Chemical Possibility and Modal Semantics

Mark F. Sharlow

msharlow@usermail.com

http://www.eskimo.com/~msharlow

Abstract

This paper is a study of a distinctively chemical notion of possibility. This is the notion of possibility that occurs in chemical discourses when chemists speak of the possibility or impossibility of achieving a given result through chemical means. This notion pertains to the possibility of processes, not of compounds, so it differs from the kind of chemical possibility mentioned in Wittgenstein's *Philosophical Investigations* or the kinds discussed in the literature on Putnam's Twin Earth argument. I argue that this process-oriented notion of possibility cannot be reduced in a simple way to physical possibility, and that standard possible worlds semantics does not allow a natural analysis of this notion. I suggest an extension of possible worlds semantics that may overcome this limitation. I finish by pointing out some open questions about chemical possibility.

Version 2

1. Introduction

The concept of possibility is not simple. It is not even a single idea. Philosophers know of many different notions of possibility. The best known among these notions are logical, conceptual, and physical possibility. Because chemistry is the study of certain aspects of the physical world, chemistry is concerned with what is physically possible. However, there is no *a priori* guarantee that all statements about possibility found in the discourse of chemistry can be interpreted simply as statements about physical possibility [1]. The question of the relationship between chemists' statements about possibility on the one hand, and the standard notions of possibility (such as physical) on the other, should be of interest to philosophers of chemistry. This relationship is especially interesting in view of the ongoing debate over the reducibility of chemistry to physics (for example, Bogaard 1978; Scerri 1991, 1994 and 1997; Le Poidevin 2005; Hendry and Needham 2007) and the role that technical discussions of possibility sometimes play in that debate (Le Poidevin 2005; Hendry and Needham 2007). It also is of interest in view of the ongoing discussion of the possibility and significance of the compound XYZ in Putnam's Twin Earth argument (Putnam 1975; for one example of the discussion, see van Brakel 2005).

The idea that there is a distinctively *chemical* notion of possibility, different from physical possibility, dates back at least to Wittgenstein's *Philosophical Investigations*. In that book, Wittgenstein offered the following observation on chemical possibility (Wittgenstein 1953):

> 521. Compare 'logically possible' with 'chemically possible.' One might perhaps call a combination chemically possible if a formula with the right valencies existed (e.g. H-O-O-H). Of course such a combination need not exist; but even the formula HO_2 cannot have less than no combination corresponding to it in reality.

This idea of chemical possibility, specifically the possibility of a *substance* of a given kind, also comes up in later literature, often in forms slightly different from the one Wittgenstein must have had in mind. Such a notion of possibility plays a major role in the ongoing discussions about the Twin Earth argument. In those discussions, a question about chemical possibility – whether a chemical compound of a particular type is in any sense possible – is central to the debate.

In this paper I will not try to pass judgment on Wittgenstein's brief, intriguing remark about chemical possibility. Nor will I try to jump into the debate over Putnam's Twin Earth argument. Instead, I wish to point out that there is a *second* notion of chemical possibility, quite different from Wittgenstein's notion, which plays an important part in chemists' informal reasoning. What is more, I will show that this notion has some interesting and unusual logical properties that deserve further study by modal logicians.

This second notion of chemical possibility is not about the possibility of substances. Instead, it is about the possibility of *processes*. It is the notion to which chemists resort when they claim that a particular chemical process or type of chemical processes is either possible or impossible. One often hears such claims in the laboratory, the office, and the classroom. For example, a chemist might tell a colleague that a certain organic synthesis pathway is impossible, and might also tell beginning students that changing one element into another by chemical means is impossible. Similar uses of possibility language also occurs in the chemical literature. (See, for example, the use of “impossible” on p. 94 of Keese, Müller and Toube 1982; or the definition of “Chemically possible” for steps in an organic synthesis, given in Smit, Bochkov and Caple 1998, p. 43.) Possibility statements of these kinds are about the possibility and impossibility of *achieving certain results through chemical processes*. They are not about the possibility or impossibility of the existence of particular substances.

In this paper, I will argue that this process-related notion of chemical possibility cannot be reduced in a simple way to physical possibility. Further, I will suggest that possible worlds semantics – the conceptual framework that philosophers normally use to analyze possibility – might not be sufficient for the formalization of the semantics of this chemical notion of possibility. I will point out a way in which we might extend possible worlds semantics to arrive at a more adequate analysis of chemical possibility. Modal logicians might want to pursue this line of inquiry further.

2. Chemical possibility

Chemists sometimes use the words “possible” and “impossible” in ways peculiar to the discourse of chemistry. For example, a chemist might say that it is possible to synthesize a particular drug from a specified set of raw materials. What the chemist normally means by this statement is that it possible to produce the drug from the raw materials *by chemical means alone*. This notion of possibility most often crops up in informal discussions of chemistry; a change in the composition of matter is labeled “impossible” because that change is unattainable by way of chemical processes. This notion of chemical possibility also occurs in the chemical literature (see references above). I will call this informal notion of possibility *chemical pathway possibility* (or *path-possibility* for short). As I stated in the Introduction, we should not confuse this notion with other, equally interesting notions pertaining to the possibility of a chemical substance or formula.

Path-possibility is not the same as physical possibility. A particular type of change in the composition of matter may be physically possible, and yet be path-impossible. An example is the changing of one element into another, which occurs routinely during nuclear reactions but cannot be accomplished through chemical changes alone. Thus, path-possibility and physical possibility do not coincide.

It is important to note that this difference from physical possibility does not make path-possibility anything less than a notion of possibility. One might wonder whether path-possibility really is a notion of possibility at all, in view of the fact that path-impossible results sometimes are *possible* to achieve if we are willing to use physical means that are not chemical. [2] The answer is that path-possibility really is a kind of possibility. It really does pertain to what can happen and what cannot happen. After all, making gold from lead by chemical means really is *impossible*. We just *can't* make lead into gold, by chemical means, period. (In this connection, note that in modal logic a situation may be impossible under one modality but possible under another. For example, logical possibility is broader than physical possibility and covers some imaginable situations that are physically impossible.)

There also is a deeper difference between path-possibility and physical possibility. Path-possibility appears to differ *semantically* from the standard notions of possibility, such as physical and logical possibility. The following paragraph explains what I mean by this.

In standard modal semantics [3], the truth conditions for statements like "It is possible that P" are formulated in terms of possible worlds. According to standard possible worlds semantics, "It is possible that P" is true at the actual world if and only if P is true at some possible world accessible from the actual world. (There are different relations of accessibility for different kinds of possibility; for example, in the case of physical possibility, a world accessible from w could be taken to be a world in which the laws of physics are the same as those in w.) However, this kind of analysis looks unnatural when applied naively to statements about path-possibility. If we try to treat path-possibility along the same lines as physical possibility, then we might try saying that "It is path-possible that P" is true if and only if P is true in some chemically possible world – that is, in some world in which the actual laws of chemistry hold. (Since chemical processes do not violate the true physical laws, we can take the laws of chemistry to include the laws of physics as a proper subset, regardless of whether chemistry is reducible to physics.) However, this analysis of path-possibility is wrong. If we take P to be the statement "Hydrogen sometimes changes into helium," then P is true in some chemically possible world – namely, the actual world, in which all the actual laws of chemistry hold, and in which hydrogen constantly changes into helium through nuclear fusion in the stars. But according to the intuitive notion of path-possibility that we introduced earlier, it is not path-possible that P. The fusion of hydrogen into helium is a nuclear process involving the changing of one element into another, and therefore is path-impossible under the intuitive notion of path-possibility. The mere fact that this change occurs in a world in which the laws of chemistry hold does not count in favor of the path-possibility of the change. What would count is the physical possibility of the change occurring *by way of chemical processes alone*. The processes that convert hydrogen to helium in the sun are not chemical processes; hence the physical possibility of those processes does not count for the path-possibility of anything.

The other notion of chemical possibility that I discussed earlier – the compound-driven notion found in Wittgenstein and elsewhere – might be expressible in terms of possible worlds. One might meaningfully speak of a world or situation as being "chemically possible" in this sense. However, based on the above discussion, it seems doubtful that path-possibility is a property of *worlds* at all.

3. The semantics of chemical possibility

It appears that one obvious possible worlds analysis of path-possibility is inadequate. A more natural analysis of path-possibility might use, instead of possible worlds alone, a domain of possible worlds plus a domain of *possible chemical processes*. Possible chemical processes are chemical processes that are physically possible. Once we have settled on a domain of possible chemical processes, we can say that (roughly speaking) a state of affairs is path-possible if and only if that state of affairs that can be brought about by way of possible chemical processes alone.

Before I try to make the last statement more precise, I will make some remarks on the notion of a possible chemical process. The condition that these processes be "chemical" recognizes the intuitive difference, familiar to chemists, between processes that are chemical and processes that are merely physical. The neutralization of an acid by a base is a chemical process. A nuclear reaction is not a chemical process; neither is the generation of radio waves by an antenna. Roughly speaking, a chemical process is one that results in a change in the molecular structure of matter and does not involve nuclear change. This might not be a fully adequate characterization of chemical processes, especially in view of the difficulties in reducing chemistry to physics. However, we will not try to make this concept more precise at this time. No matter how one makes this notion precise, the domain of possible chemical processes should coincide at least roughly with the domain of those physically possible processes that chemists typically regard as chemical rather than as merely physical.

Once we decide on a domain of possible chemical processes, the suggested analysis of path-possibility would run something like this:

> "It is path-possible that P" is true at world w if and only if: at world w, for some possible chemical process K, if K occurs then P.

For example, "It is path-possible that some sample of sodium bicarbonate neutralizes some sample of acetic acid" is true if and only if there is a possible chemical process K such that if K occurs then some sample of sodium bicarbonate neutralizes some sample of acetic acid. (Such a process K could be, for example, a process in which a drop of acetic acid lands on a chunk of sodium bicarbonate.) As another example, "It is path-possible for aspirin to be synthesized" is true if and only if there is a possible chemical process K such that if K occurs then aspirin is synthesized. (Such a process K could be any process of organic synthesis that creates aspirin.)

As it stands, this definition is incomplete, because it is not clear what the "if...then..." really amounts to in the clause "if K occurs then P." Philosophers know of several kinds of implication, the best known being material, formal, and strict implication. The natural language construction "if… then…" can express any of these implications. Intuitively, it seems reasonable to suppose that the implication in our definition is *physically necessary* implication. That is, "if K occurs then P" means that in any physically possible world (i.e. world physically possible from the standpoint of the actual world), K materially implies P.

We arrive at the following semi-rigorous definition of the notion of path-possibility:

> "It is path-possible that P" is true at world w if and only if: at world w, for some possible chemical process K, it is physically necessary that if K occurs then P.

Here the final "if...then..." expresses material implication.

This semi-formalized notion of path-possibility still involves possible worlds, but possible chemical processes now play a prominent role.

We note that the domain of possible chemical processes may, in principle, vary from world to world. To best reflect the intuitive notion of path-possibility, we might want to take the domain of possible chemical processes in the preceding definition to be the domain of possible chemical processes in the actual world. (More on this later.)

4. Future directions

We have arrived at a preliminary sketch for a semantics of the notion of path-possibility. In doing so, we introduced a special semantical device: a domain of possible processes, which plays a role in the semantics along with the domain of possible worlds. Before closing the paper I will point out a few open questions for further philosophical work on the concept of path-possibility.

(1) One question has to do with the structure of the domain of possible chemical processes. It is well known that the domain of possible worlds may have a nontrivial internal structure. For example, one usually defines an accessibility relation upon that domain. The accessibility relation has different formal properties for different notions of possibility. We may ask whether the domain of possible chemical processes has any internal structure relevant to the semantics of path-possibility, and whether giving this domain more (or less) internal structure might lead to interesting alternatives for the semantics and the resulting logic.

To begin exploring this structure, note that the domain of chemical processes has a nontrivial *algebraic* property: that of closure under a certain binary operation. Two possible chemical processes, performed one after the other, constitute a single possible chemical process. Hence the set of possible chemical processes has a binary operation * defined as follows: a*b is the process consisting of process b followed by process a. (I have defined “a*b” to mean b followed by a, instead of a followed by b, to conform to the mathematicians’ convention for multiplication of operators.) If we count the *empty* process (a “process” in which nothing happens) as a possible chemical process, then the binary operation * has an identity element, and the chemical processes form an algebraic structure known as a *monoid*.

One might ask what the algebraic properties of the “real” set of possible chemical processes are like – and whether different choices for those properties might lead to substantively different notions of path-possibility, in much the same way that different choices for the accessibility relation lead to different notions of possibility in conventional modal semantics.

(2) Another question is the possible variation of the domain of possible chemical processes from world to world. Perhaps the distinction between chemical and non-chemical processes must be drawn

differently in different possible worlds. For example, what about a possible world in which temperatures are very high and electromagnetic fields are intense almost everywhere? This could destabilize molecular structures to the point that some “chemical” processes are hard to distinguish from merely “physical” processes. Such a possible world has little resemblance to the actual world, but its physical possibility might result in a different domain of possible chemical processes at that world, which in turn might affect the modal logic of path-possibility.

(3) A final problem lies in determining what the modal logic of path-possibility will look like. Given a modal semantics for this notion of possibility, what will the axioms of the resulting modal logic be? What sort of modal system (or systems) will we get?

The chemical pathway notion of possibility may have seemed simple at first, but it offers plenty of opportunities for further study.

Acknowledgment

The author wishes to thank Prof. Eric Scerri for his advice during the preparation of this paper. The author also wishes to thank two anonymous reviewers for suggestions that improved the paper.

Notes

[1] The same might be said about notions of possibility used in other sciences besides chemistry – for example, phonetics. See: Sharlow, M., “Phonetic Possibility and Modal Logic,” preprint, http://www.eskimo.com/~msharlow/phonetic.pdf, accessed 6 Jul 2013.

[2] I want to thank an anonymous reviewer for raising an objection that made me think about this question.

[3] Readers desiring an introduction to modal semantics may wish to consult textbooks on modal logic. See, for example, Chellas 1980. I have assumed background information on modal semantics and logic on a level comparable to that found in textbooks in the field.

References

Bogaard, P.A.: The Limitations of Physics as a Chemical Reducing Agent. *PSA*, 2, 345–356 (1978)

Chellas, B.F.: *Modal Logic: An Introduction*. Cambridge Univ. Press, Cambridge, UK (1980)

Hendry, R.F., Needham, P.: Le Poidevin on the Reduction of Chemistry. *Br. J. Philos. Sci.* 58, 339–353 (2007)

Keese, R., Müller, R.K., and Toube, T.P.: *Fundamentals of Preparative Organic Chemistry.* Ellis Horwood Limited, Chichester, UK (1982)

Le Poidevin. R.: Missing elements and missing premises: a combinatorial argument for the ontological reduction of chemistry. *Br. J. Philos. Sci.* 56, 117-134 (2005)

Putnam, H.: The Meaning of 'Meaning'. In Putnam, H.: *Philosophical Papers, Vol. 2: Mind, Language and Reality.* Cambridge Univ. Press, London, UK (1975).

Scerri, E.: The Electronic Configuration Model, Quantum Mechanics and Reduction. *Br. J. Philos. Sci.* 42, 309–25 (1991)

Scerri, E.: Has Chemistry Been at Least Approximately Reduced to Quantum Mechanics? *PSA* 1994, 1, 160-170 (1994)

Scerri, E.: The Periodic Table and the Electron. *Am. Sci.* 85, 546–553 (1997)

Smit, W.A., Bochkov, A.F. and Caple, R.: *Organic Synthesis: The Science behind the Art.* The Royal Society of Chemistry, Cambridge, UK (1998).

van Brakel, J.: On the Inventors of XYZ. *Foundations of Chemistry* 7: 57-84 (2005).

Wittgenstein, L.: *Philosophical Investigations.* Trans. G.E.M. Anscombe. Basil Blackwell, Oxford, UK (1953)