay Kadane for some quick lessons on the art of bird watching at Itatiaia National Park, and for valuable advice received from anonymous referees and from CHK final editor, Jeanette Bopry, whose suggestions were used to improve this work.

Some nice figures to fill this gap – The Möbius band in Art and Technology
Including: R.Davis' noninductive and nonreactive resistor; G.Anderson's
universal recycling symbol; a pentagonal paper folding; and the all-seeing
Ouroboros in the Greek manuscript Chrysopoeia of Cleopatra, circa 100 C.E.



References

- Alfonso-Goldfarb,A.M. (2001). *Da Alquimia à Quimica.* São Paulo: Landy.

- Balmer,J.J. (1885). Notiz über die Spectrallinien des Wasserstoffs. *Annalen der Physik,* 261, 5, 80-87. Translated as: Note on the Spectral Lines of Hydrogen. in H.A.Boorse, L.Motz (1966). The World of the Atom, V.1. New York: Basic Books.

- Balmer,J.J. (1897). Eine neue Formel für Spectralwellen. *Annalen der Physik,* 296,2,380-391. Translated as: A New Formula for the Wave-Lengths of Spectral Lines. *Astrophysical Journal*, 5,199-209.

- Banet,L. (1966). Evolution of the Balmer series. *American J.of Physics,* 34, 496-503.

- Banet,L. (1970). Balmers manuscripts and construction of his series. *American J.of Physics,* 38, 821-828.

- Bensaude-Vincent,B. (1991). Lavoisier: Una Revolución Científica. In M.Serres (Ed.). *Historia de las Ciencias.* Madrid: Cátedra.

- Beretta,M. (1993). *The Enlightenment of Matter: The Definition of Chemistry from Agricola to Lavoisier.* Uppsala Studies in History of Science, 15. Science History Publications, USA.

- Blackwell,D.; Girshick,M.A. (1954). *Theory of Games and Statistical Decisions.* New York: Wiley. Reprint (1976) New York: Dover.

- Bohr,N.H.D. (1913). On the Constitution of Atoms and Molecules. *Philosophical Magazine*, Part I: 26, 1-24; Part II: 26, 476-501.

- Bohr,N.H.D. (1987, 1998). *The Philosophical Writings of Niels Bohr.* V.I (1987)- Atomic Theory and the Description of Nature. V.II and III (1987)- Essays on Atomic Physics and Human Knowledge. V.IV (1998)- Causality and Complementarity. Woodbridge, CN: Ox Bow Press.

- Border,K.C. (1989). *Fixed Point Theorems with Applications to Economics and Game Theory.* Cambridge University Press.

- Borges,W.; Stern,J.M. (2007). The Rules of Logic Composition for the Bayesian Epistemic e-Values. *Logic Journal of the IGPL*, 15, 5-6, 401-420. doi:10.1093/jigpal/jzm032 .

- Brier,S. (2001). Cybersemiotics and Umweltlehre. *Semiotica*, Special issue on Jakob von Uexküll's Umweltsbiologie, 134 (1/4), 779-814.

- Brier,S. (2005). The Construction of Information and Communication: A Cyber-Semiotic Re-Entry into Heinz von Foerster's Metaphysical Construction of Second Order Cybernetics. *Semiotica,* 154, 1, 355–399.

- Cerezetti,F.V. (2013). *Arbitragem em Mercados Financeiros: Uma Proposta Bayesiana de Verificação.* Ph.D. Thesis, Institute of Mathematics and Statistics of the University of São Paulo.

- Chalmers,A. (2012). Klein on the origin of the concept of chemical compound. *Found.Chemistry*, 14, 37-53.

- Crosland,M.P. (1962). *Historical Studies in the Language of Chemistry.* Harvard Univ.Press.

- DeBrander,F. (2007). *Spinoza and the Stoics.* New York: Continuum.

- Donder,T.E.de (1936) *Thermodynamic Theory of Affinity: A Book of Principles.* Brussels: Stanford University Press.

- Donovan,A. (1988). Lavoisier and the Origins of Modern Chemistry. *Osiris,* 4, 214-231.

- Donovan,A. (1993). *Antoine Lavoisier: Science, Administration and Revolution.* Oxford, UK: Blackwell.

- Donovan,A. (1990). Lavoisier as Chemist and Experimental Physicist: Reply to Perrin. *Isis,* 81,2,270-272.

- Dubins,L.E.; Savage,L.J. (1965). *How to Gamble If You Must. Inequalities for Stochastic Processes.* New York: McGraw-Hill.

- Duncan,A.M. (1996). *Laws and Order in Eighteenth-Century Chemistry.* Oxford: Clarendon Press.

- Einstein,A. (1905). Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt (On a Heuristic Viewpoint Concerning the Production and Transformation of Light). *Annalen der Physik*, 17, 6, 132-148.

- Eklund,J. (1975). *The Incomplete Chemist: Being an Essay on the Eighteenth-Century Chemist in his Laboratory, with a Dictionary of Obsolete Chemical Terms of the Period.* Smithsonian Studies in History and Technology, 33, 1-49. Washington, DC: Smithsonian Institution Press.

- Enge,H.A.; Wehr,M.R.; Richards,J.A. (1972). *Introduction to Atomic Physics.* New York: Addison-Wesley.

- Feng,Y.; Goldstone,R.L.; Menkov,V. (2004). ABSURDIST II: A Graph Matching Algorithm and its Application to Conceptual System Translation. pp.640-645 at Barr,V.; Markov,A. (2004). 17th FLAIRS Conference. Palo Alto, CA: AAAI Press.

- Feyerabend,P.K. (1999). *Against Method: Outline of an Anarchistic Theory of Knowledge.* London: New Left Books.

- Finetti,B.de (1972). *Probability, Induction and Statistics.* New York: Wiley.

- Finetti,B.de (1974). *Theory of Probability,* V1 and V2. London: Wiley.

- Foerster,H.von (1995). Anthology of Principles Propositions, Theorems, Roadsigns, Definitions, Postulates, Aphorisms, etc. Downloaded on 01/01/2013 from `http://www.cybsoc.org/heinz.htm`

- Foerster,H.von (2003). *Understanding Understanding: Essays on Cybernetics and Cognition.* New York: Springer.

- Fontenelle,B.B.de (1718). Sur les Rapports de Differentes Substances en Chimie. *Histoire de l'Académie Royale des Sciences*, 1718, p.35-37.

- Geoffroy,E.F. (1718). Table des Différents Rapports Observés en Chimie entre Diffrentes Substances. *Mémoires de l'Académie Royale des Sciences*, p.202-212.

- Goldstone,R.; Rogosky,B. (2002). Using Relations within Conceptual Systems to Translate across Conceptual Systems. *Cognition,* 84, 295-320.

- Golinski,J. (1995). The Nicety of Experiments: Precision of Measurement and Precision of Reasoning in Late Eighteenth-Century Chemistry. p.72-91 in M. Norton-Wise (1995). *The Values of Precision.* Princeton Univ.Press.

- Gough,J.B. (1988). Lavoisier and the Fulfillment of the Stahlian Revolution. *Osiris*, 4, 1, 15-33.

- Goupil,M. (1991). *Du Flou au Clair? Histoire de l'Affinité Chimique de Cardan à Prigogine.* Paris: CTHS.

- Guerlac,H. (1961). *Lavoisier - The Crucial Year: The Background and Origin of his First Experiments on Combustion in 1772.* Cornell Univ. Press.

- Guldberg,C.M.; Waage,P. (1867). *Études sur les Affinités Chimiques.* Oslo: Brogger and Christie.

- Hansen,B. (1978). Science and Magic. Ch.15, p.480-506 in D.C.Lindberg, *Science in the Middle Ages.* Univ.of Chicago Press.

- Harnad,S. (1990). The Symbol Grounding Problem. *Physica D*, 42, 335-346.

- Holmes,F.L. (1989). *Eighteenth Century Chemistry As an Investigative Enterprise: Five Lectures Delivered at the International Summer School in History of Science Bologna.* Berkeley Papers in History of Science, Vol. 12. Berkeley, CA: Office for History of Science and Technology.

- Holmes,F.L.; Levere,T.H. (2002). *Instruments and Experimentation in the History of Chemistry.* Cambridge: The MIT Press.

- Ingrao,B.; Israel,G. (1990). *The Invisible Hand. Economic Equilibrium in the History of Science.* Cambridge, MA: The MIT Press.

- Inhasz, R., Stern, J. M. (2010). Emergent Semiotics in Genetic Programming and the Self-Adaptive Semantic Crossover. *Studies in Computational Intelligence*, 314, 381-392.

- Inhelder,B.; Garcia,R.; Vonèche,J. (1976). Epistémologie Génétique et Équilibration. Hommage à Jean Piaget. Neuchâtel, Switzerland: Delachaux et Niestlé.

- James,F.A.J.L. (1983). The Establishment of Spectro-Chemical Analysis as a Practical Method of Qualitative Analysis, 1854-1861. *Ambix,* 30, 1, 32-53.

- Jastrow,J. (1899). The Mind's Eye. *Popular Science Monthly*, 54, 299-312. Reprinted in J.Jastrow (1900). *Fact and Fable in Psychology.* Boston: Houghton Mifflin.

- Jech,Th.J. (1973). *The Axiom of Choice.* Amsterdam: North-Holland.

- Jensen,W.B. (1986). The Development of the Blowpipe Analysis. p.123-149 in Stock,J.T; Orna, M.V. *The History and Preservation of Scientific Instrumentation,* Dordrecht: Reidell.

- Kihlstrom,J.F. (2006). Joseph Jastrow and His Duck - Or Is It a Rabbit? On-line document, University of California at Berkeley. Retrieved September 10, 2014 from
`http://socrates.berkeley.edu/~kihlstrm/JastrowDuck.htm`

- Kirchhoff,G.R. (1860a). Über die Fraunhofer'schen Linien. *Annalen der Physik,* 185, 1, 1860, 148-150. Transl: On Fraunhofer's Lines, *Philosophical Magazine,* 19 (1860), 193-197.

- Kirchhoff,G.R. (1860b). Über das Verhältnis zwischen dem Emissionsvermögen und dem Absorptionsvermögen der Korper fur Wärme und Licht. *Annalen der Physik,* 185, 2, 275-301. Transl: On the Relation Between the Radiating and Absorbing Powers of Different Bodies for Light and Heat. *Philosoph. Magazine,* 20, 1-21.

- Kirchhoff,G.R.; Bunsen,R.W. (1860). Chemische Analyse durch Spectralbeobachtungen. *Annalen der Physik,* 186, 6, 161-189. Translated as: Chemical Analysis by Spectrum-Observations. *Philosophical Magazine,* 22 (1861), 329-249, 498-510.

- Kirchhoff,G.R. (1863). Zur Geschichte der Spectral-Analyse und der Analyse der Sonnenatmosphäre. *Annalen der Physik,* 194, 1, 94-111. Translated as: Contributions Towards the History of Spectrum Analysis and the Analysis of the Solar Atmosphere. *Philosophical Magazine,* 25, 250-262.

- Klein,U. (1996). The Chemical Workshop Tradition and the Experimental Practice: Discontinuities within Continuities. *Science in Context*, 9, 3, 251-287.

- Koirtyohann,S.R. (1980). A History of Atomic Absorption Spectroscopy *Spectrochimica Acta,* 35B, 663-670.

- Krohn,W., Kueppers,G., Nowotny,H. (1990). *Selforganization. Portrait of a Scientific Revolution.* Dordrecht: Kluwer.

- Kuhn,T.S. (2000a). What are scientific revolutions? p.13-32 in Kuhn et al. (2000).

- Kuhn,T.S. (2000b). Commensurability, Comparability, Communicability. p.33-57 in Kuhn et al. (2000).

- Kuhn,T.S.; Conant,J.; Haugelan,J. (2000). *The Road Since Structure.* University of Chicago Press.

- Lavoisier,A.L.de (1772). Memorandum of February 20. Reprinted in Guerlac (1961, p.228-230).

- Lavoisier,A.L.de (1774). Opuscules physiques et chimiques (review). *Histoire de l'Académie Royale des Sciences,* 71-78. Also in Lavoisier (1862). *Oeuvres*, v.2, p.89-96. Paris: Imprimerie Impériale. Lavoisier is identified as the author of this review in *Oeuvres*, v.5 (1892), p.320.

- Lavoisier,A.L.de (1788). Mémoire sur la fermentation spiritueuse. *Histoire de l'Académie Royale des Sciences.* Reprinted in Lavoisier (1865). *Oeuvres.* v.3, p.777-790. Paris: Imprimerie Impériale.

- Lavoisier,A.L.de (1789). *Traité élementaire de chimie, pérsenté dans un ordre nouveau et d'après les découvertes modernes.* Paris: Chez Cuchet. Translation: Kerr,R. (1790). *Elements of Chemistry.*

- Leicester,H.M.; Klickstein,H.S. (1963). *A Source Book in Chemistry, 1400-1900.* Cambridge, MA: Harvard University Press.

- Levere,T.H. (2001). *Transforming Matter: A History of Chemistry from Alchemy to the Buckyball.* Baltimore, MD: The Johns Hopkins University Press.

- Lewowicz,L. (2011). Phlogiston, Lavoisier and the Purloined Referent. *Studies in History and Philosophy of Science,* 42, 436-444.

- Luhmann,N. (1989). *Ecological Communication.* Chicago Univ. Press.

- Madruga,M.; Esteves,L.; Wechsler,S. (2001). On the Bayesianity of Pereira-Stern Tests. *Test*, 10,291–299.

- Mann,N.I.; Dingess,K.A.; Slater,P.J.B. (2006). Antiphonal four-part synchronized chorusing in a Neotropical wren. Biology Letters 2, 1-4.

- Maturana,H.R.; Varela,F.J. (1980). *Autopoiesis and Cognition. The Realization of the Living.* Dordrecht: Reidel.

- McGucken,W. (1969). *Ninteenth Century Spectroscopy. Development of the Understanding of Spectra 1802 - 1897.* Baltimore: Johns Hopkins.

- McMullin,B. (2004). Thirty Years of Computational Autopoiesis: A Review. *Artificial Life*, 10, 3, 277-295.

- McMullin,B.; Varela,F.J. (1997). Rediscovering Computational Autopoiesis. p. 38-47 in Husbands,P.; Harvey, I. *14th European Conference on Artificial Life.* Cambridge, MA: The MIT Press.

- Melhado,E.M. (1985). Physics, and the Chemical Revolution. *Isis,* 76, 2, 195-211.

- Meldrum,A.N. (1930). *The Eighteenth Century Revolution in Science The First Phase.* Calcutta: Longmans, Green and Co.

- Morgenstern,O.; Neumann,J.von (1947). *The Theory of Games and Economic Behavior.* Princeton University Press.

- Morveau, L.B.G.de; Maret, M.; Duhamel, M. (1786). *Encyclopédie Méthodique: Chymie, Pharmacie et Métallurgie.* Paris: Chez Panckoucke. (Entry *Affinité* at v.2, p.535-613) Translated as: Affinity, p.391-405 in *Supplement to the Encyclopaedia or Dictionary of Arts, Sciences and Miscellaneous Literature.* Philadelphia: Thomas Dobson (1803).

- Morveau, L.B.G.de; Lavoisier,A.L.; Berthollet,C.L.; Fourcroy,A. (1787). *Méthode de Nomenclature Chimique.* Paris: Chez Cuchet. Reprinted (1994) w.introduction by B.Bensaude-Vincent. Paris: Ditons du Seuil.

- Muir,P. (1907). *A History of Chemical Theories and Laws.* New York: John Wiley.

- Partington,J.R. (1962). *A History of Chemistry.* London: Mcmillan.

- Pearson,T.H.; Ihde,A.J. (1951). Chemistry and the Spectrum Before Bunsen and Kirchhoff. *Journal of Chemical Education*, 28, 5, 267-271.

- Pereira,C.A.B.; Stern,J.M. (1999). Evidence and Credibility: Full Bayesian Significance Test for Precise Hypotheses. *Entropy Journal*, 1, 69–80.

- Pereira,C.A.B.; Wechsler,S.; Stern,J.M. (2008). Can a Significance Test be Genuinely Bayesian? *Bayesian Analysis,* 3, 1, 79-100.

- Perrin,C.E. (1984). Did Lavoisier report to the Academy of Sciences on his own Book? *Isis,* 75, 343-348.

- Perrin,C.E. (1990). Chemistry as Peer of Physics: A Response to Donovan and Melhado on Lavoisier. *Isis,* 81, 2, 259-270.

- Poirier,J.P. (1993). *Antoine Laurent Lavoisier: 1743-1794.* Paris: Pygmalion

- Rasch,W. (2000). *Niklas Luhmanns Modernity. Paradoxes of Differentiation.* Stanford Univ.Press.

- Richter,J.B. (1792). *Anfangsgründer der Stöchyometrie oder Messkunst chymischer Elemente.* Breslau-Hirschberg: J.F.Korn.

- Rosenberger,F. (1890). *Geschichte der Physik in Grundzügen mit Synchronistichen Tabellen der Mathematik, der Chemie ind Beschreibenden Naturwissenschaften sowie der Allgemeinen Geschichte.* Braunschweig: Friedrich Vieweg.

- Schirrmacher,A. (2003). Experimenting theory: The proofs of Kirchhoffs radiation law before and after Planck. *Historical Studies in the Physical and Biological Sciences*, 33, 2, 299-335.

- Segal,L. (2001). *The Dream of Reality. Heintz von Foerster's Constructivism.* New York: Springer.

- N.Sevcenko (2000). Apresentação ou O Arco-Íris, o Pote de Ouro e o Lago. p.11-14 in W.Weischedel (2000). *A Escada dos Fundos da Filosofia.* São Paulo: Angra.

- Shafer,G.; Vovk,V. (2001). *Probability and Finance, It's Only a Game!* New York: Wiley.

- Shashkin,Yu.A. (1991). *Fixed Points.* Providence, RI: American Mathematical Society.

- Spinoza,B. (1677). *Ethica: Ordine Geometrico Demonstrata.* Reprint (2007) w. Portuguese translation, São Paulo: Autêntica.

- Stern,J.M. (2003). Significance Tests, Belief Calculi, and Burden of Proof in Legal and Scientific Discourse. *Frontiers in Artificial Intelligence and its Applications,* 101, 139–147.

- Stern,J.M. (2004). Paraconsistent Sensitivity Analysis for Bayesian Significance Tests. *Lecture Notes Artificial Intelligence,* 3171, 134–143.

- Stern,J.M. (2007a). Cognitive Constructivism, Eigen-Solutions, and Sharp Statistical Hypotheses. *Cybernetics & Human Knowing*, 14, 1, 9-36.

- Stern,J.M. (2007b). Language and the Self-Reference Paradox. *Cybernetics & Human Knowing*, 14,4,71-92.

- Stern,J.M. (2008a). Decoupling, Sparsity, Randomization, and Objective Bayesian Inference. *Cybernetics & Human Knowing*, 15,2,49-68.

- Stern,J.M. (2008b). *Cognitive Constructivism and the Epistemic Significance of Sharp Statistical Hypotheses.* Tutorial book for MaxEnt 2008, The 28th International Workshop on Bayesian Inference and Maximum Entropy Methods in Science and Engineering. July 6-11 of 2008, Boracéia, São Paulo, Brazil.

- Stern,J.M. (2011a). Constructive Verification, Empirical Induction, and Falibilist Deduction: A Threefold Contrast. *Information*, 2, 635-650

- Stern,J.M. (2011b). Symmetry, Invariance and Ontology in Physics and Statistics. *Symmetry*, 3, 3, 611-635.

- Stern,J.M.; Pereira,C.A.B. (2014). Bayesian Epistemic Values: Focus on Surprise, Measure Probability! *Logic Journal of the IGPL*, 22, 2, 236-254.

- Stern, J.M.; Nakano, F. (2014). Optimization Models for Reaction Networks: Information Divergence, Quadratic Programming and Kirchhoff's Laws. *Axioms*, 3, 109-118. doi:10.3390/axioms3010109

- Stevens,A. (1999). *Ariadne's Clue: A Guide to the Symbols of Humankind.* Princeton Univ.Press.

- Stevens,A.; Price,J. (2000). *Evolutionary Psychiatry: A New Beginning.* London: Routledge.

- Stevens,A. (2003). *Archetype Revisited: An Updated Natural History of the Self.* Toronto: Inner City Books.

- Sutton,M.A. (1976). Spectroscopy and the Chemists: A Neglected Opportunity? *Ambix,* 23, 16-26.

- Szabadváry,F. (1966). *History of Analytical Chemistry.* London: Pergamon Press.

- Szabó,A. (1978). *The Beginnings of Greek Mathematics.* Budapest: Akadémiai Kiadó.

- Tomonaga,S. (1962). *Quantum Mechanics. V.1 Old Quantum Theory; V.2, New quantum theory.* Amsterdam: North Holland.

- Varela,F. (1978). *Principles of Biological Autonomy.* North-Holland.

- Wittgenstein, L. (1953). *Philosophical investigations.* Oxford: Blackwell.

- Zangwill,W.I.; Garcia,C.B. (1981). *Pathways to Solutions, Fixed Points, and Equilibria.* New York: Prentice-Hall.

A Morveau's Affinity Tables and Diagrams

For the reader's convenience, Appendix A presents some examples of Morveau's reaction diagrams and a small affinity table, see Morveau (1786, p.553,558,773), Morveau (1803, p.399-401), and also Goupil (1991, L.II, Ch.V, Sec.4, p.179-189). These examples should make clear how to compute, from the affinity data, quiescent and divellent affinities. If the former are smaller than the latter, the involved displacement (irreversible) reactions are supposed to occur[9]. In order to facilitate the reading of these diagrams, we also provide translations of chemical names and formulas, even though fully aware that successive translations chains like: Vitriol of potash, Sulphat of potash, Potassium sulfate, K_2SO_4; or Mephite of barytes, Carbonate of barytes, Barium carbonate, $BaCO_3$; require non-trivial and consecutive diachronic ontological alignments. The ionic valencies (of today's chemistry) involved in the next reactions are as follows; Cations: Hydrogen, H^{1+}; Potassium, K^{1+}; Ammonium, $(NH_4)^{1+}$; Barium, Ba^{2+}; Calcium, Ca^{2+}; Anions: Hydroxide, $(OH)^{1-}$; Chloride, Cl^{1-}; Nitrate, $(NO_3)^{1-}$; Carbonate, $(CO_3)^{2-}$; Sulfate, $(SO_4)^{2-}$. From these ionic valencies it is easy to set up the following stoichiometric balance equations, dry and wet.

In contrast to the sophisticated calculations based on the numerical values displayed at Morveau's table and its underlying additive structure, Geoffroy's table, see Figure 9, displays pure and simple ranking orders.

Table 1: Guyon de Morveau's Table of Numerical Expression of Affinities

Base/ Acid	Vitriolic	Nitric	Muriatic	Acetic	Mephitic
Barytes	65	62	36	28	14
Potash	62	58	32	26	9
Soda	58	50	31	25	8
Lime	54	44	20	19	12
Ammonia	46	38	14	20	4
Magnesia	50	40	16	17	6
Alumina	40	36	10	15	2

$$\begin{array}{ccccc} & & \underline{\text{Muriate of Potash, KCl}} & & \\ \text{Muriate of} & \left\{ \begin{array}{ccc} \text{Muriat.Ac.} & 32 & \text{Potash} \\ 36 & + & 9\ (=45) \\ \underbrace{\text{Barytes}} & 14\ (=46) & \underbrace{\text{Meph.Ac.}} \end{array} \right\} & \text{Mephite} \\ \text{Barytes,} & & & & \text{of Potash,} \\ BaCl_2 & & \text{Mephite of Barytes, } BaCO_3 & & K_2CO_3 \end{array}$$

$$BaCl_2 + K_2CO_3 \rightarrow 2KCl + BaCO_3\ ,$$
$$[Ba(OH)_2, 2HCl] + [2KOH, H_2CO_3] \rightarrow 2[KOH, HCl] + [Ba(OH)_2, H_2CO_3]\ ;$$
$$\text{Quiescent affinities} = 36 + 9 = 45 < \text{Divellent affinities} = 32 + 14 = 46\ .$$

[9] In contemporary chemistry, divellent and quiescent affinities, also known as forward and reverse chemical affinities, are the absolute values of stoichiometricaly weighted partial sums over products and reactants defining the vector of changes in chemical potential for a reaction network. The words divellent and quiescent are etymologically derived from the Latin verbs *divellere* - to separate, to tear apart - and *quiescere* - to remain quiet, to stay still. This etymological derivation conveys the idea that forward reactions separate the constituent elements of reacting compounds in order to form new products, while reverse reactions regenerate original reactants. For further details, see Stern and Nakano (2014).

$$\underbrace{\text{Vitriol of Potash, } K_2SO_4}$$

$$\begin{array}{ccccc} \text{Sulph.of} & \left\{ \begin{array}{ccc} \text{Vitriol.Ac.} & 62 & \text{Potash} \\ 65 & + & 9\ (=74) \\ \text{Barytes} & 14\ (=76) & \text{Meph.Ac.} \end{array} \right. & \text{Mephite} \\ \text{Barytes,} & & \text{of Potash,} \\ BaSO_4 & & K_2CO_3 \end{array}$$

$$\underbrace{\text{Mephite of Barytes, } BaCO_3}$$

$$BaSO_4 + K_2CO_3 \rightarrow K_2SO_4 + BaCO_3 \ ,$$

$$[Ba(OH)_2, H_2SO_4] + [2KOH, H_2CO_3] \rightarrow [2KOH, H_2SO_4] + [Ba(OH)_2, H_2CO_3] \ ;$$

$$\text{Quiescent affinities} = 65 + 9 = 74 < \text{Divellent affinities} = 62 + 14 = 76 \ .$$

$$\underbrace{\text{Vitriol of Lime, } CaSO_4}$$

$$\begin{array}{ccccc} \text{Sulph.of} & \left\{ \begin{array}{ccc} \text{Vitriol.Ac.} & 54 & \text{Lime} \\ 46 & + & 44\ (=90) \\ \text{Ammonia} & 38\ (=92) & \text{Nitr.Ac.} \end{array} \right. & \text{Nitrate} \\ \text{Ammonia,} & & \text{of Lime,} \\ (NH_4)_2SO_4 & & Ca(NO_3)_2 \end{array}$$

$$\underbrace{\text{Nitrate of Ammonia, } NH_4NO_3}$$

$$(NH_4)_2SO_4 + Ca(NO_3)_2 \rightarrow CaSO_4 + 2NH_4NO_3 \ ,$$

$$[2NH_4OH, H_2SO_4] + [Ca(OH)_2, 2HNO_3] \rightarrow [Ca(OH)_2, H_2SO_4] + [2NH_4OH, 2HNO_3] \ ;$$

$$\text{Quiescent affinities} = 46 + 44 = 90 < \text{Divellent affinities} = 54 + 38 = 92 \ .$$

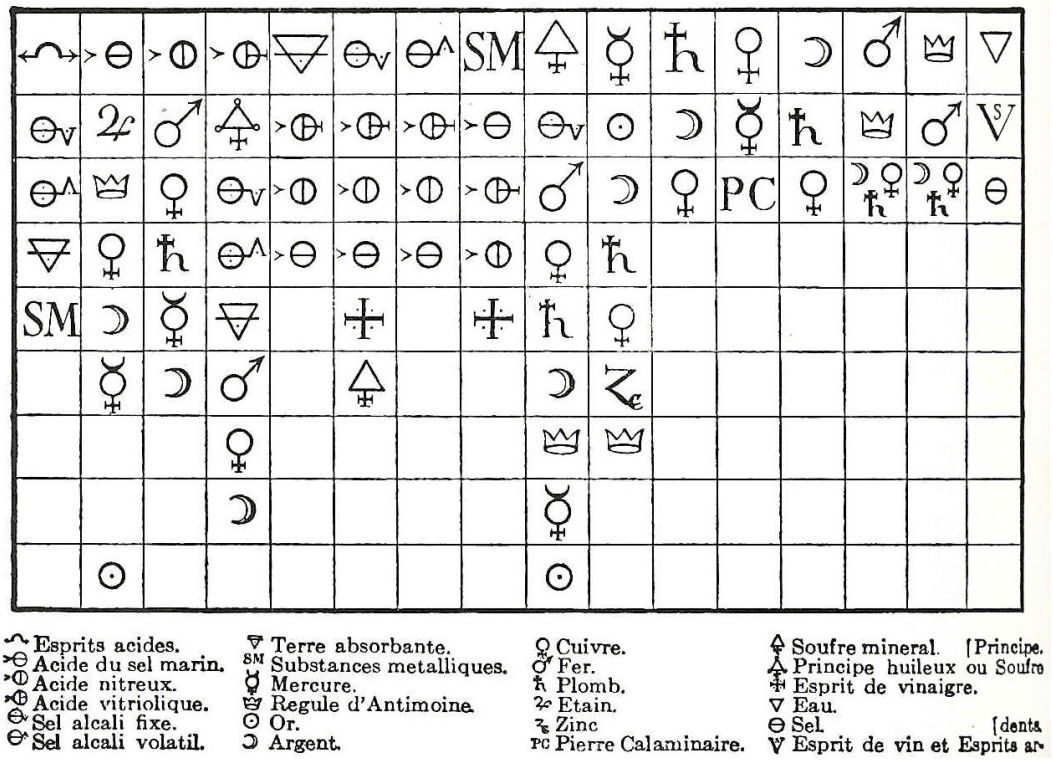


Figure 9: Affinity table by Geoffroy (1718).