Investigating Consistencies, Inconsistencies, and the Meaning of the *Ceteris Paribus* Clause in Chemistry

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ABSTRACT

Chemists do not aim at testing preconceptions or theoretical hypotheses only; they first and foremost produce and determine the object of chemical investigation: they learn through making. They never cease to create and stabilize heterogeneous devices, methods, models, and theories in order to act upon the world. Chemical bodies cannot be studied in isolation; their properties constitutively depend on what surrounds and acts upon them. Starting from the specificity of chemical practices, this paper investigates the meaning of consistency, inconsistency, and that of the *ceteris paribus* clause, in this domain of science. In so doing, it defends the idea that studying what we call 'a lack of consistency' should always include the scrutiny of: (1) the way a particular scientific practice is stabilized, and (2) the ontological or pragmatic assumptions about the entities and processes upon which this practice revolves.

1. Introduction

Cum-sistere, the Latin etymological origin of the word consistency means 'stand together' or 'hang together.' Different experimental outcomes are consistent in experimental sciences if there is 'absence of unacceptable conflicts' between them. Different inferences made from given premises by justification-transmitting rules are consistent if there is no contradiction between them (Nagel 1979). Furthermore, the connections between premises, experimental outcomes, and inferences may include logical entailments and relations of inductive confirmation, i.e., a mutual support structure (Bender 1988).

Inconsistency in experimental sciences thus mainly refers to contradictory inferences or incompatible experimental outcomes made or obtained from the

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use of a particular kind of investigation – a method, a model, or a reasoning – being used in order to study a *phenomenon*. It could also be about contradiction or incompatibility between inferences or experimental outcomes made or obtained when scientists use and try to articulate different methods, models or reasonings, in order to validate their assumptions and to strengthen their knowledge about that *phenomenon* (Bonjour 1985).

The interconnection between science and technology on the one hand, and the interconnection between many sciences within interdisciplinary projects on the other, imply the emergence of a large variety of scientific practices in biology, ecology, toxicology, chemistry, materials sciences, nanotechnologies and biotechnologies, and physics; each having its own way of investigating and acting upon the world. The growing number of highly sophisticated domains of scientific expertise, and the necessity to develop interdisciplinary projects for facing environmental issues, raise the question of the co-existence, and that of the global consistency, of those different modes of investigation and justification. This rising methodological pluralism is a good opportunity for philosophers of science and technology to study the way pluralism is compatible with notions such as consistency and inconsistency, and especially to check if a specific type of pluralism entails a specific understanding of both consistency and its correlative inconsistency toleration, and conversely.

Chemistry, which has always been a science and an industry *at the same time*, is relevant to study such questions. Indeed, laboratory chemical practices do not aim at testing preconceptions or theoretical hypotheses only; chemists first and foremost produce and determine the object of chemical investigation: they learn through making. Theories, in chemistry, are rarely meant at explaining *phenomena* by deriving them from a general law or from quantum physics. This deductive type of explanation conveys no chemical understanding of *phenomena* (Hoffmann 2007). Chemical theories are more like narratives, telling the story of what is supposedly going on in the black box of the flask where a series of reactions take place. To do so, chemists have always been stabilizing multifarious and heterogeneous methods tailored for achieving specific aims. In addition, they often articulate them *pragmatically*, in the sense that the reason for introducing a given substance or mathematical structure into the theoretical framework of chemistry is not some assumed correspondence with an independent reality, but the fact that this substance or this mathematical structure fulfills one or more functions needed for chemists to successfully carry out their work. In short, they serve as *guidance* for the production of new substances a million times per year. Chemistry thus challenges the canons and moral economy of the ideal of science, which has attracted the attention of philosophers for too long (Bensaude-Vincent & Simons 2008).

Our idea in this paper is not to propose a ready-to-use philosophical analysis from the outset but, on the contrary, to identify what a philosophical enquiry should integrate into its premises in order to investigate the meaning of consistency and inconsistency in chemistry. To do so, we will first highlight: (1) the way chemical reactions and bodies are codefined, and (2) the constitutive role of the modes of intervention and the surroundings in the definition, always open and provisional, of chemical bodies. We will then insist on the epistemic limitations of chemistry and on how the methodological pluralism proposed by chemists is a tool for addressing this epistemic situation. Thirdly, we will emphasize that, if chemical discourses refer to active bodies and simultaneous variations of factors to describe and explain each particular action upon matter, the application of the *ceteris paribus* clause is not illusory in chemistry, but implies that we adapt our understanding of what is 'stabilized' within such practices. Last but not least, we will show how this change of the meaning of the *ceteris paribus* clause in chemistry is of interest to understand how consistencies and inconsistensies are integrated into open-ended sets of practices of stabilization.

2. Chemical bodies and chemical reactions

Chemistry as a science is the exploration of possible combinations and reactions between substances. Chemical knowledge is based on the concept of 'pure substances,' both empirical (e.g. production, characterization, and classification) and theoretical (e.g. molecular models). A chemical property of a substance is its ability to change into other substances under certain conditions, and such changes from one substance to another are called 'chemical reactions or transformations.' Chemical reactions between bodies allow chemists to define chemical entities and properties, while operations allow them to obtain pure chemical bodies, or, more exactly, bodies having a *certain degree of purity*, depending on their reactivity and the chemical nature of the surroundings. We should bear in mind that a sample of matter can only be *approximately* purified because of practical limitations of purification procedures and for thermodynamic reasons. Furthermore, the presence of small quantities of impurities can drastically shape and change chemical behavior. As a consequence, chemical purity is not an 'intrinsic' property of matter, but the temporary outcome of sophisticated purification procedures from composites. Those purified bodies then enter into new reactions and result in new compounds that, once purified, enable chemists to widen and deepen their classification by analogy. This process is open-ended and depends upon the modes of intervention used by chemists in specific contexts in order to stabilize a certain group of relations between bodies and their surroundings. In chemistry, *relata* cannot exist prior to reactions, and reactions are not achievable without purifying operations and the presence of already purified chemical bodies. This conclusion does not stem from a logical or a linguistic study of chemical languages or reasoning only, or from an ontological perspective grounded on chemistry, but from a close inquiry about the ways chemists synthesize, purify, stabilize, and use the bodies engaged in their transformation of the world.

The first conclusion to which a close attention to chemists' activities leads is that *chemical relata and relations are constitutively co-defined within chemists' investigative and transformative enterprise: they depend on one another* within an *ordered and evolving network involving chemical bodies and operations* (Llored & Bitbol 2013). As Schummer asserts:

> Chemistry at the core is a science of peculiar relations. Instead of studying isolated objects to be measured, compared and put into a classificatory scheme, dynamic relations between objects constitute the basic set of chemical knowledge, and, at the same time, provide the grounds for the classification of the objects themselves. [...] The resulting classification has turned out to be again a network structure, with substance as nodes and chemical class relation as connections. (Schummer 1998, p. 131, and p.157)

The way molecules and materials are obtained and defined, and the way they act upon other bodies, cannot be captured and addressed by referring either to an ontology of pure *relata*, or to another using relations only. Chemical grammars require *relata* and reactions-relations at the same time, and often use both of them in a pragmatic manner within the same discourse in order to keep on developing new ways of doing chemistry. At this stage of our paper, we would like to underline how a chemical body is characterized before entering into more details about consistencies and inconsistencies in chemistry.

3. Composition, structure, *and* operations

Identifying the structure and the composition of a body is *a* way to characterize it.

Since the 19th century organic chemists have developed classical chemical structure theory that assigns to each compound a molecular structure, based on its elemental composition and chemical reaction properties. According to this theoretical approach, a molecular structure does not correspond to the arrangement of atoms in space only, but to that of 'functional groups,' for instance the group 'OH' for alcohols, that represent the substance's chemical reactivities, which, in turn, are modelled by a growing set of standardized reaction mechanisms. This theory provides explanations and predictions of chemical properties, and enables chemists to foresee and carry out new chemical synthesis of hitherto unknown compounds (Schummer 2014). Tens of millions of new compounds have been predicted and synthesized by that approach. In contrast, quantum chemical modelling of molecular structure provides a unique approach to the explanation and prediction of electromagnetic and many thermodynamic properties, but is still rather poor regarding chemical transformations (Llored 2012). For instance, no one could have been able to predict that chlorofluorocarbons (CFCs), such as chlorodifluoromethane, could cause ozone depletion from the basic knowledge of its composition, structure, and from what she/he already knew about all already stabilized reactions involving this kind of body at that time.

Chemistry is not about explanations and predictions only. Instead, theoretical concepts are also developed and judged according to their potential for synthesis, a major activity of chemists for various, mostly nontechnological, ends (Schummer 1997, 2004). From the beginning of chemistry, chemists always have to face the impossibility to predict a wide range of reactions from composition and structure. To face this situation, Eighteenth-century chemists – and current nanochemists as well – define a body by means of the attributes that it can display, in a precise context, against other bodies, and also by means of the operations involved to individuate it. Following this line of defining bodies, the French chemist and apothecary, Guillaume François Rouelle, for instance asserted that

> [c]hemistry is a physical art which, by means of certain operations and instruments, teaches us to separate the various substances which enter into the composition of bodies, and to recombine these again, either to reproduce the former bodies, or to form new ones from them (Eklund 1975, p. 2)

In the same vain, describing the third column of his "Table des rapports", Venel asserted that

> One applies mercury to a silver dissolution in nitrous acid; this substance having more

> relation with this acid, than this acid has with silver, it unites to it and precipitates silver. If one decants the liquor one will have separated silver, and on the other side mercury dissolution in nitrous acid, if one adds a lead blade to this mercury dissolution, lead has more relation with nitrous acid than mercury, it unites it and precipitates mercury. If one decants it the precipitated mercury remains on one side and on the other side a lead dissolution in nitrous acid; if one adds a copper blade to this dissolution, copper has more relation with nitrous acid and unites to it, lead will be precipitated too and there remains a copper dissolution in nitrous acid; if one adds iron copper is precipitated, if one separates as must always be done, one will have the iron dissolution. (Venel quoted and translated by Lehman 2010, p. 21)

At this period, the word chemical 'operation' was used to mean what we currently call a chemical 'reaction' (Holmes 1996). Notwithstanding the various change of nomenclature that occurred from this period to current chemistry and nanochemistry, instead of studying isolated bodies to be measured, compared and put into a classificatory scheme, dynamic operations against bodies or reaction between them have always constituted the basic set of chemical knowledge, and, at the same time, provide the grounds for the classification of the bodies themselves, as it is the case, for example, for defining scales of acidity in particular solvents. This situation reminds us Peirce's definition of lithium:

> If you look into a textbook of chemistry for a definition of *lithium*, you may be told that it is that element whose atomic weight is 7 very nearly. But if the author has a more logical mind he will tell you that if you search among minerals that are vitreous, translucent, gray or white, very hard, brittle, and insoluble, for one which imparts a crimson tinge to an unluminous flame, this mineral being triturated with lime or witherite rats-bane, and then fused, can be partly dissolved in muriatic acid; and if this solution be evaporated, and the residue be extracted with sulphuric acid, and duly purified, it can be converted by ordinary methods into a chloride, which being obtained in the solid state, fused, and electrolyzed with half a dozen powerful cells, will yield a globule of a pinkish silvery metal that will float on gasolene; [then] the material of *that* is a specimen of lithium. (Peirce, 1931-1958, CP 2.330)[1]

Peirce confidently endorses the idea that lithium can be defined as a set of instructions aimed at permitting not only the identification but also the production of a specimen of lithium. This definition is clearly *provisional* so that the word 'lithium' will acquire new meanings as we learn more about the stuff to which it refers,

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[1] Peirce's use of italics.

using new contexts of chemical operation or new types of chemical bodies. Knowing that something is a chemical substance means knowing *certain* observable effects of *certain* ways of acting upon it. This situation cannot but evolve over time. What water is today for chemists does not correspond to what it was in the past (Chang 2012). Whatever may be the chemical body under investigation, new instruments and new empirical conditions enable chemists to stabilize new substances and properties. The definition of a chemical body is thus always, at least partly, operative. When referring to a chemical substance using everyday language (e.g., "carbon dioxide"), or a chemical formula (e.g., CO_2) and its correlative structure, chemists are implicitly referring to a set of properties. In this respect, a chemical substance concisely embodies the knowledge chemists have of the observable effects likely to occur when they produce or act upon the substance *at a particular time of the history of chemistry.*

The second conclusion to which a close attention to chemists' activities leads is that *chemical explanation requires structure, composition, and operations-reactions in order to be successful in analyzing and synthesizing new bodies.* Depending on the period and the practice at stake, those three basic notions have a pragmatic meaning for chemists, in the sense that the pragmatic meaning of a term is the set of practical effects that can be deduced from it, by all the members of a community, when this term is used in a certain context (Bächtold 2008). In chemistry, the practical effects mainly refer to what chemists observe as a consequence of their operations in the laboratories. For most chemists, those three notions are tools for action only. At this stage of our paper, we would like to further insist on the dependence of chemical bodies and properties on the 'milieu' within which they are present.

4. Context-dependence of chemicals and the role of associated milieux

Talking about the provisional definition of any chemical body, the historian of chemistry Ursula Klein says that

> [t]he example of early nineteenth-century organic chemistry demonstrates that chemists' new definition and identification of organic substances was entwined with new ways of material production and individuation of these things. The nineteenth-century culture of organic chemistry material production and individuation, and the instruments, skills and connoisseurship involved in these activities, were as much a part of the constitution of the objects of inquiries as theories, beliefs, social interests, and power. (Klein 2008, p. 42)

In a footnote (p. 42), she even adds "I consider experimental production and individuation of objects to be part of their 'constitution'." This statement increasingly gains relevance as chemists explore the world, using new bodies, instruments, explanations, and models. The material production and individuation of bodies has enormously expanded in current nanochemistry, solid-state chemistry and materials science. New instrumentation and chemical devices enable chemists to explore temporal and spatial scales which have been completely unreachable until now. Chemists have gained an enlarged capacity to synthesize, scrutinize, and modify particle size and distribution, crystal structure, chemical composition, surface area, surface chemistry, surface charge, porosity, and interfaces. A 'science of individuals or particulars' arises and chemists are now able to generate and study multifarious details at the individual level (Llored 2013). All those achievements are not solely a question of ingredients, quantities, and structure. They also depend on the devices and the instruments involved, i.e., on the context in which chemical synthesis are carried out. For instance, the same ingredients, used in the same quantity, but using different acid solutions, do not bring the same chemical individual ZnO:

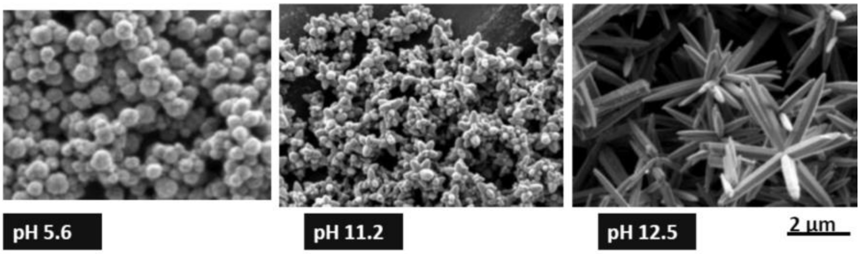

Figure 1
Polymer-assisted precipitation of ZnO nanoparticles with narrow particle size distribution. A. Aimable, M. T. Buscaglia, V. Buscaglia, P. Bowen, Journal of the European Ceramic Society, 30, (2010), 591-598. Anne Aimable's courtesy.

Let us take the example of the synthesis of a solid sample of $CaCO_3$ in order to highlight the role played by the contexts both in the synthesis and the definition of a chemical body. Starting from different contexts, particles will grow to attain different final sizes and morphologies (Aimable *et al.* 2013). Thus, the end product may appear completely different, depending on whether a reactive material is added all at once or gradually. By adding a small amount of fine material to be precipitated (i.e., seeds), one can better control the apparently chaotic nucleation step. For example, adding calcite seeds allows for the precipitation of pure calcite. On the other hand, without seeds, one obtains a mixture of calcite and vaterite – two bodies having the same formula $CaCO_3$ – with a larger particle size distribution and various morphologies. The body $CaCO_3$ depends on the process used and on the time employed. This body is furthermore distributed or size-dispersed in the sense that the sample does not contain a single body $CaCO_3$ but, on the contrary, encompasses many similar bodies $CaCO_3$ which differ in size. *Neither the device nor the history of the chemical reaction can be eliminated from the final result: they take thus part of the definition of the 'nanobody' under study.*

The mode of access to this body, that is to say the way chemists synthesize it, cannot be eliminated from the final product insofar as it contributes to the very determination of the whole body and its correlative parts and structure. The structure of the crystals may also differ if the chemical device changes. It can even differ within the same particular chemical device, depending on the size of the crystals, which itself depends on what surrounds the body in process of individuation. In a nutshell, the internal arrangement can be grain-size sensitive. *Chemical operations and the other chemical bodies which surrounds the body at stake during the ongoing synthesis do not 'reveal' pre-existing chemicals but, on the contrary, actively take part in their very constitution.* Conversely, the body takes part in the redefinition and the chemical reactivity of what surrounds it. As a result, it seems difficult to define a body at the nanoscale, or a collection of bodies at a wider scale, and the 'properties' related to them at those scales, by abstracting those bodies from other bodies or external conditions and operations required for obtaining and stabilizing them.

It is not meant, of course, that it is impossible for a chemist, or a philosopher, to describe chemical bodies using their composition and their internal structure only, as if they were in isolation, and as if they were displaying intrinsic properties or dispositions only. Up to a certain point, this strategy could even turn out to be a very efficient heuristic way to produce new bodies, or to explain a certain type of reactivity during a chemical reaction. We cannot but acknowledge that such descriptions have often been used by chemists in order, for instance, to correlate the structure of a body and its chemical reactivity and properties against a biological target. But composition, that is to say, what a particular body contains, and the internal structure of a molecule or a material, can change depending on the solvent and the whole context, as it has been known for a long time by chemists in the case, for instance, of acid or oxidative properties. As a consequence, such 'intrinsicalness' and 'being in isolation' can play, at best, a *functional role* in a particular scientific practice, but no more, if one takes the way chemists actually work into account.

In order to insist on the fact that the surroundings and the context in which the body is synthesized are not just a spectator, a place detachable from the body under study, but are, by contrast, an active element of its constitution, we would like to refer to the concept of 'associated milieu' coined by the French philosopher of Technology, Gilbert Simondon (1964). For Simondon, the expression "associated milieu" should not be understood as something already given, but rather as that complement of the individual that is brought into being by processes of individuation. In our case, the individual in progress is not a living body, or a technical object, but a chemical body. Bodies consist in a provisional unity of doings in particular "associated milieux". They achieve their individuality through the *modus operandi* of their actions upon other bodies, and through the action of other bodies upon them. Things are constituted out of the flow reactions and purification procedures; and substantiality is subordinate to activity. Things are simply what they do, or what they can do, in particular associated milieux.

Furthermore, as we have just shown, chemists have recently learnt that composition and internal structure can also depend on the chemical device used in nanochemistry. Knowing all the ingredients, the components of a body and their relative position from one another in space, and computing them, do not enable quantum chemists to deduce and forecast *all* the possible reactions and properties of a body within a *single* calculation, but only *a* molecular geometry, *an* energy threshold, or *a* particular kinetic or thermodynamic attribute of the reaction, using a host of heterogeneous models. What chemists know about bodies, using experiments or modellings, is provisional and incomplete. It is the *articulation* between multifarious and, sometimes, heterogeneous practices, that is to say the provisional outcome of what Schummer (2014) calls a *methodological kind of pluralism* that enables chemist to widen the scope of their knowledge and know-how. Chemists need structure and composition, and the modelling of the chemical "associated milieu" as well, in order to perform calculations, or to carry out an experiment to identify a new property, or a new type of reactivity (Llored 2010, 2012, 2014). *Chemists have contrived specific methods within which the whole at stake (a molecule or a* *material for instance) and its parts are constitutively co-defined in the presence of an associated milieu.* Structure and composition are often sufficient to practice chemistry, but not always, in particular in nanochemistry or within research projects undertaken at the frontier with materials science where the 'milieu' of reaction becomes metastable or unstable. *Sooner or later, depending on the investigation at stake, and the finer-grained description required within a particular research, the need to refer to a wider network including bodies, instruments, operations, and milieux within which the body under study gets is provisional significance and relevance, will become inescapable.*

The third conclusion we draw from the scrutiny of chemical practices is relative to *the constitutive role of the associated milieux in the definition, always open and provisional, of 'active' chemical bodies.* We would like to insist on the fact that chemists tailor *networks of interdependencies* within which chemical bodies and properties are 'milieu-dependent' and mutually determine by means of particular chemical operations or transformations. Let us now draw epistemic conclusions before investigating consistencies and inconsistencies in chemistry.

5. Epistemic limitations of chemistry and *methodological pluralism*

According to Schummer:

> [P]erfect purity is a conceptual ideal that can never be fully reached in practice. Thus, any real substance as an object of experimental investigation contains impurities, whereas any conceptual description needs to assume perfect purity or a well-defined mixture of pure substances. Because even very small amounts of impurities can drastically change chemical properties, through catalytic activity, there is always the risk that the gap between concepts and objects leads to misconceptions and wrong conclusions. On the other hand, because chemists know well about the problem, they can take particular care about possible impurities that they assume are relevant in each case. Secondly, and more importantly, the pure substances that chemists produce and put in bottles for chemical investigations do not exist outside the laboratory. Instead, the materials outside the laboratory are messy and mostly under continuous flux and interaction with its environment and hardly a perfect homogeneous mixture. The problem is not to describe all that; rather the problem is that any accurate description of material phenomena outside the laboratory turns into

> an endless list of facts. Moreover, if a mixture contains more than five or ten substances, the theoretical reasoning of chemistry fails because of over-complexity. Hence, the conceptual framework of chemistry is not very suitable to describe the real material world, but still it is the best we have for that purpose. The way chemists deal with such real world issues is, again, by making assumption about what is relevant and what not by focusing on specific questions for which the relevance of factors can be estimated or control. (Schummer 2010, p. 169-70)

As a consequence, our knowledge about material properties will always remain incomplete. Science does not create knowledge only. It also transforms the world and produces 'the unknown.' Chemical bodies are milieu-dependent; the ways they act upon the world always depend on associated milieux. Chemical bodies, as we have pointed it out, are mutually defined within a network including operations, instruments, transformations, and other purified bodies or mixtures: they are not simply totally predictable by considering the body in isolation. Their dependence to the associated milieu explains why chemistry is, by nature, an incomplete knowledge. Schummer asserts:

> With every production of a new substance, the scope of non-knowledge increases tremendously, by the number of undetermined properties of the new substance as well as by all chemical reactivities of the already existing substances with the new one. (Schummer 2001, p. 110)

In the same line, Godard states that

> Another feature of chemistry as a science is that it produces new substances and not only knowledge of the existing material world. New substances introduce new properties that are difficult to anticipate, with possible consequences that are difficult to fully comprehend... Due to the massive number of new chemical substances that are being introduced into ecosystems, this creative process entails an increasing unpredictability of environmental changes. The creation of a new substance and putting it on the market generates a new unpredictable potential for harming the environment and public health, increasing the difficulties associated with the control of these harms. This is a legitimate source of concern: Chemistry is a major factor in making our world unpredictable. (Godard 2013, p. 87)

To face this situation, chemists thus have to distinguish between relevant and irrelevant facts; which, in turn, requires pragmatic perspectives to decide what is important in each case, rather than an absolute point of view from nowhere. Pragmatic perspectives, we will show it in the next section, can be flexibly varied and multiplied through new relevance aspects, new problems, and new methods. This is the reason why, according to Schummer (2010, 2014), methodological pluralism, i.e., the claim that the more methods and theories we have, the better is our knowledge of the world, allows flexibly dealing with complexity by splitting up approaches according to what matters. This is typically what chemists have always been doing using a pluralism of methods in a pragmatic way. In line with Bachelard (1932, 1940) who stated that each interesting problem, each experiment, or even each equation, requires a philosophical reflection of its own, Schummer highlights that in order for chemists to circumvent the incompleteness of their knowledge, the quality of a chemical model is not judged by standards of truth and universality but, instead, by its usefulness and the precision by which its scope of applications is limited. If, as Dewey asserts (1938, p. 129): "A chemical substance is represented not by enumeration of qualities as such, but by a formula which provides a synoptic indication of the various types of consequences that will result," we should nevertheless bear in mind that the synoptic indication in question here is always restricted: knowing chemical properties does not enable chemists to anticipate *all* the possible observable *consequences* issued from the operations made on the substance under study. It is now time to investigate how all the point we have stressed so far can be of help for reflecting upon consistency and inconsistency in experimental sciences.

6. *Ceteris paribus* clause, consistency, and inconsistency, in chemistry

The way we define inconsistency depends upon a certain theory of knowledge, and upon ontological commitments. If we consider that the way we intervene upon a body, by means of instruments or by using other chemical bodies, just reveals its reality and its intrinsic properties, inconsistency in scientific results and explanations can, for instance, be related to: (1) the uncertainty of measure, (2) a mistake done in the way the experiment has been processed, or (3) the presence of contradictions or of unacceptable divergences between inferences drawn from a set of assumptions about this body.

But, if the properties of bodies are, even partly, constituted by the mode of access, for example by an instrument, within a chemical transformation, and turn out to be milieu-dependent, it seems that the sentence "all other things being equal", which enables us to decide if different explanations or experimental outcomes are consistent or not, should be understood in a specific way. As the matter of fact, in the framework of both milieu-dependence and active bodies, a bearer of an attribute does not necessarily have an 'identity' independent of that attribute throughout the transformation involved (Harré & Llored 2013). So, the first thing we have to do in our case is to check if the status and the meaning of the *ceteris paribus* clause remain the same in chemistry.

It is impossible to abstract the body from the operative framework in which it is stored or used. Accordingly, the practice of inserting a *ceteris paribus* clause cannot deal with any particular reaction of the same body *in all circumstances* but is, by contrast, primarily concerned with what we shall call the couple {bodies-associated milieu}. The associated milieu can be, among many other possibilities, a solvent or a mixture of solvents, a gas vector, a mineral matrix, i.e., the substrate in which the molecules to be characterized and titrated are located (e.g. biological fluid, vegetable matter, etc.). Only one parameter must vary in order to characterize the chemical behavior of this couple in relation to the qualification "all things being equal." In this respect, the use of the clause does not permit any nomological implication in connection with the intrinsic properties of bodies. The conclusion of chemical reasoning is about the couple {chemical bodies-associated milieu} under study. Both relations and *relata* are thus taken into account at the same time, in accordance with the first conclusion previously drawn.

We have now to include the instrumentation that enables chemists to quantify their products in our investigation. We cannot consider the mode of access apparatus as a transparent window through which to see the world as it would have existed had the mode of access never been constructed and switched on, in accordance with the second conclusion drawn from our scrutiny of chemical practices. The central problem is that of the co-stabilization of an apparatus with the set of bodies with which it interacts; a problem which includes various acts of modelling as part of the global project. It is the whole complex composed by the apparatus, the methods carried out for calibrating and using it, the bodies, the associated milieu, and the ancillary devices which should be the starting point of our epistemological enquiry (Llored 2015). To investigate the meaning of the *ceteris paribus* clause in chemistry requires an investigation of the conclusions that chemists can relevantly draw from comparisons with reference to the complex {apparatus-methods-bodies-associated milieu-devices}. Following this line of arguments, despite the fact that many factors do not cease to change during a chemical transformation or a chromatographic analysis – for instance the mixture of bodies is gradually separated, the polarity of solvents is modulated, the flow rate can evolve as well as the temperature, and so on – one thing must remain the same inside strict boundaries: the concentration of the bodies under study. In this context, the *ceteris paribus* clause is about the possibility for a particular determination of a quantity to belong to a very short *confidence interval*, notwithstanding all the fluctuations which continue to occur. This result is relative to the complex {apparatus-methods-bodies-associated milieu-devices} at stake (Llored 2015).

The method of analysis is not used in the same way if the triad composed by the apparatus, the bodies, and the associated milieu has changed. In this context of activity, methods can never be blandly detached from the content it yields. The association between the apparatus and the method depends on the associated milieu, the device, and the bodies under study. The five elements of the complex are co-adapted to one another. If chemists change a factor, for example a type of column, the mode of injection of the solvents, the quantity of product, the matrix from which it is originated, the preparation of the sample, the detector, among other possibilities, they will have to resume the process of co-adaptation from the very beginning because the complex does not work anymore. In short, chemists must stabilize a specific domain of application of the whole complex in order to determine a quantity of a particular type of body within certain limits imposed by standards of normalization and laws. The sentence "all things being equal" encompasses the co-adaptation and the channelling of multifarious fluctuations which, in turn, leads to the very possibility of making holistic inferences as regards the performance of the whole complex within the normative framework of a quality control process. Consistency and inconsistency are about different measures or inferences taken or drawn from this whole complex. A result or an inference must fit into the complex; and the performance of the complex is more or less justified depending on how well it hangs together as a whole for achieving its particular goal. The density of such interconnections contributes to the consistency of the empirical outcomes, and to that of the inferences, obtained or made from the complex at stake. *A relational consistency thus stems from a practice of stabilization.*

This situation depends on the precision of the outcomes. Because precision is sensitive to the way it is determined some specific types of precision should be distinguished. *Reproducibility* is the measure of agreement between results obtained with the same method on identical test or reference material under different conditions, executions by different persons, in different laboratories, with different equipments and at different times. The measure of reproducibility is the standard deviation of these results. *Repeatability* is the measure of agreement between results obtained with the same method on identical test or reference material under the same conditions, the job done by one person, in the same laboratory, with the same equipments, at the same time or with only a short time interval. Repeatability corresponds to the *ceteris paribus* clause as it is usually defined by logicians in domains different from chemistry. Chemists then resort to the study of *the within-laboratory reproducibility* which is the agreement between results obtained with the same method on identical test material under different conditions, execution by different persons, with the same or different equipments, in the same laboratory, at different times. This is a more realistic type of precision for a method over a longer span of time when conditions are more variable than defined for repeatability. Last but not least along this non-exhaustive list, they have to ensure the *robustness/ruggedness* of an analytical procedure which is defined as the measure of its capacity to remain unaffected by small, but deliberate variations in method parameters and provides an indication of its reliability during normal usage. Each step of the co-stabilization of the whole complex reveals a certain amount of repetitions and holds a wide range of multifarious tools together.

It is the complex made of methods, apparatus, devices, associated milieu, and bodies under studies, which enables chemists *to validate right inferences or results* and to adapt the whole procedure in case inconsistencies, be they inconsistent quantitative outcomes or inferences. Consistency and inconsistency are about the inferences and results originated from this complex. What can be accepted and what must be rejected or considered to be inconsistent, depend upon cumulative work experience of the community of chemists at stake, and upon confidence intervals which characterize the confidence or the credibility which can be ascribed to the result of a particular quantitative determination. Confidence intervals consist of a range of values that act as good estimates of the unknown population parameter. However, it is not unusual that none of these values covers the value of the concentration that must be quantified. A level of confidence of the confidence interval is thus chosen using chemical knowledge and know-how which are already at the disposal of chemists. This level of confidence indicates the probability with which the confidence range captures the 'true' value of the quantity under consideration. This interval is calculated from the standard deviation characterizing the dispersion of the operational process, i.e., thanks to the statistical modelling of sets of data. Is there any connection between pluralism of methods and inconsistency toleration? Does a specific type of pluralism, such as the one involved by the stabilization of the aforementioned complex, entails specific type of inconsistency toleration commitments? The reply is positive because intervals and levels of confidence depend upon the specific knowledge and know-how which have been gradually stabilized in a particular field of practice. They differ according to the kinds of body, instruments, methods, and goals at stake. Chemists often use different complexes in order to quantify the same amount of pollutant or to characterize particular properties of a chemical body or of a mixture of bodies. They have to recourse to inter-comparison between the results originated from each complex in order to study their compatibility inside relevant confidence intervals. They look for agreement or disagreement between independent, unrelated complexes, that is to say, for consilience (Whewell 1840).

For instance, if from comparisons between atmospheric measurements of the spatial distribution of the pollutants and modelling work, significant discrepancies are recurrently detected, the ensuing question would be: what is wrong? Is it the measurement or the modelling work? Before concluding that the knowledge of the stratospheric chemistry needs improvements, chemists must re-examine the whole data analysis process. This work needs coordination between the teams who operate the instruments in the atmosphere and the laboratory scientists. Finally, if the discrepancies are confirmed, one could conclude that our knowledge of the stratospheric chemistry is partly erroneous. Then, the chemical reaction rate constants must be re-analysed in the laboratory and some new channels for production/destruction of the pollutants must be searched for. It must be noticed that other important parameters, as computation of transport (in other words "atmospheric dynamics") of pollutants in the modelling works, could be re-analysed and improved. Nevertheless, artificial detections from atmospheric observations are still possible (Berthet & Renard 2013). The investigation thus reaches another level of interrelated tools. In this case, inconsistencies are about the impossibility to articulate different results or to gain a global consistency from the inferences stemming from each complex, its correlative assumptions, and its models. Chemistry is about this kind of difficult work: stabilizing articulations between heterogeneous methods, knowledge, and know-how, while interacting with a specific associated milieu.

7. Conclusion: Provisional and open-ended process of co-stabilization

In chemistry, the *ceteris paribus* clause gets a *pragmatic meaning* related to the result of an analysis stemming from a prepared complex. The clause ceases to be a premise or a metaprinciple which would be available independently of the situation. Rather, it acquires the epistemological status of *a result* of a long series of articulations and stabilizations; a result which, once obtained, makes it possible for chemists to validate or not to validate the quantification whenever all but the quantity of the body under investigation is channelled by co-stabilization. The clause gets its meaning within the provisional and open-ended process of co-stabilization of bodies, instruments, and methods; knowing that each step reveals decisions related to what chemists already know and to what they have to do.

The clause is thus a goal to reach and not a starting point from which inferences can be drawn. It plays an important heuristic function in guiding and developing research. In this respect, it has practical consequences for the way chemists work in the sense that the goal to reach, i.e., having "all other things being equal", has implications for what the whole process of stabilization will or should be, and thus for what consitency and inconsistency are or should be within this process. The *ceteris paribus* clause thus gets a meaning in chemical metrology, but this meaning is different from that used in logic or within the framework of the deductive and nomological reasoning proposed by Hempel (1966). It has been transformed and not simply transposed from a particular sphere of scientific activity or human inference to another.

Putnam has shown that neither concepts nor the most basic categories are unique, unavoidable or absolute: “The logical primitives themselves, and in particular the notions of object and existence, have a multitude of different uses rather than one absolute “meaning”. (Putnam 1987, p. 19) We claim that it is the same situation for allegedly cross-context premises, postulates, and clauses. As a matter of fact, the meaning of a clause or a premise can indeed be transformed depending on the scientific domain involved insofar as many principles, assumptions, theoretical tools, complexes in the sense that we previously defined, and the axioms that it encompasses, are themselves transformed, and take another semantic, operative, and technological meaning. We should take the couple {scientific and technological preparation-ontological assumptions associated to them} into account in order to investigate human inferences, and not exclusively scientific languages, logics, or apparatus. This is why, what we call a lack of consistency should always be investigated by considering both the way a particular scientific practice is stabilized, and the ontological assumptions and commitments about the entities and processes under study upon which this particular scientific practice revolves.

Both the complex {apparatus-methods-bodies-associated milieu-devices} and the group of chemists charged with the validation of the result of the sample analysis co-emerge from the stabilization procedure. The final complex, the quantification itself, the group of chemists guided by these standards, chemical knowledge and know-how can only be defined and described together, despite the presence of standards and formal rules which guide the action rather rigidly from the outset. It is the whole complex and its associated group of chemists that change and become a condition of possibility of the study of future variations. Once the co-stabilization is reached, the truth of the studied variation is validated with a certain degree of confidence. This story is not about the ‘dissolution’ of Truth but, by contrast, deals with the ‘co-constitution’’ of the subject-object polarity in a particular field of scientific practice from within the world and interacting with it. “It is not the variation of Truth with the subject, but the condition under which appears to the subject the truth of a variation.” (Deleuze 1988, p. 27)

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