

Three Concepts of Chemical Closure and their Epistemological Significance

Joseph E. Earley, Sr.
Department of Chemistry, Georgetown University
earleyj@georgetown.edu

An earlier version of this paper was presented at the workshop
Epistemology of Chemistry: roots, methods and concepts.
at the *Centre de Recherche en Épistémologie Appliquée,*
École Polytechnique, Paris, France. September 11, 2010.

Abstract

Philosophers have long debated 'substrate' and 'bundle' theories as to how properties hold together in objects — but have neglected to consider that every chemical entity is defined by *closure of relationships* among components — here designated '*Closure Louis de Broglie.*' That type of closure underlies the coherence of spectroscopic and chemical properties of chemical substances, and is importantly implicated in the stability and definition of entities of many other types, including those usually involved in philosophic discourse — such as roses, statues, and tennis balls. Characteristics of composites are often presumed to 'supervene on' properties of components. This assumption does not apply when cooperative interactions among components are significant (as they usually are in chemistry). Once correlations dominate, then adequate descriptions must involve different entities and relationships than those that are involved in 'fundamental-level' description of similar but uncorrelated systems. That is to say, descriptions must involve different semantics (topology) than would be appropriate if cooperative interactions were insignificant. This is termed '*Closure Henri Poincaré.*' Networks of chemical reactions that have certain types of closure of processes display properties that make other more-complex coherences (such as biological and cultural systems) possible. This is termed '*Closure Jacques Cauvin.*' Each of these three modes of closure provides a sufficient basis for warranted recognition of causal interaction, thus each of them has epistemological significance. Other modes of epistemologically-important closure probably exist. It is important to recognize that causal efficacy generally depends on closure of relationships of constituents.

Keywords: substrate theory, bundle theory, closure, dihydrogen molecule, Process Structural Realism, asymptotic approximation, concentration robustness, networks of chemical reactions, Louis de Broglie, Henri Poincaré, Jaques Cauvin, affordance, epistemology of chemistry, philosophy of chemistry.

Substrates and Bundles

At least¹ since David Hume rejected John Locke's supposition that properties inhere in 'substrates' and argued instead that objects are nothing but 'bundles of properties,' philosophers (mainly English-speaking) have debated how properties hold together in ordinary objects. Currently, Locke's substrate theory has vigorous proponents (e.g., Sider 2006) but a larger number of philosophers favor versions of Hume's 'bundle' approach and assert that a 'compresence relationship' holds properties (or 'tropes' — individual instances of properties) together (e.g., Robb 2005, Simons 1994). When intelligent people carry on vigorous debates about important matters for extended periods, it sometimes turns out that all parties to the dispute have made unwarranted assumptions, or that both sides have overlooked important considerations. This paper suggests that time cannot be ignored in discussions of properties and that coherence of the properties of each individual entity requires *closure* of networks of relationships between and among components. Such closure is an important aspect but has not been considered in the debates, perhaps because synchronic rather than diachronic approaches have been used.

Jiri Benovsky (2008) examined more than six current versions of both substrate and bundle theories. Some of those versions involved 'tropes' and others recognized universals, some had a single identical unification-relation for all objects, others had a single unification-relationship but allowed variable numbers of relata ('polyadicity'), still others had distinct unification-relations for each object. Benovsky considered, in some detail, how proponents of each of these approaches defended themselves against objections. At the end of this inquiry, he concluded that both substratum and bundle theories *share* a common central postulate: namely, that each object has a feature, different from all other features of the object, which functions as a unifying device. (This unique feature is called the 'substrate' or 'bare particular' in one theory, and designated the 'compresence relationship' in the other approach.) Benovsky identified both of these postulated special features as *theoretical entities* (items that are "individuated by their theoretical role") and pointed out that both "play the same role in the same way" in all their applications — therefore the two special features should be regarded "as identical (*metaphysically equivalent*)." (p. 183) Benovsky concluded that substratum and bundle theories are 'twin brothers' rather than 'enemies' — and that both these approaches are seriously deficient, since neither has succeeded in clarifying the nature of the basis of unification that they both require.²

¹ This debate is related to controversies in ancient philosophy. (Earley 2009)

² Mathematicians recommend that if a particular problem proves to be intractable then one should make a strategic switch to a different and easier problem that retains important features of the original task (Polya 1985). If the second problem can be solved, that solution may provide tools or hints that will allow the original problem to be clarified. The objects discussed in substrate or bundle debates have generally been ordinary items encountered in everyday life — e.g. roses, tennis-balls, statues. Perhaps, as the mathematicians suggest, greater success might be obtained by considering items that are less familiar but are understood in more detail, such as the entities with which contemporary chemists deal.

Property Persistence through Interaction

Remarkably, recent participants in substrate/bundle discussions seldom or never mention findings of physical chemists regarding how properties of well-defined chemical substances relate to the composition of those materials. Hilary Putnam (1969) pointed out that philosophers often encounter serious problems because they generally use the word 'property' to denote anything that can be said about an object – any *predicable*. Philosophers who discuss substrate and bundle theories seem mainly concerned with *logical* structure, proper modes of speech, and maintaining customary patterns of thought (respectfully designated as 'intuition'). Chemists have different priorities³ and generally use a more-restricted concept of property – one described by American chemist and philosopher Charles S. Peirce [1839-1914], who defined a property as *how a thing behaves, or would behave, in a specified operation*. This usage exemplifies Peirce's 'pragmatic principle':

Consider what effects, that might conceivably have practical bearings, we conceive the object of our conception to have. Then our conception of these effects is the whole of our conception of the object. (Peirce, 1878)

All the entities with which chemists deal are somehow composed of smaller items. All of these objects (both composites and components) are known to be in incessant thermal motion and also in continual interaction with other items. In order for any composite to remain more or less the same through motion and interaction there must be features of that composite that insure sufficient resiliency for integrity to be maintained. Paul Weiss (1959) described this situation well:

Each actuality is a substance. It maintains a hold on whatever it contains, produces, and intrudes upon. It persists and it acts. It has an irreducible, independent core, and receives determinations from insistent, intrusive forces. ... If an actuality were not a substance, its parts would not belong to it, and it would disperse itself in the very act of making its presence evident. The very items which it dominates, it would not control; nor would it continue to be despite an involvement in change and motion. It would be inert and solely in itself, or it would be a mere event. In either case, it would not be a source of action.

The well-established dynamic aspect of nature – incessant motions of all items – requires an account of the factors to which Weiss calls attention: how properties of objects are maintained through time, how they interact with others, and how they maintain their own integrity during such interaction.

Participants in substrate/bundle debates generally ignore temporality and explicitly or implicitly adopt 'synchronic' approaches in preference to 'diachronic' ones. (Humphrys 2008, Earley 2003b) The shared (but certainly false) assumption that history is negligible seems to have been a major factor contributing to the failure of both conceptual schemes. The long-term stability of composite chemical

³ It seems participants in these debates have little concern as to whether the features they postulate are in fact exemplified in nature. In Shakespeare's *King Henry IV, Part I*, Welsh chieftain Owen Glendower boasts: "I can call spirits from the vasty deep." His English cousin and rival Hotspur replies: "Why, so can I, or so can any man; But will they come when you do call for them?" (Act 3, Scene 1.) Hotspur probably would approve chemists' use of Peirce's pragmatic concept of 'properties'.

entities – molecules of dihydrogen or crystals of table salt for instance – even while the components are in constant motion requires that such motion is somehow *constrained* so that the entities maintain their integrity. We now consider how such coherence is achieved.

Closure Louis de Broglie.

When Louis de Broglie resumed his study of physics after the close of World War I, the then-existing theories of Bohr and Sommerfeld could adequately rationalize the extensive body of experimental data that was available on the line spectra of atomic hydrogen and ionized helium – but only by making the unsupported assumption that electrons in atoms are restricted to certain specific energy values ('orbits'). As de Broglie pointed out in his 1929 Nobel Prize address, those early versions of quantum mechanics *could not* explain: "why, among the infinity of motions which an electron ought to be able to have in the atom according to classical concepts, only certain ones were possible,". In a note in *Comptes rendus*, de Broglie (1923) proposed that each electron within an atom had a frequency intrinsically associated with it, and also was connected with a wave that carried no energy.⁴ He then introduced a postulate:

"It is *almost necessary* to suppose that the trajectory of the electron will be stable *only* if the fictitious wave passing O' catches up with the electron in phase with it: the wave of frequency ν and speed c/β has to be in resonance over the length of the trajectory"

This postulate envisions that an atomic system will be stable (that is, will persist) only if two oscillations agree in phase. The 'only' in this postulate (emphasized in the French original) is a clearly a requirement of a specific relationship between two quantities (phases of waves). On the basis of this postulate, de Broglie was able to derive the Bohr-Sommerfeld criteria for stable states of the electron in the hydrogen atom. This was a great triumph: de Broglie was awarded the 1929 Nobel Prize for Physics on the basis of his 1924 doctoral thesis.⁵ The essential novelty of this contribution was that it provided a *criterion* that served as a basis for understanding *why* some states of electrons in atoms were capable of extended existence while other apparently equivalent 'states' were not capable of existence.

Related sorts of closure and analogous criteria are, I submit, characteristic of *all* stable chemical entities. The general requirement for such criteria is a key factor that has been left out of past and current philosophical discussion of bundle and substrate theories.

⁴ Later, this 'fictitious wave' became known as 'the phase wave' or 'the pilot wave'.

⁵ Through Einstein's mediation, this thesis also inspired Schrödinger's development of wave mechanics. In the Solvay Conference of 1927 de Broglie's approach was criticized by Wolfgang Pauli and others, and was then largely supplanted by Bohr's 'Copenhagen Interpretation.' (Bonk 1994) De Broglie's approach has been partially revived by Bell and used in recent models of the internal constitution of the electron.

Molecular Properties

In chemical entities, distances between components remain within narrow limits because of balance of attractive and repulsive interactions (a type of closure). Attractive forces tend to pull components inward while repulsive interactions impel those constituents outward. As the positive centers separate for whatever reason, attractive forces draw them back together. Figure 1 displays calculated curves showing how potential energy varies with distance between positive centers for the three lowest-lying electronic states of the dihydrogen molecule, H_2 . The upper and lower curves correspond to situations in which the two electrons have opposite spins ('singlet states'). The central curve corresponds to a circumstance in which the two electrons have the same spin (a 'triplet state'). The lowest curve features a minimum in a region of negative potential energy. The central curve has no minimum. The third curve has a minimum but in a region of positive potential energy and at a larger internuclear distance than the lower minimum.

If two hydrogen atoms with opposite electronic spins were to collide and somehow to transfer energy to a third body (say, a helium atom or the wall of a reaction-chamber) a dihydrogen molecule might result. Once produced this two-centered entity would move through space as a unit — while vibrating more or less vigorously (that is, while oscillating within the 'potential-well' defined by the minimum in the lower curve). (Earley 2003a) Texts in physical chemistry and quantum chemistry show that factors that determine the potential-energy versus distance curves for dihydrogen are now understood rather well.

Properties that depend only on the constitution of dihydrogen molecules could be interpreted as deriving directly from the potential-energy versus internuclear distance curve. The molecular weight would be one such property.⁶ Two other types of properties are of great interest to chemists. '*Spectroscopic properties*' involve transition between various stable energy states of a given molecule with concomitant emission or absorption of energy. '*Chemical properties*' involve interactions (of molecules with like or different others) and lead to transition to a different potential-well corresponding to alternative molecular compositions, or to new topologies of connection of elemental centers.

Spectroscopic and Chemical Properties

Vibrational and rotational energies are 'quantized' — restricted to specific values that are spaced in regular ways — just as electronic energies are. Energy levels are spaced more widely for electronic states, less widely for vibrational states, and quite closely for rotational states. Figure 2 shows the several vibrational states that correspond to the two low-lying electronic states of the dihydrogen molecule that have potential minima. Each of these vibrational states has several associated rotational

⁶ If a nonvolatile molecular substance were introduced into some appropriate volatile solvent, the freezing and boiling points of that solution would differ from the corresponding values for the pure solvent. For a dilute solution, both the boiling-point elevation and the freezing-point depression would be proportional to the lowering of vapor pressure of the volatile solvent due to presence of the nonvolatile solute. Such 'coligative' properties of solutions depend on the number of molecules of a given type that exists in a specific volume of solution and are not influenced by the properties of individual solute molecules. This would be another strictly 'molecular' property.

states. The designation 'state' implies that, absent any disturbance, the system might remain in any one of these states indefinitely.⁷ But transitions between states can occur: such transitions provide the means for the molecule to interact with the rest of the world while retaining its integrity as dihydrogen, by maintaining the H—H bond. *Closure* is what allows each molecule to 'make a difference.' (Earley 2008, 2004; Ney 2009)⁸

Detailed study of 'spectroscopy', the energy absorbed or released when chemical systems change for one energy state to another, accounts for much of the success modern chemical science. For a single instance, Martini et al (1990) used emission from the first vibrational excited state of dihydrogen to the ground (lowest) state to gather information about conditions in several 'reflection nebula' — immensely distant galaxy-clusters that are thought to be regions of active star-formation. Consideration of the details of the closure of relationships in the dihydrogen molecule is essential to account for the observed colors of these nebulae. Stability of any chemical species corresponds to a closure of relationships that defines a minimum of potential energy in for a specific pattern of connectivity of elemental centers. The details of each such potential well determine how each system interacts with other systems, and so specifies the properties (in Pierce's pragmatic sense) of the total coherence.

The central and essential parts of chemistry have to do with turning less-valuable materials into more-valuable items — making cheap stuff into expensive stuff. Every chemical change involves decrease in 'chemical potential' (free energy). Chemical reaction corresponds to transition between stable states — change from one potential well to another. Chemical reactions correspond to production of new closures — every chemical process is 'a becoming.' (Earley 2004) Transition from reactant to product potential wells necessarily involves passage through intermediate configurations that correspond to higher potential energy. Slower rates of chemical reaction involve traversing configurations corresponding to 'barriers' of higher potential energy between reactant and product potential wells.⁹

⁷ For this reason the middle curve in Figure 1 does not correspond, properly speaking, to a state. The 'triplet state' designation is used 'by courtesy.'

⁸ Transition from a state associated with the lower electronic curve in Figure 2 to a state associated with the upper curve would involve a dihydrogen molecule absorbing a photon of appropriate energy. Once in the upper well (with a longer distance between the elemental centers) vibrations and rotation could occur. Sooner or later the molecule would emit a photon and move to one of the states associated the lower curve, or the molecule would split up into free atoms. Transitions between molecular energy states are subject to a restriction chemists know as 'the Franck-Condon principle': no nuclear motions occur *during* state-to-state transitions. Notice that in the figure lines indicating transitions are all vertical. This restriction applies because nuclei are relatively heavy and therefore move vastly more slowly than nearly weightless electrons. In this consideration the parts of the dihydrogen molecule are taken as two protons and two electrons of opposite spin. Even though the formula of dihydrogen is H₂, that molecule does not 'consist of' two hydrogen atoms, Strictly speaking there are *no* atoms 'contained in' dihydrogen or any other molecule. (Most philosophers appear to be misinformed on this elementary chemical concept.)

⁹ For instance, change from the stable *cis*-conformation of 1,2 dichloroethane to the equally stable *trans*-configuration encounters only a small barrier: the corresponding reactions of 1,2 dichloroethylene

Closure Henri Poincaré

Discussions of composite objects generally assume (implicitly or explicitly) that properties of composites depend only ('supervene') on the properties of components. That is, the properties of the lowest ('ultimate mereological') level determine all properties. (E.g. Armstrong 2010, pp 29 ff.) Characteristics of dilute gases can sometimes be inferred from information regarding component molecules – based on the approximation that each molecule acts fully independently. However, when gases are cooled so that conditions come closer to those of the gas-liquid transition, correlations of molecular motion develop – first over short ranges, then over longer and longer distances. The result is that motions of individual molecules are no longer independent but rather become more or less interrelated.

Similarly, the simple model that chemical reactions occur by 'elementary steps' that all involve 'instantaneous' collisions of pairs of molecules is usually an oversimplification. Frequently, 'sticky collisions' produce 'resonances' – more or less persistent aggregates. These also give rise to correlations among molecules. For example of resonances in a simple reaction, the reaction between a beam of F atoms and a second beam of HD molecules shows nonlinearities in the energy versus reaction-rate ('cross-section') profile that are interpreted as arising from the presence of three rotational states of a tri-nuclear resonance transiently formed in this exceedingly simple reaction. (Dong 2010, Althorpe 2010)

In both phase-change and chemical-reaction cases, as correlation increases applications of 'fundamental' theory are unwieldy, impracticable and under certain conditions (at 'singularities') become *impossible in principle* as computed quantities rapidly go to infinity. While dealing with problems of physical dynamics in the late nineteenth century, Henri Poincaré encountered similar situations in which standard methods failed due to singularities. In such cases, near singularities he replaced variables with divergent series ('asymptotic expansions'). This technique (Berry 1999) often led to discontinuous change (at the singularity) in the equations that described the situation. At and beyond the singularity, Poincaré found that relatively simple expressions applied which emphasized contextually important features and suppressed irrelevant detail. When such asymptotic expansions become necessary, plots of 'reduced' (unit-less) variables typically show lack of dependence on properties of individual substances. For instance,¹⁰ at various *reduced temperatures* (T/T_c), compression factors of many gases *have the same* dependence on reduced pressure (P/P_c) independent of their quite diverse individual properties. (Moran 1995) That is to say, properties other than those that influence critical behavior are irrelevant to deviations of gases from ideal-gas behavior.

encounter a larger barrier and are much slower. Properties such as the melting temperature of a solid or the boiling temperature of a liquid can be considered as chemical properties, referring to especially simple chemical reactions involving interaction of molecules of only a single type.

¹⁰ At 'the critical point' [critical temperature, T_c ; critical pressure, P_c] distinction between liquid and gas phase disappears. Compression factor, $Z = PV_m/RT$, measures deviation from ideal-gas behavior. (V_m = molar volume.)

The simpler description that asymptotic expansion yields at and after singularities has different semantics (another 'topology') than the 'fundamental-level' description that applied before the singularity. Properties of highly correlated systems do not 'supervene on' properties of components system but require quite new and topologically incommensurable descriptions. (Batterman 2009, 2005, 2002, 1998; Bishop 2006, 2005; Primas 1998, 2000). It can be argued (Laughlin 2005) that many aspects of 'fundamental' physics *result from* such cooperative interactions.

Cooperative interactions in condensed phases sometimes yield spectacular results. At room temperature, cesium chloride crystals can exist in two different spatial arrangements — one with six positive ions around each negative ion and one with eight. One structure is more stable at lower temperatures, the other form is more stable at higher temperatures — but conversion between the two structures does not occur readily. At a particular temperature a given crystal of this salt might have either internal structure depending on its prior history. Transition from the unstable to the stable form of cesium chloride does not occur smoothly and gradually but rather happens abruptly — with an audible click usually accompanied by fragmentation of the crystal. This remarkable behavior (a *Martinsitic* transition) is interpreted as occurring by coordinated and simultaneous small motions of immense numbers of ionic centers. (Chakabarti 1979, Earley 2003c)

When cooperative interaction of units becomes dominant, situations adequately described by fundamental theories change into to situations that require approaches that use quite different sets of entities and relationships (other 'topologies'). This transition is also a kind of closure — a type of interaction that brings about epistemological and ontological change. (Primas 1998) We call this circumstance '*Closure Henri Poincaré.*' Occurrence of such closure vitiates assumptions that properties of chemical entities can be adequately understood on the basis of descriptions based on properties of component parts, as Humean presuppositions imply. This situation is well described by Hans Primas.¹¹

The task of higher level theory is not to approximate the fundamental theory but to represent new patterns of reality... According to quantum theory the material world is a whole, a whole which is not made of independently existing parts. ... Quarks, photons, electrons, atoms or molecules are ... contextual objects without an independent existence. (Primas 1998)

Closure Jacques Cauvin

Investigation of the properties of networks of processes (such as interconnected chemical reactions) is one of the most active fields of twenty-first century science. Surprisingly, in some biological situations, critical reagents involved in networks of reactions somehow remain at quite constant concentrations for long periods. A remarkable theorem as to how this can come about was published in spring 2010. (Shinar and Feinberg 2010) To understand this achievement, we need some concepts that are illustrated with reference to Figure 3.

¹¹ Prof. Primas was trained as a chemical laboratory technician and functioned as such before establishing himself as a leading theoretical chemist. (Atmanspacher 1999)

- *Nodes* are distinct combinations of chemical species that stand at heads and tails of reaction arrows. (Each node appears only once in a standard network diagram.) In the figure there are eight nodes: 2A, B, C, B+C, D, 2B, A+E, and F.
- Sets of mutually-linked nodes are known as *linkage classes*. There are *two* linkage-classes in the network shown, as indicated by the solid lines on the right half of Figure 3.
- A group of nodes constitute a *strong linkage class* if there is a path of directed arrows from one node to each of the others and also from each of the others to that one (dashed lines in the figure).
- A strong linkage class is *terminal* if none of its nodes involve an arrow leading to another linkage class. In the figure, both C and the class [2B, A+E, F] are terminal classes. There are two non-terminal classes, each of which has two nodes.
- The *rank* of a network is the maximum number of *independent* reactions the network contains. Only *five* of the ten reactions shown in Figure 3 qualify as being independent.
- The *deficiency* of a network is an integer index obtained by subtracting both the number of linkage classes and the rank from the number of nodes. For the network of Figure 3 the deficiency is one, because there are eight nodes, two linkage classes, and the network has a rank of five.
- A system is said to have 'absolute concentration robustness in species S' if the system admits a positive steady state and if the concentration of S is the same in all positive steady states.

The theorem Shinar and Feinberg established by *a priori* reasoning is:

Consider a mass-action system that admits a positive steady state and suppose that the deficiency of the underlying reaction network is one. If, in the network, there are two non-terminal nodes that differ only in species S, then the system has absolute concentration-robustness in S.

In the network shown in Figure 3 there are two non-terminal nodes (B+C and B) that differ only in species C. The theorem therefore requires that the network shown exhibits robustness in the concentration of species C. That is, over a wide range of the other concentrations involved, the concentration of C will have the same value. This theorem correctly rationalizes approximate concentration robustness that has been experimentally observed in several biochemical networks. Presence of concentration robustness in a network favors incorporation of that network as a reliable component part of larger dynamic systems.

In some biochemical systems where the concentration-robustness theorem applies, the key species is a single bifunctional enzyme that acts as a catalyst for two quite-different reactions. Presence of such a bifunctional catalyst in a reaction network is a good indication that the network may display concentration robustness. Remarkably, a naturally-occurring example of such a bifunctional catalytic species has recently been found in ancient organisms. Say and Fuchs (2010) report discovery of a bifunctional glycolytic enzyme, 'fructose 1,6-bisphosphate aldolase/phosphatase.' This substance catalyzes the combination of two small molecules to produce the six-carbon sugar fructose 1,6-bisphosphate. Simultaneously the same molecule also catalyzes removal of one phosphate group from that rather unstable initial product to yield a the much more stable fructose monophosphate. (Please see Figure 4.) This new type of enzyme has been found to be contained in "virtually all archaeal groups" — including many ancient biological species that have high-temperature

'chemoautolithotrophic' metabolism. These are critters of exceedingly ancient lineage that live at temperatures close to or above the boiling point of water and fulfill their food requirements by chemically degrading rocks.

Current theories of the origin of life at sites of undersea volcanic activity (e.g., Smith and Morowitz 2005, Earley 1998a) postulate that, at or just prior to the origin of life, previously-existing endothermic reaction-networks that produce six-carbon sugars from three-carbon precursors (using geologic energy for glycogenesis) *reversed their direction of operation* to yield exothermic reaction-networks that use six-carbon sugars to produce three-carbon products (in energy-releasing glycolysis) and thereby made biological activity possible. This quite novel bifunctional catalyst was discovered in the most ancient currently existing organisms, has characteristics conducive to concentration robustness, and brings about an essential step in the postulated glycogenetic mechanism. Taken together these facts have been interpreted to suggest that this enzyme may be a 'dynamic fossil' that preserves information relevant to the dawn of proto-biology. (Gunawardena 2010) This specific suggestion is speculation. What is not speculation is that closure of dynamic networks of chemical processes, what we here call *Closure Jacques Cauvin*, did play a central role in the origin of life, and also in the beginnings of each of the myriad more-complex dynamic coherences that now characterize our world.

In *The Birth of the Gods and the Origins of Agriculture* (1994, 2000) anthropologist Jacques Cauvin explored how prior changes in concepts and social practices *made possible* initial development of agriculture, and thereby grounded the flourishing of subsequent human cultures. It is on this basis that we designate as '*Closure Jacques Cauvin*' any mode of interrelation of processes that makes further network formation possible. The concentration-robustness theorem quoted above is one example of such closure, the discovery of the ancient bifunctional enzyme to which that theorem applies is a second example. Elsewhere, I consider such systems as examples of 'Process Structural Realism' (Earley forthcoming, 2008a, 2008b, 2006, 2003b, 2003d).

Cauvin's insight has been developed by recent studies based on evolutionary network theory (Atran 2010) that have clarified how human agents have themselves been shaped by relational networks — at the same time each of those networks has been created by the choices of such agents. As Marjorie Grene (1978) observed: "We do not just *have* rationality or language or symbol systems as our portable property. We *come to ourselves* within symbol systems. They have us as much as we have them." One perhaps surprising finding of Atran's recent (2010) research is the conclusion that transmission of a conceptual system is greatly enhanced rather than impeded if that scheme of thought involves some counterintuitive (i.e. nearly incredible) concepts. Such 'counterintuitive' propositions clearly have played essential roles in major advances in human evolution. Perhaps the widespread acceptance of the counterintuitive doctrine that 'objects are bundles of properties' can be understood on this basis. Human individuals do develop their identities *within* social and technological networks, but the actions of those persons (along with other factors) *constitute* those networks. Such complex closures are dealt with in Rom Harré's *Positioning Theory* (Harré 1999), Isabelle Stengers' *Cosmopolitics* (Stengers 2010), and Bruno Latour's *Actor Network Theory* (2010, 2005).

Conclusion

Each of the three types of closure described above corresponds to a transition in topology of description. Louis de Broglie clarified (for his time) how coherence of electrons and protons constitute atoms – basic units of an 'ontology.' Henri Poincaré demonstrated how new topologies (ontologies) result from cooperative action of molecules. Jacques Cauvin showed how the invention or discovery of human conceptual systems enabled ('afforded') yet further evolutionary advance. Each of these three sorts of closure corresponds to a type of major transition in the history of the world, and makes additional kinds of human understanding possible. Undoubtedly other modes of closure exist: the important point is that causal functions ('properties') of items depend, in every case, on underlying defining closure of relationships. As *Closure de Broglie* provides the basis for intra-molecular processes and super-molecular coherences, and *Closure Poincare* grounds the ontological change brought about by highly cooperative inter-molecular interaction, so *Closure Cauvin* make possible evolution of still more-complex dynamic coherences of *processes* – including ourselves and our cultures. All of these can be regarded as examples of the 'affordances' that Rom Harré discusses elsewhere in this volume. The characteristics of the objects that philosophers usually discuss (such as roses, statues, tennis balls) depend on the chemical closures that involve the components of those entities, and also on closures (e.g. decisions) of other sorts (involving plant breeders and gardeners, sculptors and their patrons, and committees of the US Lawn Tennis Association).

Much current philosophy of science seems to be subject Putnam's objection: "Once we assume that there is, somehow fixed in advance, a single 'real,' a single 'literal' sense of 'exist' – and, by the way, a single 'literal' sense of identity – one which is cast in marble and cannot be either contracted or expanded without defiling the statue of the god, we are already wandering in Cloud Cuckoo Land." (Putnam 2004, p.84-85). Taking such attacks seriously supports the conclusion of Atmanspacher & Primas (2005): "... States and properties of a system which belong to an epistemic description in a particular domain can be considered as belonging to an ontologic description from the perspective of another domain." This move would be quite consistent with science-related 'policy realism' of Rom Harré (e.g. Bhaskar 1990) and also with Michel Bitbol's (1998) contemporary version of transcendental epistemology: "objects are no longer regarded as constituents of our experience but rather as (i) potential aims for our research and resolution and (ii) elements in our strategy for anticipating the outcomes of our activities."

In addition to providing excellent opportunity for technological participation in the development of future societies, chemistry --"The Central Science" -- could contribute significantly to increase in philosophic understanding, hopefully to help humanize evolving and dynamic structures – technological, conceptual, and social.

Acknowledgement: I am grateful to Professor Jean-Pierre Llored, to Professor Michel Bitbol, and to the École Polytechnique for the opportunity to participate in this workshop. I also thank the Graduate School of Georgetown University, and the Georgetown Chemistry Department, for additional support.

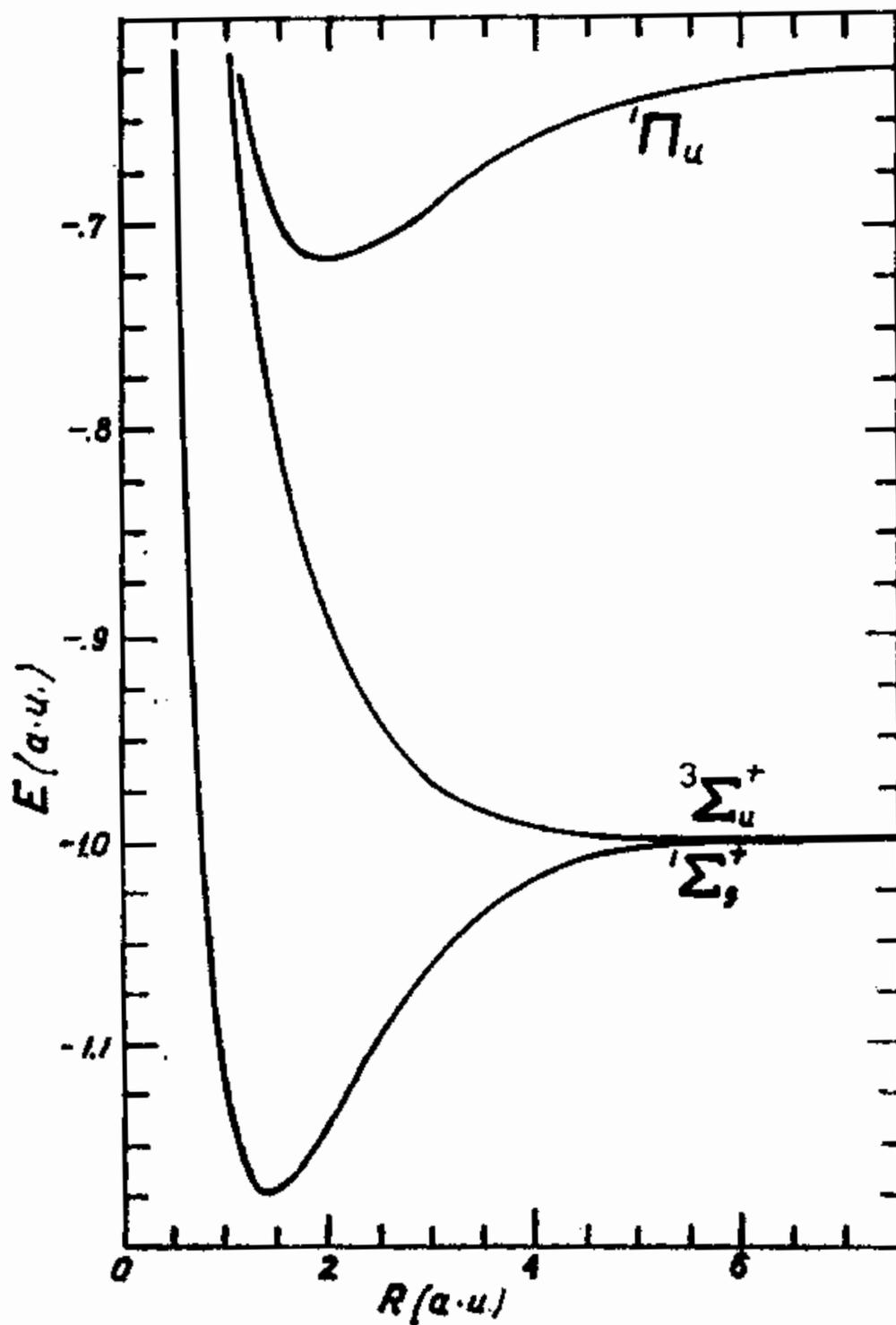
Figure 1. Calculated potential-energy curves for the dihydrogen molecule. (Kolos 1965)

Figure 2. Electronic, vibrational, and rotational energy levels for the dihydrogen molecule. (After Kolos, 1965)

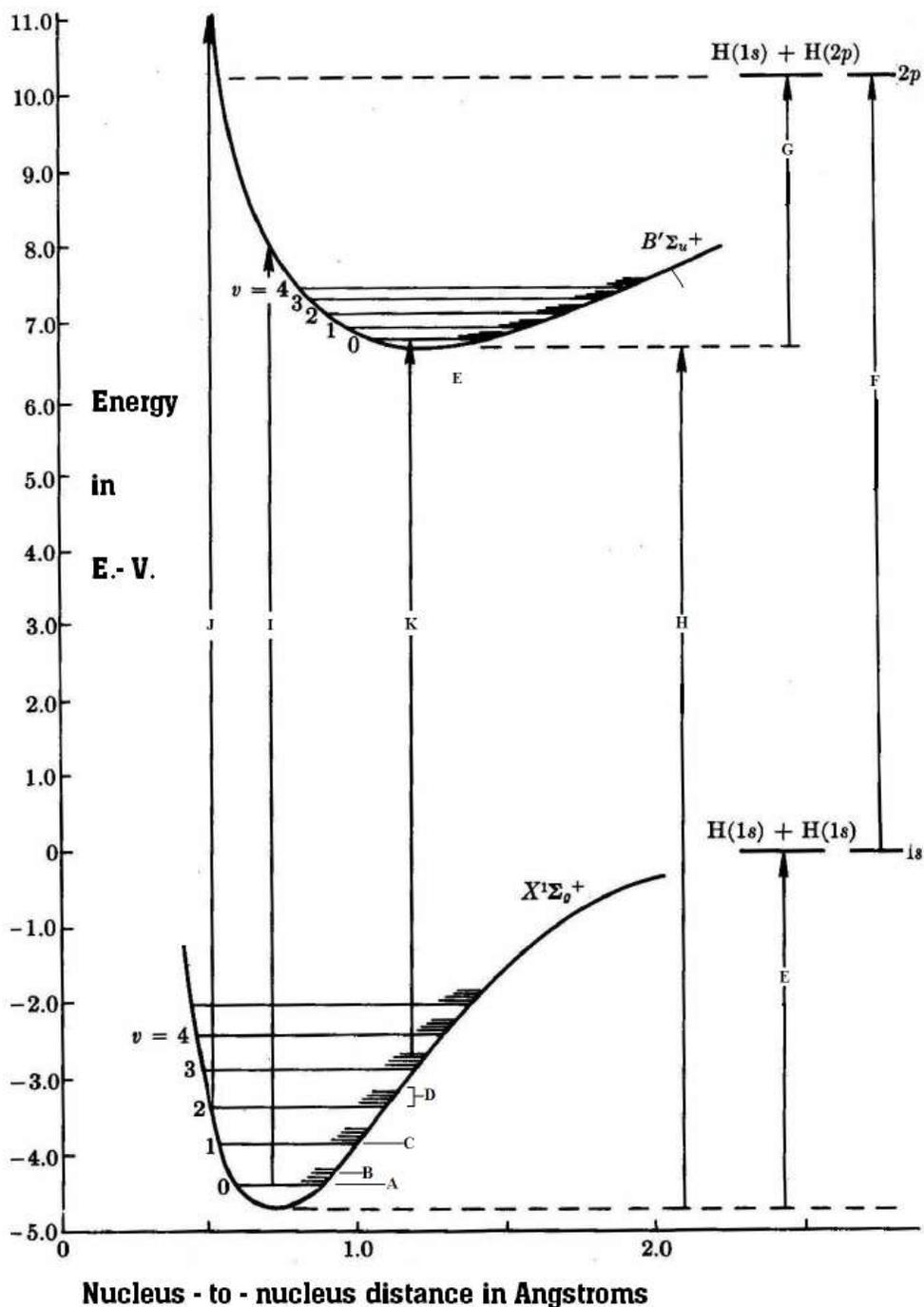


Figure 3. A reaction network that exhibits absolute concentration robustness. From Shinar 2010.

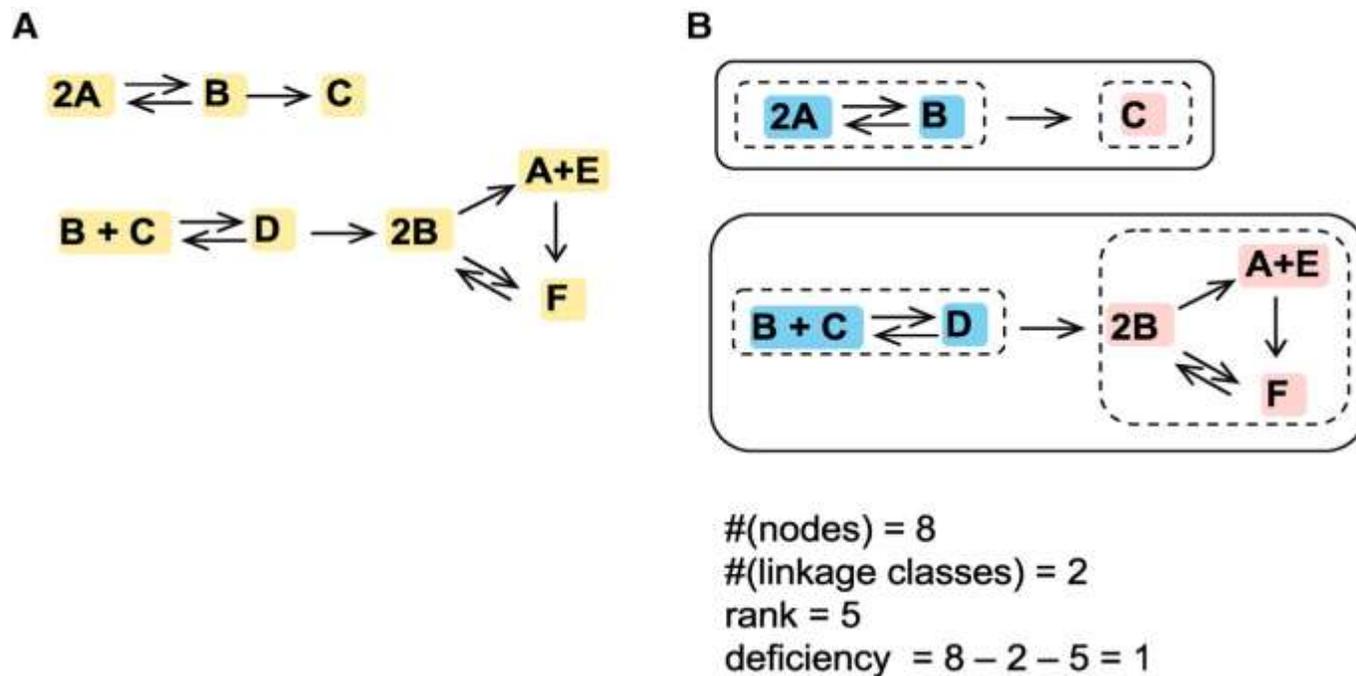
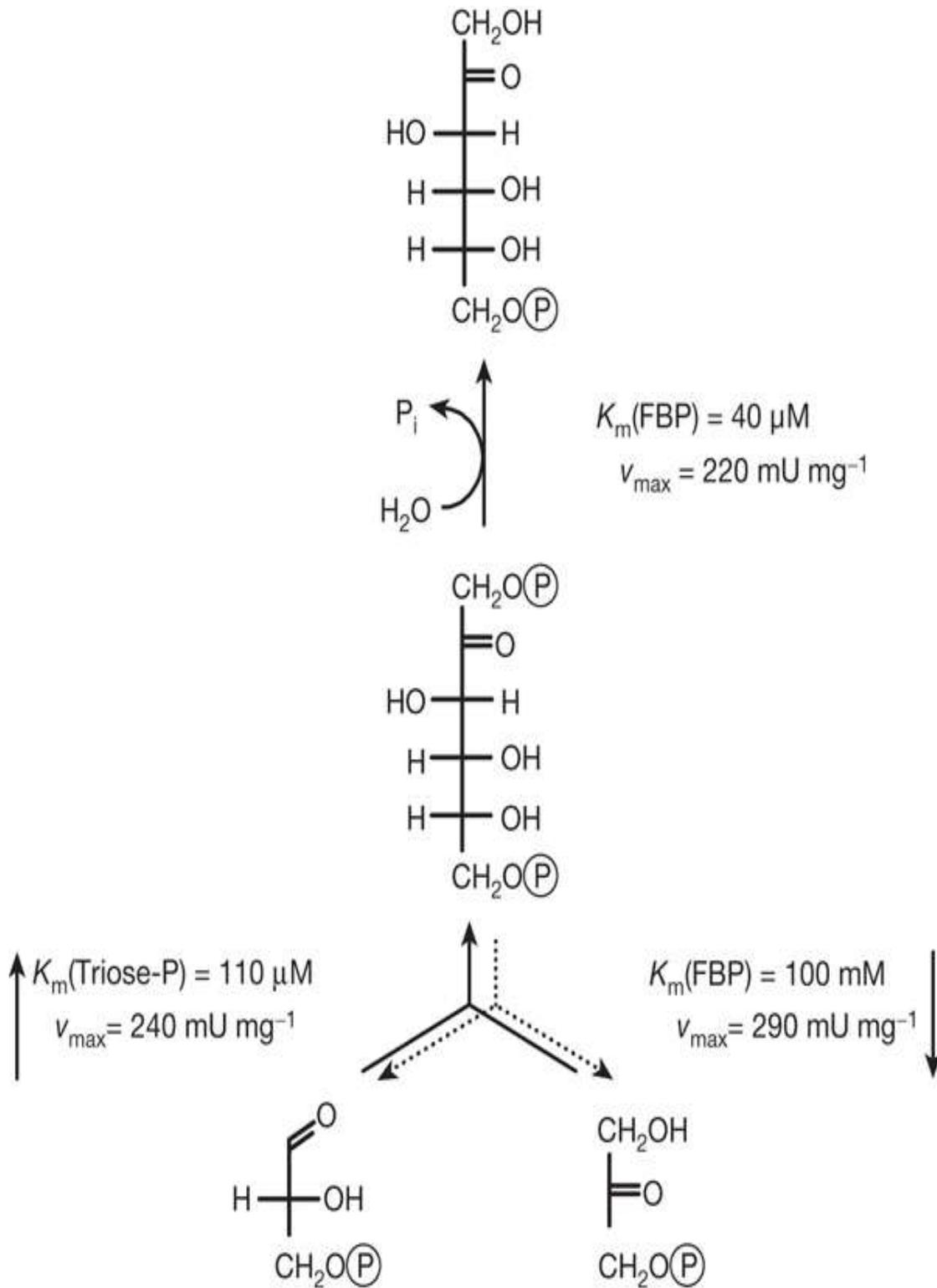


Figure 4. Action of bifunctional fructose 1,6-bisphosphate aldolase /phosphatase. From Say 2010.



References:

- Althorpe, Stuart C. (2010). "Setting the Trap for Reactive Resonances." *Science*, 327, 1460-1461.
- Armstrong, D.M. 2010. *Sketch for a Systematic Metaphysics*. Oxford: Oxford University Press.
- Atmanspacher, Harald and Primas, Hans (2005). "Epistemic and Ontic Quantum Realities." *Foundations of Probability and Physics - 3. AIP Conference Proceedings, Volume 750*, pp. 49-62.
- Atmanspacher, H., Aman, A. and Müller-Herold, editors (1999). *On Quanta, Mind and Matter: Hans Primas in Context*. Dordrecht: Kluwer.
- Atran, Scott and Joseph Henrich, (2010). "The Evolution of Religion: How Cognitive By-products, Adaptive Learning Heuristics, Ritual Displays, and Group Competition Generate Deep Commitments to Pro-social Religions". *Biological Theory*, 5(1), 18-30.
- Batterman, Robert W. (2009). "Idealization and modeling," *Synthese*, 169, 427-446.
- (2005). "Critical phenomena and breaking drops: Infinite idealizations in physics." *Studies in the History and Philosophy of Modern Physics*, 36, 225-244.
- (2002) *The Devil in the Details: Asymptotic Reasoning in Explanation, Reduction, and Emergence*. Oxford: Oxford University Press.
- (1998). "Why Equilibrium Statistical Mechanics Works: Universality and the Renormalization Group" *Philosophy of Science*, 65(2), 182-208.
- Benovsky, Jiri (2008). "The bundle theory and the substratum theory: deadly enemies or twin brothers?" *Philos. Stud.*, 141: 175-190.
- Berry, Michael.(1994). Asymptotics, Singularities and the reduction of Theories, in Logic, Methodology and Philosophy, IX, D. PraWitz, B. Skyrms and D. Westerstahl, editors, Elsevier B.V. 597=607.
- Bishop, Robert C. and Harald Atmanspacher (2006). 'Contextual Emergence in the Description of Properties'. *Foundations of Physics*, 36 (12), 1753-1777.
- Bishop, Robert C. (2005). "Patching Physics and Chemistry Together", *Philosophy of Science*, 72, 710-722.
- Bonk, Thomas, (1994), "Why has deBroglie's Theory been Rejected?" *Stud. Hist. Phil. Sci.*, 25, 375-396.
- Cauvin, Jacques, (1994). *Naissance des divinités, naissance de l'agriculture*. Paris: CNRS.
- (2000). *The Birth of the Gods and the Origins of Agriculture*, Translated by Trevor Watkins. Cambridge, Cambridge University Press.
- Chakrabarti, S. K. and S. Sengupta (1979). "Temperature-induced phase transition and lattice mechanics of CsCl." *J. Phys. C: Solid State Phys.* 12, 2249.
- de Broglie, Louis (1923). 'Radiation – Waves and Quanta', Translated by Brigitte and Barton Lane from: *Comptes rendus*, 177, 507-510.
- Bhaskar, Roy, editor (1990). *Harre and his Critics*. Oxford: Blackwells.
- Bitbol, Michel (1998). "Some steps towards a transcendental deduction of quantum mechanics." *Philosophia naturalis*, 35, 253-280.
- Dong, Wenrui, Chunlei Xiao, Tao Wang, Dongxu Dai, Xueming Yang, Dong H. Zhang (2010). "Transition-State Spectroscopy of Partial Wave Resonances in the F + HD Reaction." *Science* : 327. 1501 – 1502.

- Earley, Joseph E. (forthcoming) "Life in the Interstices: Systems Biology and Process Thought" Spyridon Koutrofinis, ed, *Life and Process. Towards a Whiteheadian Biophilosophy*, Frankfurt: Ontos Verlag.
- (2009). "How Chemistry Shifts Horizons: Element, Substance, and the Essential." *Foundations of Chemistry*, 11: 65-77.
- (2008). "How Philosophy of Mind Needs Philosophy of Chemistry" *HYLE: International Journal for the Philosophy of Chemistry*, 14, 1-26.: <http://www.hyle.org/journal/issues/14-1/earley.htm>)
- (2008a). "Ontologically Significant Aggregation: Process Structural Realism (PSR)". *The Handbook of Whiteheadian Process Thought, Vol. 2*, 2008, Michel Weber and Will Desmond, eds, Frankfurt: Ontos Verlag, 179-191.
- (2008b) "Process Structural Realism, Instance Ontology, and Societal Order," in "*Researching with Whitehead: System and Adventure*" Franz Riffert and Hans-Joachim Sander, eds Berlin: Alber, , 190-211.
- (2006). "Chemical 'Substances' that are not 'Chemical Substances.'" *Philosophy of Science*, 73, 814-852,
- (2005). "Why there is No Salt in the Sea," *Foundations of Chemistry*, 7, (85-102) 2005.
- (2003a). On the Relevance of Repetition, Recurrence, and Reiteration." *Chemistry in the Philosophical Melting Pot*, Danuta Sobczyńska, Pawel Kreidler, and Ewa Zielonaka-Lis, eds, Frankfurt, Peter Lang, 171-186.
- (2003b)"Constraints on the Origin of Coherence in Far-from-equilibrium Chemical Systems" in *Physics and Whitehead: Quantum, Process and Experience*, eds Timothy E. Eastman and Henry Keeton. Albany; State University of New York Press, 63-73.
- (2003c)."Varieties of Properties: An Alternative Distinction among Qualities." *Chemical Explanation: Characteristics, Development, Autonomy*, Edited by Joseph E. Earley, Sr. *Annals of the New York Academy of Science*, 988, 80-89,.
- (2003d). "How Dynamic Aggregates May Achieve Effective Integration." Joseph E. Earley, Sr. *Advances in Complex Systems*, 6, 115-126."
- (2000). "Varieties of Chemical Closure." *Closure: Emergent Organizations and Their Dynamics*, edited by Jerry L. R. Chandler and Gertrudis Van de Vijer, *Annals of the New York Academy of Sciences*,. 901, 122-131.
- (1998a) "Naturalism, Theism, and the Origin of Life". *Process Studies*, 27, 267-279
- (1998b). "Modes of Chemical Becoming", *Hyle—International Journal for the Philosophy of Chemistry*, 4(2), 1998. <http://www.hyle.org/journal/issues/4/earley.htm>
- Harré, Rom and Luk van Lagenhov, editors (1999): *Positioning theory: moral contexts of intentional action*, Oxford: Blackwells.
- Humphreys, Paul (2008). "Synchronic and Diachronic Emergence," *Mind and Machines*, 18, 431-442.
- Grene, M.: 1978, 'Paradoxes of Historicity', *Review of Metaphysics*, 32, 15-16.
- Gunawardena, Jeremy (2010). "Biological Systems Theory," *Science*, 328, 581-581.
- Kolos, W. and L. Wolniewjcx (1965), "Potential Energy Curves for the X $^1\Sigma^{e+}$, b $^3\Sigma^{u+}$, and C $^1\Pi^u$ States of the Hydrogen Molecule, *J. Chem Phys*, 43,

- Latour, Bruno. (2010). "Networks, Societies, Spheres: Reflections of an Actor-network Theorist". Annenberg Foundation International Seminar on Network Theory, San Diego, CA, February 19. YOUTUBE.
- , (2005) *Reassembling the social : an introduction to actor-network theory*. Oxford : Oxford University Press.
- Laughlin, Robert B. (2005). *A Different Universe: Inventing Physics from the Bottom Down*. NY: *Basic Books*.
- Ney, Alyssa (2009). "Physical Causation and Difference-Making." *Brit. J. Phil. Sci.* 60, 737–764.
- Newth, David and John Finnigan (2006), "Emergence and Self-organization in Chemistry and Biology," *Aust. J. Chem.* 59, 841-848.
- Martini, Paul, K. Sellgren, and D. L. Depoy (1999). "Near-infrared Spectroscopy of Molecular Hydrogen Emission in Four Reflection Nebulae: NSG 1333, NGC 2023, NGC 2068, and NGS 7023." *The Astrophysical Journal*, 526: 772-787.
- Moran, M. J., and H. N. Shapiro, (1995), *Fundamentals of Engineering Thermodynamics*, 3rd ed., Wiley, New York, Fig. 3.11, section 3.4, p. 94.
- Peirce, Charles (1878). "How to Make Our Ideas Clear," *Popular Science Monthly*, 12, 286-302.
- Primas, Hans (1998). "Emergence in the Exact Natural Sciences," *Acta Polytech. Scand. Ma* 91, 83-98.
- (2000). "Asymptotically disjoint quantum states", in *Decoherence: Theoretical, Experimental and Conceptual Problems*, edited by Ph. Blanchard et al. Springer: Berlin, pp161-178.
- Polya, G. (1985). *How to Solve It*. Second Edition. Princeton: Princeton University Press.
- Putnam, H. (2004) *Ethics without Ontology*. Cambridge, MA: Harvard university press.
- (1969). "On Properties." In *Essays in Honor of Carl G. Hempel*. N. Rescher, et al., eds. Reidel. Dordrecht. (Reprinted in J. Kim et al., eds. (1999). *Metaphysics: an Anthology*. Blackwell's. Oxford, UK.)
- Robb, David (2005). "Qualitative Unity and the Bundle Theory," *The Monist*, 88(4): 466-493.
- Say, Rafael F. and George Fuchs (2010). "Fructose 1,6-bisphosphate aldose/phosphatase may be an ancestral gluconeogenic enzyme." *Nature*, 464, 1077-1082
- Shinar, Guy and Martin Feinberg, "Structural Sources of Robustness in Biological Networks," *Science*, 327, 1389-1391.
- Sider, Theodore (2006), "Bare Particulars," *Philosophical Perspectives*, 20: 387-397.
- Simons, Peter (1994). "Particulars in Particular Clothing: Three Trope Theories of Substance," *Philosophy and Phenomenological Research*, 54(3): 553-575.
- Smith, E. & H. J. Morowitz, "Universality in intermediary metabolism" *PNAS (USA)*, 2004 ,101 (36), 13168-13173.
- Stengers, Isabelle, Translated by Robert Bononno (2010). *Cosmopolitics I*. Minneapolis University of Minnesota Press .
- Weiss, Paul (1959). *First Considerations*. Carbondale: Southern Illinois University Press.