

Chapter 2

Breaking the Arrows of Causality: The Idea of Catalysis in its Making

Jaan Valsiner

Life ... becomes a chemical symphony based on the simple melodic line of water, and is worked out in relation to carbon, nitrogen, phosphorus, sulfur, iron, sodium, potassium, calcium, and traces of other elements, but the greatest of these components is the water. As in great musical masterpieces only the initiated can fully appreciate the achievement of the master, so here the initiated alone can only appreciate the versatility and the amazing chemical beauty of this creation. Viewed in this way water is the music, the carbon compounds and colloids are the instruments, *the catalysts of the various changes produced are the players*, and the whole is possible because the qualities of the energy fields that correspond to the air of the room in which the “orchestra” plays. Sometimes the “performance” goes awry, owing to anomalies in one or more of the above and we have pathology and even death. Who can say then whether the music, the instruments, the players, or the “energy field” is the most important in the “ensemble” known as life?

Witzemann 1943, p. 178 (added emphasis)

Immanuel Kant was brutal. His verdict about two parallel sciences—dealing with compounds of different kinds—was negative. Kant believed that psychology and chemistry, cannot become sciences since they cannot be mathematical. The godly role of mathematics haunted the secularizing sciences in the eighteenth century. Not mathematical—not science!

Looking back, we can see that Kant was half-right: psychology has proven unable to become science, as it has failed to reach generalizations of the level of abstraction, characteristic of mathematics. Despite—or maybe because—its dedication to statistics—and the General Linear Model—psychology remains pseudo-empirical (Smedslund 1997, 2009) and theory-phobic. One can observe recurrent unhappiness by psychologists with such sad state of affairs in their discipline. That takes the form of active denial (“we are science, after all!”) or equally active lament. Neither solves the problem.

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However, Kant was quite wrong in his characterization of the other science—chemistry—that according to him was also doomed to the fate of being nonscience. While being similar in their epistemological credos in Kant’s time (1780s), chemistry became a respectable science in the nineteenth century (1830s–1870s), while psychology became a hostage to the ideological war between *Naturwissenschaften* and *Geisteswissenschaften* (Valsiner 2012). How could chemistry do what psychology has failed to accomplish?

By trying to answer this question, I here admittedly position myself on the side of those chemists who considered history and philosophy of their discipline relevant (such as Humphrey Davy) (Abbri 1994), and in clear opposition to the founders of contemporary chemistry who—Lavoisier and Berzelius in the lead—denied the value of history of science for progression of ideas toward the future. Here, I enter into the history of ideas in chemistry to find out which of the intellectual turns these ideas took in chemistry—and have failed to take in psychology—could be borrowed for the latter discipline. History matters—both for understanding the past and producing the future.

What Went Right for Chemistry?

Many things did. Lavoisier’s *Traité élémentaire de chimie* (1789) set up the basic scientific revolution in the discipline that by early 1800s had escalated its empirical productivity by a manifold. But empirical proliferation does not guarantee breakthroughs in ideas. Fortunately, the philosophical intellectual context in chemistry—mostly dominated by promoters and opponents of German *Naturphilosophie*—provided a fertile ground for invention of corresponding abstractions. The basic concept of polarity and the presumption of the unitary phenomenon consisting of opposites which may be in tension—are all stable notions for chemistry that have roots in *Naturphilosophie*.

By the 1830s chemistry reached the stage of formalization of its language, and by 1870s—with the gradual acceptance of Mendeleev’s Periodicity Table—reached a solution to the “induction or deduction problem” of scientific inference in the form of *uniting* the inductive and deductive parts of science. Instead of conflict between empirically observed (and inductively generalized) practices of “empirical science” and that of “top-down” axiomatically driven (and hence always suspect to the discipline’s alchemical past), the post-Mendeleev’s chemistry was a new science of theoretically oriented and empirically tested knowledge of the potential transformations of known chemical compounds into new, not yet known, ones. Chemistry became the map of principles and of their possible combinations (Abbri 1994, p. 38). And such combinations take time—chemistry is a science where sequence of ongoing reactions, and their subcomponents, is taken as a primary target for investigation. An outcome of a chemical reaction can be explained only by unveiling the sequence of intermediate reaction chains that lead to such outcome.

In some ways, this focus maps on the developmental perspective in psychology—before the final act of a developmental innovation occurs, there exists a series of time-bound events that leads up to it. Yet, there is a difference—in chemistry each of these reactions constitutes a unity of binding and unbinding—the relationships between reagents are crucial for the arrival at the final product. In developmental psychology, however, where the notion of binding is not a theoretical core concept, such intermediate relationships are back-translated into essentialist “causes” and viewed as if they “have an effect” (rather than “bring the system to the outcome”). Psychology’s enslavement by the notion of causality is analyzed by Toomela (2013) in detail.

Thus, the main difference between chemistry and psychology is in the adoption of different models of causality. While psychology continues to search for linear causal ties along the lines of inductive generalization, using all the statistical inventions of the twentieth century (Gigerenzer et al. 1989), chemistry since 1830s has moved into the focus on catalytic processes, together with structural depictions of binding processes (Klein 2004). Psychology’s sticking to the search for linear causality has led it into conceptual stagnation over the twentieth century (Toomela 2012). While working hard to find causal “main effects” and “interaction effects” through the ANOVA-type thinking that turns methods into theories (Gigerenzer 1991), psychology has overlooked the alternative ways of thinking about causality. Chemistry’s move into the use of the notion of catalysis—from 1830s onward, and particularly after 1890—has created an alternative framework of thinking that maps onto the reality of binding and un-binding processes of chemicals.

There are also other linkages with various disciplines. Chemistry these days becomes united with biology. Contemporary biology operates with the centrality of catalytic functions—enzymatic processes—on and off membranes. The frontiers of biological science is in the functioning of dynamic structures. In contrast, psychology—emulating some image of physics—attempts to reconstruct its object through “measures” that supposedly reflect some underlying (essential) quality. Comparing with chemistry that has left the notion of “saltiness” of “salts” very far behind, psychology is involved in an alchemical kind of act.

My goal in this chapter is to give an overview of the history of the catalytic process in general—extrapolating from chemistry—in ways that could be productive in bringing the notion of catalysis to the epistemology of psychology. It is mildly ironic that in the twenty-first century one needs to translate between “sister” disciplines that have developed in almost opposite directions. Reasons for that can be found in the socio-moral implications of psychology (Dolby 1977). Knowledge of the mind (or soul) is by far more sensitive in social living than that of various chemicals. The goals are also different—establishing the stability of the mind, in contrast to the transformability of chemicals. Psychology has focused on analysis, while chemistry is a science of synthesis. The focus on making something—bombs or pharmaceuticals—is the opposite of making sense of the already happened ruptures of the souls. Yet, both predicaments are practical in their nature.

Proving Immanuel Kant Wrong: How Chemistry Has Come to Be a Science

Each science has its ghost. If for psychology such ghost is mysticism, for chemistry it has been alchemy. Trying to break with the mystical explanations—moving from the “stone of wisdom” to contemporary explanations—has been a long way of development of chemistry as science (Ertl and Glonya 2003). The context of such distancing from alchemy in the nineteenth century was *Naturphilosophie* and the German Romantic tradition as a whole (Snelders 1970). Chemistry was in-between the Romanticism of new formations and the pragmatism of the direct look at substances—first of all in mineralogy. A discipline that collects and orders various minerals is certainly a next door neighbor to chemistry—yet one who might look at the acts of chemists with distrust. What a mineralogist has found and classified is for him final—but not for the chemist.

In the dialogue with mineralogy, chemistry fought the battle with the immediately observable—different observed structures of minerals overshadowed chemists’ efforts to find their common chemical underpinnings (Melhado 1980). Fighting both the poetic romanticism that kept alive traces of alchemy and the rugged direct perspectivism coming from mineralogy, chemistry synthesized the focus on different languages of explanation that would fit different purposes. Without bringing the conceptual house in order, chemistry and mineralogy were on a clash course in early 1800s. The situation between these disciplines was that of fight against chemistry “swallowing” mineralogy through its greater explanatory potentials. Yet, the immediately available (mineralogical) picture of substances seemed to tell a different story. The introduction of Eihlard Mitscherlich’s principle of isomorphism in 1819 consolidated chemistry’s perspective.

The issue at stake then has a striking resemblance to the “competence versus performance” discussion in cognitive psychology since the 1960s. The “performance” of minerals—two similar (or different) looking specimens A and B, could be considered different (or similar) by chemists analyzing their chemical structure. If they looked similar but were claimed to be chemically different, or if they looked different but were claimed to be chemically similar—the mineralogists’ trust in chemistry was deeply challenged. As minerals come to our attention in a myriad of forms—tainted in appearance by all kinds of additives—the direct perception and classificatory habits of mineralogists was a serious obstacle for the acceptance of chemical explanation. One has only to remember that around the same time—the first half of the nineteenth century—biology went through a similar process of “going beyond the information given” with the outcome of adopting the Wallace–Darwin evolutionary theory.

Borders of different disciplines were actively maintained in the nineteenth century science. Chemistry was not united—the contrast between inorganic and organic branches of the discipline was a major domain of disputes in early nineteenth century. The arguments in general were about reductionism—could one reduce the complexity of organic compounds to its elementary constituents that were of inorganic kind? Furthermore—can one reduce the ways in which living organisms exist to the general

principle of organic chemistry¹? In other terms—can life be reduced to nonlife, in sum? The fate of similar boundary negotiations continued between biology and physiology—is the biological functioning of organisms reducible to physiological principles? And, finally, can psychological phenomena be reduced to physiological or genetic elements?

Interestingly, similar borders were present between chemistry and physics, and between psychology and physiology—chemists resisted actively to the idea that chemical phenomena can be explained away in physical terms.

The importance of flexible moves between the immediate and the abstract are conceptual benefits for chemistry where they move toward increasing abstractness of concepts. This feature of chemical language use allows for quick movement between general—categorical but vague—and specifically precise—language uses.

A Key to Conceptual Solution: Accepting Polylingualism in Chemistry

Scientific language in any discipline is central for negotiating its investigative orientation with the integration of knowledge and its accessibility to the nonscientific public. The various languages usable in chemistry became formulaic—chemistry moved away from the common sense through developing generalized formulae that are applicable across concrete contexts. However, such progress in chemistry was slow. It was by the 1870s when the formulated chemicals were organized into a system of specifiable knowledge (Mendeleev's table).

In contrast, in psychology, the issue of language has been poorly differentiated. Efforts were made either to reduce its scientific language to its common sense counterpart, or to move toward inductively based theories that mimic the logic of analysis of variance. Either way, psychology uses its selected method, such as factor analysis, as the basis for a theory (e.g., 5-factor theory of personality).

In contrast, chemistry has overcome its alchemical language uses in the seventeenth to nineteenth centuries (Crosland 1978, Vickers 1984). In ways very analogical to our modern day psychology's labeling of inductively discovered factors and then believing that the labels have a causal force², the alchemists operated on the basis of analogies between celestial, material, and mystical meaning systems. Alchemy compressed layers of abstraction into a complex of meanings where the reactions performed in a laboratory could be explained by occult forces, analogies with planets, or at least by the sensorially available characteristics of the states of chemicals³.

¹ The border between the chemical and biological worlds was at stake: "Nineteenth-century chemists submitted animal compounds to elementary analyses in their laboratories, while physiologists claimed that they could not understand the processes transpiring in living bodies because they dealt with dead matter" (Bensaude-Vincent 2003, p. 209).

² e.g., "my high introversion makes me to be shy in public".

³ A particularly difficult mental puzzle for the alchemists was an apparent disappearance of such perceivable characteristics at different phases of alchemical experimentation. For example—if gold

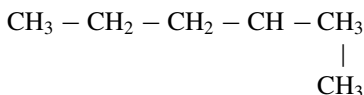
As a result of breaking free from its alchemical past, chemistry has incorporated a differentiated system of layers into its scientific language. Such differentiated picture of such language layers affords the discipline flexibility of presentation of ideas in relation to the desired audience. Such differentiated language domain allows for fitting the messages to the recipients as the common language meaning.

... survives in their synchrony in a different manner than is the case in natural languages. In natural languages diachrony manifest itself only through the etymology while in chemistry lay and semi-lay terms coexist today as clear synonyms with and to the functional and systematic names, and the choice of terms is determined by the efficacy rationale of the various communication situations pertaining to the field of chemistry (Mounin 1981, p. 218, added emphasis)

It is important to underscore the *functional flexibility* of the idea of this new way of language use in chemistry. Languages developed did not represent what the essence of the named substance is (e.g., in common sense: salt = “something salty”), but the presentation of the chemical for a particular way of reacting with other chemicals, to arrive in a new synthesis. From the generic notion salt, one cannot predict any potential to enter into reactions with others, but from a formulaic version one can chart out possible future connections with other reagents.

At the level of concrete terminology, there are at least four layers of names—for the same substances—used in the chemical nomenclature. The first one overlaps with those in the common language—terms like water or salt are used both in chemistry and everyday life. In chemistry one can encounter at least four layers of names for the chemicals talked about (Mestrallet Guerre 1980—referenced via Mounin 1981, pp. 217–218):

1. Lay terms that represent either a specialization of common sense terms (water, salt, ammoniac) or neologisms based on alchemic roots of chemistry (aqua forte, tincture of litmus). These names do not represent the actual chemical composition of the substance, and are arbitrary encoding of the objects. So, the term water has no implications about its composition of H–O–H.
2. Semi-lay terms that combine the root of a common sense word with a prefix or a suffix that connects to a paradigm (benzene, ethylene, propylene); nothing in the name gives information on the structure of the chemicals, yet their function as a category name can be elaborated in the terms of the components.
3. Functional names that specify major chemical function (phosphoric acid, benzoate of soda, silver chloride).
4. Names that describe the sum of the elements—rigorous and absolutely unambiguous reconstruction of the substance is possible—2-methyl pentane:



turns into red crystals—has it vanished? Or is it merely disguised? Explanations for such transformations could be built on analogy with transmutation (of souls), or masking. The latter became demonstrated through reversal of the reaction—red crystals could turn back into gold (Crosland 1978, p. 38).

Through opting for multiple labels, chemistry keeps its creativity open through the flexibility of its language use—and by the interesting aspect of it: *the most concrete use of the language is simultaneously the most abstract*. The latter is the result of introduction of a new formulaic language to chemistry in the 1810s–1830s, largely thanks to Jöns Jakob Berzelius (Melhado and Frängsmyr 1992). That language brought hierarchical order to chemistry and thus allowed the discipline to emerge as one that unites structural and functional features of chemical transformations within the same formal system. That order also entailed the elaboration of the notion of causality—moving beyond the Aristotelian legacy—and to formulate principles of catalysis and (in biology) enzymatic functions.

The Road to the Idea of Catalysis

As chemistry is a science of synthesis, the question of participation by various chemical reagents in the synthesis of the final product is the key conceptual issue in the science. Such participation may be direct, as in the case of reactants that directly bind to others, or indirect, that happen on the margins. The latter are necessary for the reactions to happen, but do not undergo change in themselves.

Such “contact action” of course does not mean that some miraculous impact of the presence of the given chemical is assumed. Rather, we can better talk of the surface of the indirect participant—a reaction taking place in the vicinity of platinum may involve the border of the metal, but not change its chemical nature. As such, the chemical both participates in the reaction (by peripheral contact) and does not do so (does not change its nature). The notion of catalysis—which could be called *causality without causes* (but by mere presence—or peripheral participation)—was a major intellectual invention of the nineteenth century. It comes from the intersection of chemistry and *Naturphilosophie*—the very idea of impact without causation fits into the holistic thought of the latter.

Johann Wolfgang Döbereiner (1780–1849) was a chemistry advisor to Johann Wolfgang Goethe, and—thanks to Goethe’s patronage—professor of chemistry, pharmacy and technology at University of Jena from 1810 until his death. While an experimenter and inventor of applied techniques first, he was interested in the philosophical issues due to his direct links with the romanticist in Jena. As a result, his look at the chemical processes was dynamic—making it possible to invent a lighting mechanism (later called *Döbereiner’s Lamp*—or *Döbereiner-Feuerzug*—Kauffmann 1999). This gadget—a lighter invented in 1823 and produced until 1880s—is built on the use of the platinum as the catalytic condition for spontaneous combustion by hydrogen. The practical device included the ideas that led Berzelius a decade later to the idea of catalysis, and has led to the use of catalytic converters in our contemporary automobile technology.

Döbereiner’s Lamp was a clever solution to producing fire through a chemical reaction (of sulfuric acid with zinc, releasing hydrogen as the first result). Döbereiner’s ingenious invention was to let the released hydrogen pass over platinum—letting the

oxygen from the air enter into mixing with the hydrogen and resulting in an intermediate product (*oxyhydrogen*) that burns and ends up as water (the binding of two gases into a liquid— H_2O).

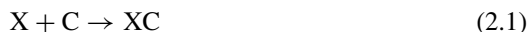
Platinum as a metal that has “miraculous” effects on various chemical reactions was known already in the eighteenth century, but it was Döbereiner’s engineering genius that made its catalytic function visible in a newly created tool of functional value. His setting up the *mere presence* of a platinum plate to the *crucial phase* of the chemical reaction—release of hydrogen and mixing it with oxygen—caused the gas mixture to burn (hence the light) while turning into water. Without the presence of the platinum as a catalyst such reaction is not enabled, but platinum (as metal) does not participate in the chemical reaction sequence of producing water out of zinc and sulfuric acid (and oxygen from air).

The notion of catalysis was first introduced by Jöns Jacob Berzelius in 1835. In his capacity of inventing new terms, the notion of catalytic force (*katalytische Kraft*); the first effort was to classify the phenomenon into a category (catalysis). Yet, not much was done with the notion in terms of understanding of how it works, until Wilhelm Ostwald launched upon large-scale research and application efforts at the end of the nineteenth century.

Catalysis as it Changes Reaction Speeds It is not very surprising that the first exploration of the new notion of catalysis was dedicated to demonstrating how a chemical reaction could be sped up—or slowed down—by conditions that were not parts of the chemical reaction itself. Traces of that focus survive in the popular presentations of the concept to the present day⁴, while the complexity of ideas about catalysis have surpassed this first approach.

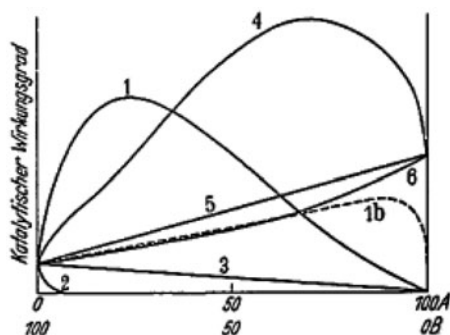
The various versions of impact of catalysts on the reaction rates were summarized by Mittasch (1938), here reproduced as Fig. 2.1. A regular one-time catalytic effect can be inhibitive (trajectory 2—Giftwirkung poisoning) or escalatory (trajectory 1—Aktivierung). The activation can be delayed by a catalyst (trajectory 4). Thus, in the outcomes of reactions, different time-dependent patterns can occur.

However, the notion—catalyst is not consumed in the reaction—does not necessarily mean that it does not—temporarily—bind itself with an intermediate state of the chemical by-products and become released from them by the end, not “losing” its nature or quantity. Thus, in a typical reaction where X and Y result in compound Z, the catalyst (C) can enter into—and exit from—the intermediate forms of the chemical reaction:



⁴ cf. Wikipedia explanation: “Catalysis is the change of rate of a chemical reaction due to the participation of a substance called catalyst. Unlike other reagents that participate in the chemical reaction, a catalyst is not consumed by the reaction itself.” The conceptual core notion that emerges here is participation—with (chemical reagents) or without (catalysts) being “consumed”. This definition has roots in the work of Berzelius and Ostwald, but becomes obscure at our time. The “not consumed” notion is better replaced by “renewed”.

Fig. 2.1 Different quantitative impacts of catalysts on reaction rates. (Mittasch 1938, p. 25)



The catalyst C here binds itself to X, followed by the hybrid binding Y to itself, and then XY becoming Z while C is present. Subsequently, the Z is the result of the chemical reaction, while C becomes reproduced in quality and quantities it existed. Note that, here the catalyst does not remain an “outside condition” for the reaction process (like the first examples of platinum as catalyst were). Instead, the catalyst becomes temporarily functionally bound into the whole reaction at its intermediate stages.

To draw parallels with psychological processes—the entrance into the chemical reaction in the middle part of the construction of a new compound in chemistry has a parallel in the microgenetic processes of psychological kind where the structure of intermediate gestalts (Valsiner and van der Veer 2000; Chap. 7) involves psychological materials that disappear as the final percept or any other psychological phenomenon becomes assembled. However, psychology—in contrast with chemistry—has not often analyzed these intermediate steps, and the ways in which the final result is produced remains unexamined. While chemistry has turned the domain between Stimulus (S) and Response (R)— $S \rightarrow R$ —into a domain where the processes in between (i.e., $S \rightarrow$ (set of intermediate transformations) $\rightarrow R$) are the focus of investigation, psychology has continued to look for formal relations⁵ between S and R, avoiding the analysis of transitions.

In contrast, chemistry depends on the explanation of the “steps in-between”, and it is precisely here that the role of catalysts becomes center. Similarly to the development of *Aktualgenese* ideas in psychology, it is the specific conditions of the intermediate states of affairs that need catalytic lead-in toward the stable end product (Fig. 2.2). The sequence of reactions depends upon the appropriate catalysts acting in the sequence at appropriate time. This turns catalytic processes into time-space

⁵ Usually representing these in terms of correlation coefficients or their derivatives. The hope is to reconstruct what happens in between through looking at the relations between S and R. Yet, as these relations are formal, they cannot re-construct the psychological process that is actually taking place.

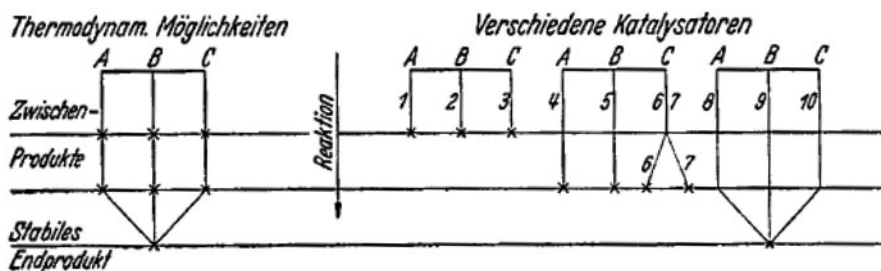
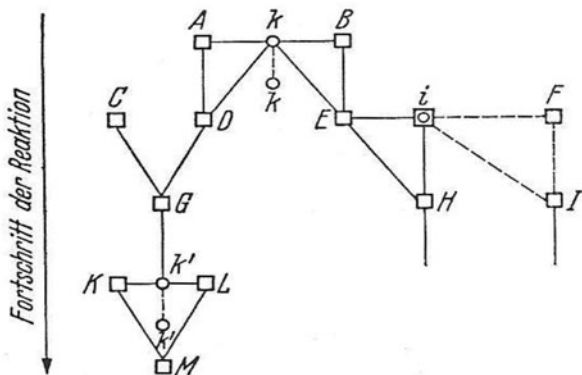


Fig. 2.2 The enabling role of catalysts in sequential reactions. (Mittasch 1938, p. 30)

Fig. 2.3 Catalytic conditions that create bifurcations. (Mittasch 1938, p. 70)



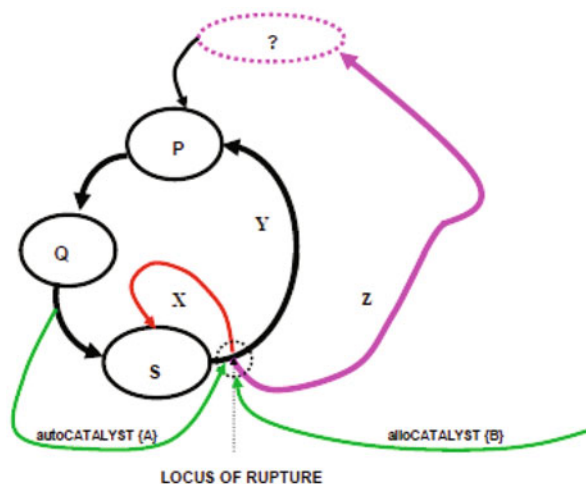
structures that can be described—and such description of the reaction sequence is the explanation of the outcome.

In Fig. 2.2, different sets of catalysts (1 . . . 10) lead the process of A-B-C to the end state of hybrid compound in a sequence; 1–7 prepare the intermediate products, but 8–10 are needed for the actual synthesis.

Catalysis as it Creates a Bifurcation Aside from unification—of the various intermediate compounds to a final one—catalysts can create the diversion of the chemical reactions into different trajectories. (Fig. 2.3).

In Fig. 2.3, it is the catalyst k for one part of the system (A- k -B)—but it can also become a part of the reaction system (K- k' -L-M). The scheme includes inductors (i), with the result that the catalyzed system can both regulate the reproduction of the catalyst (k') and induce new outcomes of the process (F, I). The discourse about catalytic forces entails both “positive” *promoters) and “negative” substances that operate on the catalyst either by inhibiting the current catalyst (“inhibitors”) or by irreversible elimination of it (“catalyst poisons”). The story about the whole catalytic process is the narrative of mutual struggle between “positive” and “negative” catalytic forces as they regulate the time-dependent proceedings of the chemical reaction. The roots of this kind of systemic thinking in the traditions of *Naturphilosophie* are obvious.

Fig. 2.4 Autocatalysis and allocatalysis in an open system



The Conceptual Relevance of Autocatalysis The notion of autocatalysis was introduced by Wilhelm Ostwald in 1890. The chemical process entails the synthesis of substance X at time T1 that would enter as a catalyst into the same reaction chain at T + N, acting in any role (promoter/inductor or inhibitor/poison)

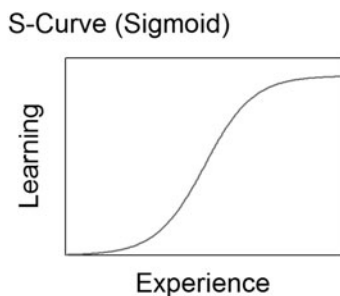
Wilhelm Ostwald was a prolific person. Not only was he the initiator of physical chemistry (receiving the Nobel Prize in 1909 for the catalysis applications), but also through his active propagation of the energetist notion that was supposed to unify all sciences, he had an impact upon psychology of his time as well.

As described in Fig. 2.4, the autocatalytic system is the key for all the three fates of the system—its collapse (trajectory X), self-maintenance (trajectory Y), and development into a new form (trajectory Z). The openness of the open systems depends on the relationships between auto- and allocatalytic processes in the system.

Autocatalysis is the basic process of the maintenance and development of open systems. The emergence of life out of inorganic components has been attributed to autocatalytic functions—which of course is the reasonable attribution in contrast to all the implications of attributing such emergence to any outside causation. Its characteristic form of the proceeding with the outcome production is the Sigmoid curve (Fig. 2.5). It indicates the feed-forward catalysis of the process—learning in this case—that speeds up the process in the intermediate stage, to be followed by the slowing down at the reaching of destination.

An Organic Example of Autocatalysis: The “Tin Pest” At 13 °C and lower, pure tin transforms from its silvery metallic form to nonmetallic “grey tin”. First that transformation is slow, but as the decomposing reaction catalyzes itself—the more of the “grey tin” is produced the more of it will be produced (until finally the tin decomposes into powder). What seems—at warm temperatures—a metallic object—can disintegrate at low temperatures in an escalatory way. By some interpretation,

Fig. 2.5 The normal example of simple autocatalytic outcomes: the Sigmoid curve



Napoleon's soldiers fighting in the Russian winter conditions lost their buttons on their uniforms because those were made of tin .

From Science to Practice One could use the development of knowledge in chemistry as an example of autocatalytic process. Ever since Wilhelm Ostwald and Alwin Mittasch provided ideas of catalysis that granted profits to chemical manufacturers, the search for catalytic solutions to practical chemistry problems has been escalating. Such escalation often involved “trial-and-error” type of learning, leading to the need for new qualitative breakthroughs in theory.

Alwin Mittasch—a disciple of Wilhelm Ostwald who most diligently carried his ideas of catalysis further both theoretically and practically—joined the BASF company in 1904 to undertake the development of commercial synthesis of ammonia⁶ (NH_3) from atmospheric air through a catalysis process. The direction of efforts was clear—to find adequate catalysts that would increase the production of ammonia to the level that was commercially viable. In that effort, the applied researchers scanned huge variety of catalysts (2,500, in year 1912; Farber 1966, p. 165). This largely “blind” process—try what one can, maybe something works—resulted in local generalization of how one could succeed⁷. Together with solving engineering problems of the scale of the production plant, the effort succeeded—the factory near Ludwigshafen started production in 1913 (it closed in 1957). By the end of 1915 the BASF plant produced 150,000 t of ammonia (in comparison, by year 2012 the World's production of ammonia was 198 million tons). Catalytic functions are the main focus of our chemical industries.

“The Partner of the Hormones is the Living Cell”⁸—Biological Catalysis The organic world is different from the anorganic. Figure 2.3 leads us to the crucial notion of autocatalysis that is of importance in biological systems. Autocatalysis is a form of catalysis where the catalyzed system itself produces substance that acts—in another

⁶ A colorless gas used widely in fertilizers and military ammunitions, as well as pharmacological industry.

⁷ The key was to purify the catalytic activators, and use various catalysts to absorb hydrogen and nitrogen separately (Farber 1966, p. 163).

⁸ Giersberg, cited via Mittasch 1938, p. 70.

location of the system—as a catalyst for the system (e.g., $k' \rightarrow k$ in Fig. 2.3, and A in Fig. 2.4)

Enzymatic Catalysis Enzymes—biological catalyzers—are molecules that regulate metabolic reactions in the biological organisms. Almost all biochemical reactions in a cell require the presence of catalysts. Enzymes determine which metabolic pathways can be taken in that cell. Enzymes are highly context-specific, and dependent on other small molecules—coenzymes—that are bound to the enzymes. Coenzymes transport chemicals from one enzyme to another (perhaps the most commonly known coenzyme is Acetyl-coenzyme-A in the Krebs cycle). Coenzymes are changed by their action.

An intricate example of the way in which enzymatic catalysis works could be taken from a further look at ammonia—how it would be met if encountered by humans (or other vertebrates) in contrast with aquatic animals (fish). For the latter—as they lack the specific enzymatic reaction to protect them from ammonia—even small concentrations of ammonia in the water turn out to be lethal. But—not so for humans! A specific pathway guarantees that ammonia cannot be built up in the bloodstream. A special enzyme—*carbamoyl phosphate synthetase*—transforms ammonia into carbamoyl phosphate, after which it is either directed further to turn into amino acids or urine. The cycle ends up re-producing the enzyme. The neutralization of the effect of ammonia for vertebrates is guaranteed here.

The enzyme action is thus a form of specific catalysis, and . . . it provides a definite, general solution for all the fundamental biological enigmas: the mysteries of the origin of living matter, of the source of variations, of the mechanisms of heredity and ontogeny, and of general organic regulation . . . Catalysis is essentially a determinative relationship, and the *enzyme theory of life*, as a general biological hypothesis, would claim that all intra-vital or “hereditary” determination is, in the last analysis, catalytic. (Troland 1917, p. 327)

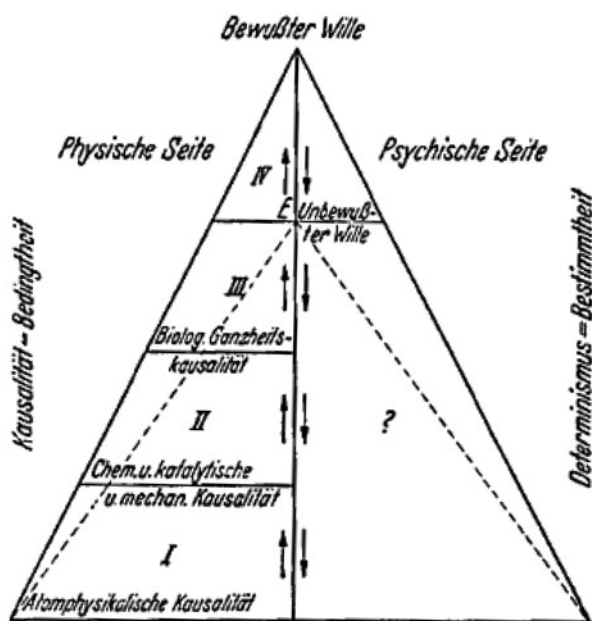
What enzymatic catalysis tells us—in psychology—is a story that makes our conceptual domains very complex, and almost completely eliminates the traditional uses of quantification in psychology. Instead of “measurements” of barely conceivable illusory psychological properties and claims of explaining small portions of “variance” we would be faced with dynamic structures of binding and un-binding processes within the phenomena of mental and affective kind. Implications of such change for psychology as science are enormous—yet realistic.

From Chemistry to Psychology: Catalysis Within Hierarchical Orders

The catalytic paradigm in chemistry is of course not a simple solution for neighbouring fields. Working with catalytic models requires a number of elaborations (Kuznetsov 1966, p. 204):

1. Exact explanation of the border between catalytic and noncatalytic reactions
2. Explanation of the great distribution of catalytic reactions

Fig. 2.6 Hierarchy of catalyzing processes. (Mittasch 1938, p. 116)



3. Differentiation of the processes of initiation and reactions by small additional composites.
4. More exact classification of catalysis than used currently.

The high variety of enzymes in the body and their narrow yet redundantly overlapping functions set the stage of even greater complexity for the psychological domains. Furthermore, they bring to psychology the focus on directedness (see Toomela 2013, on the paradoxes of the catalytic causality model).

Catalysts as directive agents in chemical reactions are akin to the organizers, inducers, and all other “directive” substances in the development of organisms. Such an analogy is helpful in the design of biological experiments, and it also points to unresolved problems. The integration of directive actions “is actually a mystery” (Farber 1966, p. 177)

The talk about organizers and inducers brings to chemical catalysis a parallel with embryonic development and the work of Hans Spemann in the field of epigenesis. Empirical evidence of organizers in embryonic development is known since 1924, from Spemann’s and Mangold’s classical study of creating twin salamanders by the way of tissue transplant (Sander and Faessler 2001).

Possible uses of catalytic terminologies in psychology need to deal with the levels of organization of the catalytic processes in the organism. Here—like in biology—the catalytic processes belong to a hierarchical order. It is of interest here to return to Alwin Mittasch’s scheme of hierarchical catalysis that includes the psychological counterpart of the biological one (Fig. 2.6)

While Mittasch—who after his retirement from BASF in 1933 turned directly to the study of philosophy of chemistry—manages to fill in the physical side of his hierarchical scheme (the left hand side of Fig. 2.6), the psychological “uncovered territory” (right hand side) is bare. He only indicated an analog of two levels of catalytic processes—chemical and biological—as counterpart to unconscious psychological processes. The final inclusion of the intentional action (*Bewusster Wille* on top) would guide psychologists to topics that were relevant in the late nineteenth century: intentionality, Gestalt nature of psychological functions, and their varied rates. Such complexity of the catalysis processes becomes the norm in the living systems that in addition to the complexity of inorganic compounds entail the capacities of movement, adaptation to changing conditions, and—in some cases—goals-directedness.

What has been accepted in chemistry and biology as the unquestionable basis for science—catalytic and enzymatic organization—is slowly beginning to enter into contemporary psychology. Catalytic ideas have found their place also in management science or organizations (Padgett and Powell 2012). Yet, old mindsets are hard to break and the illusory beauty of the General Linear Model keeps its dominance in psychology, leading to the theoretical “blind spot” of not noticing the nonlinear and noncausal nature of the psychological phenomena. Theoretical innovation of basic models—of causality and catalysis—needs to precede any empirical inquiry.

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