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Pure possibilities and some striking scientific discoveries

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Abstract Regardless or independent of any actuality or actualization and exempt from spatiotemporal and causal conditions, each individual possibility is pure. Actualism excludes the existence of individual pure possibilities, altogether or at least as existing independently of actual reality. In this paper, I demonstrate, on the grounds of my possibilist metaphysics—panenmentalism—how some of the most fascinating scientific discoveries in chemistry could not have been accomplished without relying on pure possibilities and the ways in which they relate to each other (for instance, in theoretical models). The discoveries are the following: Dan Shechtman's discovery of quasicrystals; Linus Pauling's alpha helix; the discovery of F. Sherwood Rowland and Mario J. Molina concerning the destruction of the atmospheric ozone layer; and Neil Bartlett's noble gas compounds. On the grounds of the analysis of these cases, actualism must fail, whereas panenmentalism gains support.

Keywords Scientific discoveries · Actualism · Excluding possibilities · Possibilism · Panenmentalism · Models

Introduction

Where everything is possible, no knowledge can exist. To know and understand anything, we must exclude various possibilities to get the valid ones. Predictions, too, require excluding possibilities. "Tomorrow will be either clear or rainy" is not a prediction worth its name. We need to know which one of these two excluding possibilities will be the case; otherwise we have no weather forecast. The same holds for truth. "That proposition is either true or false" provides us with no knowledge of whether the proposition in question is true or not.

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Though excluding possibilities is necessary for any scientific progress, no less important is saving possibilities, for excluding some possibilities has turned out to be almost fatal for scientific progress: excluding the possibilities of quasicrystals did not contribute to the recent progress of crystallography, materials science, chemistry, and physics; instead, it hindered it (although excluding these possibilities contributed to the development of classical crystallography at the time). Today, quasicrystals are being considered as actualities although, until his last years, one of the greatest chemists of all time, Linus Pauling, declared them to be impossible. Quite a few great scientific discoverers have been doomed to fight strong opinions about the impossibility of their discoveries.

The first step in saving such vital possibilities is to acknowledge them as pure. To exclude the pure possibility of something means, from the outset, that such a thing cannot exist at all. To acknowledge, identify, understand, explain, and predict something, we must first acknowledge its pure possibility. For instance, as long as physicists had neither established final evidence for the actual existence of the Higgs boson nor such evidence for its actual nonexistence, they still had very good reasons to acknowledge its pure possibility. Physicists have thought that such possibility *exists* and is not excluded; they knew a priori how to *identify* it; they understood and explained *why* it had to exist; they expected to discover its actual existence; and, thus, they *predicted* this discovery.

Logical, mathematical, or theoretical possibilities, for instance, are pure possibilities ("theoretical" refers to any epistemic or scientific field; hence there are physical, chemical, biological pure possibilities and so forth). Regardless or independent of any actuality or actualization and exempt from spatiotemporal and causal conditions, each individual possibility is pure. Mentioning individual pure possibilities, I do not rely upon the idea of possible worlds. The philosophical view that does not admit individual pure ("mere") possibilities—altogether or at least as existing independently of actual reality—is called "actualism," whereas the view that does acknowledge such possibilities is called "possibilism." Actualism is generally allowed to use the idea of possible worlds and possible world semantics. Nevertheless, to the best of my knowledge, no actualist theory, including the most recent ones, admits the aforementioned absolutely independent existence of individual pure possibilities *or*, more traditionally, even any existence of them (consult, for instance, Bennett 2005, 2006; Nelson and Zalta 2009; Contessa 2010; Menzel 2011; Woodward 2011; Vetter 2011, and Stalnaker 2004, 2012).

In the last 15 years, I have introduced and elaborated on an original possibilist metaphysics—panenmentalism or panenpossibilism (Gilead 1999, 2003, 2009 and 2011). Challenging actualism, panenmentalism is a possibilism *de re*, according to which pure possibilities are individual existents, existing independently of actual reality, any possible-worlds conception, and any mind (hence, they are not ideal beings). To the best of my knowledge, panenmentalism differs from any other kind of possibilism. Claiming that, it is not in my intention to argue that it is preferable to the other kinds; I say only that it is a novel alternative to them, by means of which we can clearly and convincingly explain scientific discoveries, such as those that will be discussed below.

The following are the main features in which panenmentalism differs from other kinds of possibilism: First, Panenmentalism is strongly realist about individual pure possibilities, which are thus independent existents rather than mere "beings" or "subsistents." Over this point, panenmentalism disagrees with Meinonigians, Neo-Meinonigians (to begin with Richard Routely [Sylvan]; see Gilead 2009, pp. 23–27, 33–38, 46–47, 83–91, 109–113, and 121) and their followers (such as Graham Priest, Nicholas Griffin, Terence Parsons, and Edward Zalta). Second, it dispenses with the idea of possible worlds, which almost all the possibilists known to me have adopted. This idea is quite problematic for various reasons:

for instance, it is not clear enough, and there are many controversies about it with no universal or long-standing consent; the problem of the epistemic accessibility from one world to another, especially from the actual world in which we live, to any possible world does not appear to have a satisfactory solution; and if we can dispense with this idea and find a satisfactory, clearer and simpler, alternative to it, we should take this possibility into consideration. Third, panenmentalist pure possibilities are not abstract objects or entities, neither are they potentialities, for abstractions (as abstracted out of actualities or actual reality) and potentialities depend on actualities which are ontologically prior to them, whereas pure possibilities are ontologically prior to and entirely independent of actualities. Four, though using truthful fictions, panenmentalism, acknowledging the full, mind-independent reality of pure possibilities, differs from any kind of fictionalism, especially modal fictionalism (Gilead 2009, pp. 80–83; this difference holds also for Kendall Walton's make-believe theory). Five, as mind-independent, pure possibilities are not concepts, hence panenmentalism is possibilism *de re* and not conceptualism or possibilism *de dicto*.

If some readers may think that the panenmentalist pure possibilities allegedly remind them of Edward Zalta's "possible objects" or "blueprints" (Zalta 1983; McMichael and Zalta 1980) or of Nino Cocchiarella's "possible objects" (Cocchiarella 2007, pp. 26–30; Freund and Cocchiarella 2008), such is not the case at all. First, these possible objects rely heavily on possible-worlds conceptions. Second, according to Cocchiarella's conceptual realism, framed within the context of a naturalistic epistemology, abstract intensional objects "have a mode of being dependent upon the evolution of culture and consciousness" (Cocchiarella 2007, p. 14), whereas panenmentalist pure possibilities are entirely independent of such evolution and of its naturalistic context as well and are a priori accessible (as I will soon argue below). Third, following Meinonigians and Neo-Meinonigians, both Zalta and Cocchiarela consider "actual" and "exists" as synonyms, while, in their view, possible objects are merely "beings." In contrast, panenmentalism treats both pure possibilities and actualities as existents, though in different senses of the term "existence" (distinguishing between the existence of pure possibilities and that of actualities—the former is spatiotemporally and causally conditioned, while the latter is entirely exempt from these conditions).

Finally, although David M. Armstrong adopts a special kind of possibilism (such as "possibilism in mathematics") and is committed to mere possibilities, namely, those without instantiation (Armstrong 2010, pp. 89–90), this is not a possibilist view in my terms. Such is the case because, in Armstrong's view, these possibilities are not existents; they do not exist (ibid., p. 90), as he states that the only existence is spatiotemporal. Hence, his hypothesis is that there are no objects outside space–time (ibid., p. 5). Furthermore, though as a "one-worldler," Armstrong rejects other possible worlds (ibid., p. 16), the mere possibilities that he adopts explicitly supervene on the actual (ibid., p. 68). Thus, they are not pure possibilities in my terms (that is to say, entirely independent of anything actual). Finally, if mere possibilities are not existents, in what sense are they discoverable?

Indeed, each of the scientific discoveries considered below is clearly and convincingly explained on the grounds of individual pure possibilities that are real, mind-independent existents, without relying on any possible-worlds conception. Each of these discoveries begins with the ontological discovery of the existence of a pure possibility (or pure possibilities and their relationality), a priori accessible, regardless of any reliance upon actualities or actual reality as a whole. Acknowledging the independent existence, the reality, of these possibilities paved the way to the discovery of their actualities. Other scientists could make such actual discoveries, had they not excluded the independent existence of these pure possibilities. No possible-worlds conception was required for any of these discoveries.

Instead of relying on the idea of possible worlds, panenmentalism refers to one total realm of all possibilities, pure and actual. Panenmentalism allows our knowledge a limited a priori access to the domain of pure possibilities, whereas the access of our knowledge to actual, empirical reality is a posteriori and must rely upon experience only. Actual reality consists of actualities, which are the outcomes of the actualization *of* pure possibilities. Actualization subjects individual possibilities to spatiotemporal and causal conditions. Each actuality has a particular pure possibility serving as the identity of that actuality. It is the knowledge of that pure possibility-identity that enables us to identify the relevant actuality. As actuality, each possibility is not pure and, hence, it is restricted by spatio-temporal and causal conditions, from which any pure possibility-identity is exempt. For reasons I have detailed elsewhere (recently in Gilead 2009), necessity pertains to the domain of pure possibilities and their relationality (namely, the ways in which they relate to each other): each pure possibility necessarily exists and each such possibility necessarily relates to all the others. In contrast, contingency inescapably pertains to the domain of actualities for there is no necessity about the actualization of pure possibilities. There could be nothing actual, whereas there could not be no pure possibilities. They are timeless entities, which are not invented but subject to discovery. Thus, nothing could avoid the existence of pure possibilities and nothing could generate them. As the actual domain is not subject to necessity, it is subject to contingency, randomness, chances, coincidences, serendipity, and the like. This is compatible with the panenmentalist view that the domain of pure possibilities is a priori cognizable, whereas the domain of actualities is a posteriori cognizable. In panenmentalism, as in the philosophy of Kant and not as in the views of Saul Kripke and others, only a priori truths can be necessary, whereas a posteriori truths are contingent.

The access of our knowledge to the domain of pure possibilities is limited for we are finite and limited creatures. Yet our imagination and intellect are sufficient for an adequate a priori access to that domain, quite independent of experience and actual reality.

If not by empirical means, how can we have access to pure possibilities, mathematical or otherwise? How can we know them, become acquainted with them, if not by means of actual experience and empirical observations?

Each pure possibility is different from any other pure possibility, and no two pure possibilities can be identical, otherwise “two” pure possibilities would have been one possibility instead of two. In case of actualities, which are actual possibilities, two or more of them might be identical (though numerically different), provided that they did not exist at the same place in the same time, whereas such could not be the case of pure possibilities, which are entirely exempt from spatiotemporal conditions or restrictions. Pure possibilities are different from actual possibilities. We can grasp counterfactual possibilities, even though we know of no similar possibilities, actual or pure. While observing actualities, we can think or imagine that things *could* be different, that there are counterfactual *possibilities*; while considering some pure possibilities, we can think also about quite different pure possibilities, each of which is *different from* the other and, hence, each *relates* to the other. This universal mutual relationality allows our knowledge a priori accessibility to a great number of pure possibilities. Our imagination and intellect are not confined, thus, to actual reality; they have access to new pure possibilities simply because they are different from the already familiar possibilities, pure or actual. Thus, we are capable of relating and referring to, imagining, thinking about, and understanding possibilities that are entirely different from the possibilities, pure or actual, with which we are already familiar.

Although it is a moot point to what extent mathematics is not empirical but, instead, is independent of actual reality, I have some reasons to think that pure mathematics consists of mathematical pure possibilities and their relationality and, thus, its discoveries are a priori accessible. Mathematical imagination, calculation, and inference have been never confined to actual reality and many most imaginable, even fantastic, mathematical discoveries have been independent of actual reality and empirical facts (Atiyah 1995). It is sufficient to think about Euclidean geometry to demonstrate such independence: for instance, unlike its representation as an actual dot, a point has a position but no dimensions (according to the first definition in Book I of Euclid's *Elements*); it cannot be measured and yet it exists in the Euclidean space (which is a purely possible domain in which geometrical pure possibilities are ordered side by side). A line (according to the second definition in that book) is "length without breadth," whereas any actual drawn line must have some breadth, however small. Pure geometrical lines and points are not subject to our observation; only their manifestations, phenomena, or representations in actual space are subject so. Pure geometrical points and lines are thus "ideal," but this does not make them abstractions from actual reality (by "ideal" I do not mean a dependence on our mind). They are neither idealizations of empirical facts for, if they were, they would be idealized according to some ideal standard or paradigm, which, in turn, must be entirely independent of empirical facts and which, hence, would have been purely possible.

Supports of the idea that pure mathematics refers to a priori accessible possibilities, independently of actual, empirical reality, can be found in Hermann Weyl (1929, p. 249), Howard Stein (1988, p. 252), Geoffrey Hellman (1989, p. 6), and others.

It is an actualist fallacy to think that no individual pure possibilities exist or that actualities are all the individual possibilities that exist. Panenmentalism argues to the contrary—that (1) individual pure possibilities exist independently of our mind, on the one hand, and of actualities, on the other; (2) our mind has enough a priori access to the domain of pure possibilities, quite independently of experience or of actual, empirical reality; (3) we discover pure possibilities, mathematical and otherwise, as much as we discover new actualities; (4) ignoring or not acknowledging relevant pure possibilities may result in passing by their actualities without noticing, recognizing, or identifying them and, thus, this hinders the progress of science and knowledge. If I am not mistaken, actualism results in fatal fallacies whenever it rejects these four statements.

Intellect and imagination are indispensable tools for scientific progress, and it is in the nature of these tools not to be confined by the actual and even to proceed beyond it. These faculties of the human ingenuity thus rely heavily upon pure possibilities and their relationality.

Since imagination plays an indispensable role in discovering pure possibilities, we should ask ourselves whether this does not leave us with fictions instead of real possibilities. We create fictions, whereas we discover pure possibilities. Fictions may well serve us in discovering possibilities that are independent of our mind. I called such fictions truthful (Gilead 2009, 2010). By means of truthful fictions we capture mind-independent pure possibilities and their relationality. In scientific discoveries, for instance, the fictions involved in thought-experiments and models serve scientists to discover mind-independent pure possibilities and to illuminate some of the deepest secrets of reality.

The first step in acknowledging the existence, let alone the possibility, of something is to acknowledge its pure possibility. Before Shechtman's discovery of an actual quasicrystal, crystallographers, physicists, chemists, or material scientists argued that quasicrystals were impossible, not only because they contradicted empirical classical crystallography and its basic principles or laws, but also because they were incompatible with the classical *geometry* of crystals and its 230 purely possible space groups. These scientists excluded in fact the very, *pure* possibility of any quasicrystal. Independent of

Shechtman's great discovery, such mathematical or theoretical pure possibilities were discovered by Alan Mackay and others. On 8 April 1982, when, for the first time, Shechtman observed the image of an actual quasicrystal, he could neither understand nor explain *why* such a crystalline structure was possible, for he was entirely unaware of Mackay's discovery (Hargittai 2011a, p. 159; Hargittai 2011c) but, as he has claimed, he was aware of the "impossibility" of such a structure according to classical crystallography. To understand and explain why such structure is nevertheless possible, Shechtman should have been familiar with the pure possibility of such a structure. Since I have discussed elsewhere (Gilead 2012) the discovery of quasicrystalline pure possibilities and Shechtman's discovery of an actual quasicrystal, I will not discuss now this most instructive case in detail again (for an updated analysis of Shechtman's discovery see Hargittai 2011a, pp. 155–172; and Hargittai 2011c).

István Hargittai has recently published an important and interesting book—*Drive and Curiosity: What Fuels the Passion for Science*—concisely detecting the process of some great scientific discoveries in the twentieth century (Hargittai 2011a). He ascribes these discoveries to two main motives that impel the discoverers—drive and curiosity. His reports of scientific discoveries have a special significance, because he himself is a distinguished scientist and a scientific editor who has conducted interviews and maintained communication with many of the discoverers mentioned in his books. Thus, he is especially familiar with the context of discovery concerning these discoverers. The clear and accessible information as well as the insightful analysis with which he provides the reader are indispensable.

Hargittai does not refer to the role of saving possibilities, to begin with pure possibilities, in fueling the drive and curiosity motivating the scientific discoverers. Nevertheless, I interpret his reports of these cases in light of some panenmentalist ideas concerning the indispensible role of acknowledging and saving pure possibilities in making such discoveries possible. The limited space of this paper has not allowed me to apply panenmentalist principles to other striking discoveries discussed in that book: Árpád Furka's combinatorial chemistry; Kary B. Mullis's polymerase chain reaction; the discovery of James D. Watson and Francis Crick of the DNA structure; Leo Szilard's idea of a nuclear chain reaction; and George Gamow's Big Bang model.

Panenmentalism is a possibilist systematic metaphysics which has branches in various philosophical areas, one of which is philosophy of science. In the past, I applied panenmentalist principles to interpreting and analyzing various scientific discoveries such as eka-elements, omega-minus, and Darwin's Predicta Moth. But it was only quite recently, since October 2011, that I have realized that panenmentalist principles are useful in philosophically analyzing or interpreting the following scientific discoveries.

Linus Pauling's discovery of the alpha helix

Describing Pauling's discovery of the alpha helix as the structure of protein, Hargittai writes:

> Pauling—ever the model builder—sketched a protein chain on a sheet of paper, which he folded while looking for structures that would satisfy the assumptions he had made. He found two. He called one the alpha helix and the other the gamma helix, but he would quickly discard the gamma helix. … Pauling found the model so attractive and so sensible that he had little doubt in its correctness. … At this time, he

> had an opportunity to visit the British group in Cambridge, and Max Perutz showed him his excellent diffraction patterns. From the X-ray diagrams it was obvious to Pauling—though not yet to Perutz—that it corresponded to Pauling's alpha helix model. Pauling was excited by what he saw but kept calm and did not say anything to Perutz. (Hargittai 2011a, p. 98)

First, the model under discussion, though depicted in an actual folded sketch, is purely possible: while Pauling constructed it, the model was entirely independent of any actual evidence. The sketch simply depicts the relationality among the chemical pure possibilities of a protein chain; a relationality that Pauling discovered. Note that pure possibilities are individual entities, whereas relationality is general, which is in the nature of models. While the model of alpha helix consists of pure possibilities and their relationality, Perutz's diffraction structure was an X-ray image of an *actual* structure. Pauling recognized it as an actuality of (or corresponding to) the model he had discovered and hence he—unlike Perutz—could identify the structure. As Hargittai reports, "[t]he Cambridge X-ray diffraction pattern showed the helical nature, but Perutz did not think about it and thus did not notice it" (Hargittai 2011a, p. 101). In contrast, Pauling had thought about the purely possible alpha helix structure, of which he had had an a priori concept, owing to which he later noticed and identified the actual alpha helix structure in Perutz's findings. It is quite interesting and enlightening (especially from a panenmentalist viewpoint) to compare this with Alan Mackay's warning in the 1980s that crystallographers should be aware of the *possibilities* of structures outside the classical system, "[o]therwise we might encounter them but walk by them without recognizing them" (Hargittai 2010, p. 82). Similarly, Perutz encountered the novel structure of the alpha helix and "walked by it" without recognizing or noticing it, only because, unlike Pauling, he had no access to the purely possible identity of the alpha helix.

This identification was possible only because Pauling already had the purely possible model in mind. Having read Pauling's paper about the alpha helix model, Perutz performed an additional X-ray experiment that gave further evidence, "showing the correctness of Pauling's result, something that Pauling himself had missed" (Hargittai 2011a, p. 104). Such actual evidence might provide the model with confirmation or with completion and correction. Indeed, in scientific discoveries, empirical experiments and observations are as vital as pure possibilities. Though the purely possible model is subject to discovery and, thus, is independent of the discoverer's mind, the first acquaintance with the model may be incomplete or faulty, as human knowledge is never perfect. Nevertheless, the acquaintance with the empirical data can help scientists in correcting and completing the model, which does not diminish its status as purely possible and as a priori cognizable.

Pauling's excitement while watching Perutz's X-ray images reminds me very strongly of James D. Watson's excitement in watching the X-ray diffraction image of the DNA produced by Rosalind Franklin, and which was a "crucial experimental evidence" (Hargittai 2011a, p. 42) for the actual existence of the double helix. Watson already had a model in his mind, a purely possible one, by means of which he could identify the image of the DNA actual structure and realize its great significance.

Still, is any such model really independent of actualities, empirical observations, and experiments? In other words, does it really consist of pure possibilities and their relationality? Is it a priori cognizable?

Indeed, in panenmentalist terms, the model relates to the relevant pure possibilities which can be actualized in empirical reality. Even if the properties on which the model is constructed are first taken from actual reality, based upon actual observations or experiments, the model concerns the relationality (for instance, the general structure) of *all* the relevant pure possibilities that are actualized, actualizable, or *predicted* to be actualized in empirical reality. All the relevant pure possibilities and their relationality lie quite far from the actual cases from which the properties of the model were supposedly selected or chosen by the theoretician-discoverer.

Scientific models draw their principles and patterns from the domain of pure or a priori cognizable possibilities or, more precisely, from the relationality of these possibilities. The purity and apriority under discussion are entirely compatible with the indispensable demand that all such models, if or when confirmed as actual, should comprise or capture all the known relevant empirical facts that have happened to be actual (and which can serve in correcting the model and adapting it further to actual reality). In themselves, models consist of pure possibilities whose meanings and significance are independent of actual reality and yet are quite actualizable. Such are all the valid and sound mathematical or theoretical models. Indeed, practical considerations play an essential role in deciding which of the purely possible models can serve us conceptually in capturing actualities or in applying pure possibilities to actualities. Yet nothing in this practicality may exclude the purity and apriority of the model of the alpha helix.

In the case of Pauling's discovery, there was no need, especially for such a self-assured and convinced scientist, to make an empirical adjustment or correction. Although, in the beginning, there was a discrepancy between his calculations and the empirical findings of Perutz, eventually "the origin of the discrepancy was understood: it was caused by the alpha helices twisting together into ropes resulting in a change in the experimental data as compared to what it would be for a single chain for which the model had been constructed" (Hargittai 2011a, pp. 99–100). Thus, in the end, "Pauling's alpha helix was confirmed even in this detail. The alpha helix has proved to be a great discovery because it is a conspicuously frequent structural feature of proteins" (ibid., p. 100).

You may, however, still counter-argue that in constructing successful models, we discern and abstract from actualities the important or significant properties to serve well our knowledge, understanding, and predications, while, at least for a time, we have to ignore other, insignificant properties or effects (this may be modified in the future depending on what the model is supposed to describe or to model). My answer would be that to discern and abstract so we need an earlier acquaintance with pure possibilities-identities and their relationality by means of which we can discern, identify, and capture these significant or important properties as pure or as actualized. Possibilities-identities are a priori referable and accessible independent of their actualization.

If indeed Pauling was ever the model builder, he knew admiringly how to use the accessibility of his imagination and intellect to the domain of chemical pure possibilities and their relationality, by means of which he could achieve his astonishing discoveries.

At present, computers help scientists to construct models. This does not render the model a posteriori or experimental. Like Pauling's folded piece of paper, computer simulations provide the scientists with images of their thought-experiments. As Mark McEvoy points out, "granted that unsurveyable computer-assisted proofs include only a priori methodology, they are a priori proofs" (McEvoy 2008, p. 386). Similarly, such computer experiments are made in the *image* of thought-experiments. All the more, Pauling's folded paper does not exclude the apriority and the pure possibility of the alpha helix model for Pauling could *imagine* how the folded pure structure could look like! At least, his methodology was a priori. He studied the possibilities, the pure possibilities, in a thought-experiment—how should their arrangement look like in various modes of folding. Pauling's thought-experiment was of a theoretical-geometrical nature.

Ironically, Pauling model did not reveal perfect symmetry, but this did not bother him greatly. He "expanded the realm of crystallography toward structures that were not part of classical crystallography" (Hargittai 2011a, p. 101). What he had allowed himself, he did not allow Shechtman later: although Pauling had been considered as a maverick in his time, he, while confronting Shechtman's daring discovery, reacted like a conservative, dogmatic "classical" crystallographer. Shechtman and others saved possibilities and expanded the knowledge of crystallographic possibilities against the strong opposition of Pauling and his followers. These two cases clearly show how saving relevant possibilities, against the scientists' prejudices, is no less indispensable for scientific progress than excluding other possibilities. Pauling's superior knowledge of structural chemistry helped him greatly in restricting the circle of possible models (Hargittai 2011a, p. 102). Following Hargittai's description, some of the great British crystallographers (Bragg, Jr. and Perutz, on the one hand, and Rosalind Franklin, on the other, extensively using X-ray images of the structures of proteins or of the DNA respectively) appear as distinguished experimenters and empirical observers, empiricists in nature and, in my terms, actualists, whereas Pauling, unwittingly, relied also and no less on pure possibilities, with his great capability to restrict them when necessary and to expand their discovery when necessary.

In 1934, Bernal pointed out the possibility of deducing atomic positions from the X-ray diffraction diagrams of a protein (a single pepsin crystal); however he did not think in terms of models but in more empirically oriented terms. Since Bernal was quite influential, his followers, including Perutz, were not enthusiastic to use models either. Bernal tried to obtain the structure from the actual determination of the atomic coordinates. Hence, he was far from the theoretical, purely possible model of Pauling, which eventually was empirically, actually confirmed in full. Deducing from actualities, in the manner that is unwittingly actualist yet admittedly empiricist, scientists—like detectives—can achieve great results, but not as great as those achieved by scientists such as Pauling.

F. Sherwood Rowland and Mario J. Molina's discovery—the destruction of the atmospheric ozone layer

Reading about the background of the discovery made by Rowland and Molina, Nobel Laureates in chemistry in 1995, I immediately recalled an episode from a novel by a Nobel Laureate in literature, Aleksandr Solzhenitsyn. In Solzhenitsyn's *Cancer Ward*, Oleg Kostoglotov, while receiving treatment for cancer, is immersed in doubt about the use of X-ray radiation for medical purposes and argues about it with his doctor (Solzhenitsyn 2001 [1968], pp. 79–95). Kostoglotov wonders why nobody at the beginning of the use of X-rays suspected that it might cause severe damage to the patients. Indeed, at that time doctors used X-rays with almost no restrictions, even in treating, with tragic cancerous consequences much later, quite minor skin diseases (such as acne—as in the case of the 1984 Nobel laureate in chemistry, Robert B. Merrifield, as documented in Hargittai 2003, p. 217—or such as tinea capitis in Israel in the 1950s). It was a dogmatic exclusion of valid pure possibilities which, in fact, had been quite prevalent, not only among scientists (though it fits tyrannical regimes or religious fanaticism). In a somewhat similar dogmatic vein, when, in the seventies, James E. Lovelock published his pioneering findings about the ubiquity in the atmosphere of chlorofluorocarbons [CFCs], which have been synthesized by humankind, he did not consider them to be a hazard; rather, he regarded them instead as inert harmless tracers, quite useful for scientific research (Hargittai 2011a, p. 196). Furthermore, having read of Rowland and Molina's warning the public about the great hazard that these compounds posed to the atmosphere's ozone layer, Lovelock accused them of "being prone to panic, saying that Rowland in particular was acting like a missionary" (ibid., p. 205; later, however, Lovelock changed his mind about the dangers to the environment and about such an attitude). Lovelock's opposition to Rowland and Molina's discovery is similar to Pauling's opposition to Shechtman's discovery of quasicrystals. The name of the game is excluding possibilities, first of all pure ones, on dogmatic, even fanatic, grounds. Even though Rowland and Molina's calculations and consideration concerning this problem were so simple, the dogmatic power of excluding possibilities was strong and quite powerful (similar to that of some philosophical exclusions). Though scientists have to exclude possibilities to pave the way toward scientific progress, they should be extremely careful when excluding such possibilities, for they are prone to exclude most significant, even fatal, ones, as in the case of the CFCs' damage to the ozone layer. Pharmaceutical history demonstrates this very well (think, for instance, about the "absolute harmlessness" claimed by the manufacturers of thalidomide at the beginning of its production!). Excluding some pure possibilities has entailed grave mistakes and fatal dangers, and the dogmatism involved is fanatic no less than religious fanaticism. A dogmatic accusation made against innovators (such as Rowland) that they were acting like missionaries may reflect more on those who cast the blame than on the innovators.

The story of Rowland and Molina's discovery began with a series of thought-experiments and calculations (Hargittai 2011a, p. 200), which means that it began with studying pure possibilities and their relationality. Instead of experiments, observations, and measurements of actualities, they had to rely on calculations and on using their imagination in investigating pure possibilities and their relationality. Intellect and imagination are indispensable tools in searching the domain of pure possibilities. In the absence of empirical means, scientists must rely upon these tools even more heavily. In Hargittai's report we read:

> If Rowland and Molina had had the means to travel to the atmosphere and carry out measurements there, they would have been more easily convinced that their calculations were correct. But this was not possible at that time so, lacking the ability to verify their findings through experimentations, they could rely only on calculations. First, they had to convince themselves that the CFCs posed an unprecedented danger to the ozone layer. (Hargittai 2011a, p. 201)

Comparing this to Lovelock's assumption that these products were causing no harm, the result of their thought-experiments and calculations was really shocking—their estimate in 1973 of the loss of the ozone layer was about 7 to 13 percent. Thus,

> By December 1973, Rowland and Molina knew they had uncovered an environmental problem of global significance. Their initial hesitation about the validity of their findings came partly from the enormity of the effects and partly from the fact that their calculations and considerations were so simple that it seemed surprising that no one before them had come to similar conclusions. Such hesitation is quite characteristic when a researcher makes a discovery, especially when it seems—at least in retrospect—simple. (Hargittai 2011a, p. 202)

The discovery of some pure possibilities is so simple that their discoverers are really surprised that no one before had thought about these possibilities or thought about them in such a way. It was very simple to imagine or think that X-ray radiation may cause great damage to the patients and, quite surprisingly, only following the empirical evidence of such damage, doctors began restricting their use of it to the possible minimum. The idea—that to expose microorganisms to antibiotics unrestrictedly may bring about their immunity and resistance to these medications—is very simple. Nevertheless, this simple possibility was not considered or taken seriously prior to the empirical evidence about the fatal outcomes of the "domestication" of these bacteria owing to their exposure to antibiotics. We are now facing a medical catastrophe because of the immunity of these microorganisms to antibiotics.

Even the acceptance of the simplest pure possibilities may be quite rare. The reason for this is that usually we think and behave like actualists, assuming that only actualities exist and that to consider counterfactual possibilities or possibilities about which, as yet, we have no actual evidence about because of our limited and confined experience, is simply an imaginary play that should not be taken seriously. Such are some prevailing attitudes toward philosophy and philosophers. Nevertheless, philosophy, or referring to pure possibilities and their relationality, plays a significant role in scientific progress. We should not blame only science or scientists for ignoring this; after all, many, if not most of the philosophers nowadays are not possibilists; many of them are, wittingly or unwittingly, actualists.

Neil Bartlett's discovery of "noble" gas compounds

In my chemistry studies at secondary school, I was quite fascinated by the supposedly established fact that noble ("inert") gases cannot react or combine with any other element. This impossibility appeared to me as solid as the most intriguing fact that the periodic table had proven to be rock-solid and its predictions, concerning all the eka-elements, has been entirely confirmed. No wonder that on hearing for the first time of Neil Bartlett's discovery of a noble gas compound, I was quite surprised. By combining xenon and platinum fluoride, Bartlett created the first noble gas compound (Hargittai 2011a, p. 238, citing the plaque on the building at UBC in which the astounding discovery was actually made). What is so fascinating about this discovery? I believe that one of the most surprising and illuminating traits of science is the intellectual revolution in which what was considered to be impossible proved to be possible and actual. These are special cases of saving possibilities and of expanding our knowledge of the possible as well as the actual.

Indeed, this discovery invalidated the assumption—having been sustained from the discovery of the noble gases, at the end of the nineteenth century, until Bartlett's discovery—that noble gases are inert, namely, as if it were impossible, at least practically, to combine them with each other or with any other element to synthesize molecules. Bartlett transformed this impossibility into a possibility. As in the case of quasicrystals, the definition of noble gases had to be changed owing to Bartlett's discovery—today they can no longer be considered as inert.

The randomness and serendipity of many actual discoveries is quite typical of actualities, especially, of their empirical knowledge. Such is, according to panenmentalism, the contingent nature of actualities and their knowledge. Fortunate circumstances or serendipity is also ascribed to Bartlett's discovery (Hargittai 2011a, p. 226); to the discovery of the first quasicrystal by Shechtman (ibid., p. 155); to the findings of Hideki Shirakawa and Hyung Chick Pyun (ibid., pp. 182 and 299), which led to the discovery of conducting polymers; to Bartlett and Lohman's producing of O_2PtF_6 (ibid., p. 226: "but it was no accident that Bartlett understood the nature of its bonding"); and, finally, to the observation of Arno Penzias and Robert Wilson that the cosmic microwave radiation amounted to three kelvins (ibid., p. 289). Hargittai details some fortuitous circumstances in which discoveries were made (including Mendeleev's great discovery of the periodic law and order; ibid., p. 227).

The possibility of combining a noble gas with another element was not invented by Bartlett; it had "always" been there, "waiting" for a discovery. Bartlett discovered that

> [T]he energy needed for removing an electron from the oxygen molecule was about the same as for removing an electron from a xenon atom. This energy is called the ionization potential… From the similarity of the ionization potentials of molecular oxygen and xenon, it was a short step to the realization that if he succeeded in combining O_2 and PtF_6, it should be possible to do the same for Xe and PtF_6. On paper, this worked fine; now the question was whether he could do the experiment. (Hargittai 2011a, p. 227).

This was a new *pure possibility* that was revealed to Bartlett's mind. It was an *actualist fallacy* to assume that no noble gas could be combined with another element and that any attempt to do so was doomed to failure from the outset. This was an actualist fallacy, for the excluding of such a possibility was based upon actual findings and not upon theoretical considerations. It was an empirical fact, an actuality—no such compound had been found before—either in nature or among human products. Though Bartlett established the pure possibility of such a compound on theoretical grounds, it needed to be established as actual in a well-planned experiment.

Like in the case of Shechtman's first observation of a quasicrystal on 8 April 1982, Bartlett, another lonely discoverer, was, on 23 March 1962, when he performed the experiment, alone in the laboratory, with no assistant nearby, with nobody to share his great actual discovery (Hargittai 2011a, p. 227–228). Interestingly, both discoveries were of compounds created by human beings and not by nature. Both great discoverers were witnessing something that nobody had seen before. Both discoverers were flooded with doubts facing the "impossible." Bartlett asked himself whether the xenon in his experiment was not pure, maybe there was some oxygen present, or maybe he was just fooling himself (ibid., p. 228). It appears that "[b]oth the urge to share the news about his experiment and the instant doubts are typical in such moments of discovery" (ibid.). After all, he had discovered an actuality that was considered impossible (at least practically) before the moment of the experimental discovery. Now, he had to *acknowledge* this possibility, and such acknowledgment could be achieved only after the possibility had passed all the tests of possible doubts.

This motif of the "lonely discoverer" is quite instructive especially against the background of saving scientific possibilities. Natural scientists are routinely working in scientific teams or communities which share common ideas and methods. To save the possibilities that these communities have excluded, as in the cases of Bartlett and Shechtman, the discoverer needs to take a "lonely" stance—to distance or dissociate himself or herself from the prejudices and some of the received ideas at the time. This was also the case of Pauling in his time (although even then his exceptionally vast knowledge of structural chemistry strengthened his confidence in his discovery). The "lonely discoverer" adopts some of the possibilities that the relevant scientific community has excluded. He or she expects that eventually this community will acknowledge the discovery. Such loneliness is valid also even for a team of scientists taking part in a great discovery that still awaits acknowledgement by the scientific community.

There is a further intriguing similarity between Bartlett's discovery and Shechtman's. Each of these discoveries opened up a whole new field in chemistry. In Bartlett's case, within quite a short period of time, more and more researchers reported on producing new noble gas compounds with interesting properties and structures (Hargittai 2011a, p. 222). And in the case of Shechtman, the production and discoveries of more and more actual quasicrystals have been reported since his discovery. In both cases, structural chemistry has been much enriched owing to these great discoveries. Both cases can teach us an important lesson: once a scientist establishes the discovery of a new possibility as real and vital—although previously it had been excluded or not accepted—within quite a short time, a "flood gate" may open for many similar discoveries. These two cases strikingly demonstrate to what extent excluding possibilities, pure or actual, may obstruct scientific progress and scientific vital discoveries.

Although Bartlett's case is quite similar to that of Shechtman, some other scientists before Bartlett tried in vain to combine noble gases with other elements. They made such attempts because the possibility was not theoretically a priori excluded unlike the case with Shechtman. Pauling predicted that since he had found fluorine to be "so electronegative, it could attract away an electron even from the atoms of the noble gases. It was a hypothesis, though, and Pauling wanted experimental confirmation" (Hargittai 2011a, p. 231). In this case, unlike that of the quasicrystals, Pauling did not commit an actualist fallacy and he was open to the pure possibilities of such compounds. But no such a confirmation was found at the time, though the experimenters, Don M. Yost and Albert L. Kaye stated that "[i]t does not follow, of course, that xenon fluoride is incapable of existing" (Yost and Kaye 1933, p. 3892). Thus, in 1933, despite the failure in actualization, Yost and Kaye did not exclude the pure possibility of xenon fluoride. In contrast, the received view that noble gases were inert was simply based on an actualist fallacy, which did not rely upon the relationality of chemical pure possibilities but only on the contingency of the actual failure to combine such gases with other elements or to find such compounds in nature. Thinking in this fallacious way, other chemists argued that there was no point in trying to perform such experiments, simply because there was no actual evidence for the existence of such compounds in nature neither had anyone succeeded in synthesizing them. Contrary to Pauling, Yost and Kaye, all those chemists committed an actualist fallacy. Indeed, this was disclosed quite soon after Bartlett's success, as more xenon compounds were discovered and the experiments to combine more noble gases with other elements were no longer considered as hopeless (Hargittai 2011a, p. 230).

The second difference between Bartlett's and Shechtman's discoveries is that Shechtman did not expect to encounter such an "impossible" crystal, whereas Bartlett expected the possibility that the reaction with the xenon would be actualized.

The discovery of noble gas compounds and the research into their molecular structures relate to various models of molecular geometry and chemical bonding (Hargittai 2011a, p. 235, and Gillespie and Hargittai 1991). Models of molecular geometry certainly rely upon mathematical-chemical pure possibilities and their relationality. The discovery of xenon hexafluoride compound served as an early proof for the validity and usefulness of one of these models that is called the valence shell electron pair repulsion (VSEPR) model and whose discoverer was Ronald Gillespie (Hargittai 2011a, p. 235). This model, too, selects some of the properties of the system that it intends to describe and ignores the rest (Hargittai 2011b, p. 5). Yet the choice is a matter of a priori considerations, like the taxonomic choice of the shape (*morphē* in classical Greek, hence morphology) of organisms to organize them in a classification of species and genus. Similarly, the chosen properties or structures function as pure possibilities, better, as the general relationality of the relevant pure possibilities. All the more pure are the possibilities that are chosen to construct, better, to discover a geometrical model. The VSEPR qualitative model has been successful because by means of it chemists have been able to predict properties of systems not yet studied and "on occasion, not yet even existing" (Hargittai 2011b, p. 5). In panenmentalist terms, they not yet *actually* existing, but their pure possibilities do exist and are not excluded. The VSEPR model has succeeded in predicting molecular shapes, geometries, and even structural variations in series of substances (ibid.). Similarly, modeling served Pauling very well in discovering the alpha helix structure of proteins (as with the case of Watson and Crick's discovery of the double-helix structure of nucleic acids), and modeling inevitably relies upon the study of the relevant pure possibilities and their relationality. The model displays the structural pure possibilities that are actualizable, and the actualization can be confirmed only by empirical findings concerning actualities, namely, by means of empirical observation and experiments.

In his foreword to the chapter devoted to Bartlett, Hargittai reminds the reader that Marcellin Berthelot likened chemistry to art, as both create their objects (Hargittai 2011a, p. 223). As I see this, in art, too, creation begins with the discovery of pure possibilities and their relationality. Think, for instance, of Michelangelo's idea about the uncovering of his sculptures by removing anything superfluous out of the marble. In fact, he selected the marble and uncovered his sculptures out of them in light of the pure "models" he had in mind and sketched on the walls of his hide-place in Florence or on paper. Thus, Michelangelo's creation was a kind of discovery, both of the pure "model" and of the actual sculpture. When chemists create new objects—when, like Bartlett, they synthesize molecules that were not known to exist before—they in fact contribute to the discovery of purely possible ways in which pure chemical possibilities relate one to the other. Thus, creation in chemistry, too, implies discovery of pure possibilities and their relationality, on which these creations supervene, wittingly or unwittingly as far as their discoverers are concerned. In the case of Bartlett, the discovery of the pure possibility of the noble gas compound preceded the creation of the actual compound and paved the way for it. Chemists, beginning with Mendeleev, have endeavored to discover all chemical pure and actualizable possibilities as well as all the ways in which they relate to each other (which is their relationality) to enable compounds. As a result, they have endeavored to discover all possible chemical compounds, whether they are created by nature or by human beings. Either way, any chemical reaction is an actualization of the relationality between some chemical pure possibilities-identities. Bartlett helped greatly in expanding our knowledge of this relationality and in exhibiting its actualization.

Conclusion

The analysis of four striking scientific discoveries clearly shows that relying upon pure possibilities and their relationality has been indispensable to achieve these discoveries. If acknowledging and saving pure possibilities in such discoveries is indeed indispensable for the scientific progress, whereas excluding them hinders such progress, actualism is inescapably invalid, whereas panenmentalism gains support. Scientific progress is achievable only when standing upon two indispensable legs—purely possible systems or models, on the one hand, and empirical, actual data, on the other. It is an actualist fallacy to ignore or exclude the former. To rephrase a Kantian idea for a panenmentalist purpose, pure possibilities without experimental studies and actual data are practically empty, whereas such studies and data without pure possibilities are blind for without the latter scientists cannot notice, recognize, or identify some of the most vital or significant facts. Furthermore, pure possibilities and their relationality are indispensable for understanding and explaining such facts and their possibilities. Empirical studies and study of the relevant pure possibilities together with their relationality are equally essential for scientific progress. Excluding pure possibilities, on actualist or other grounds, has been shown to hinder scientific progress.

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