Response to Vollmer's Review of *Minds and Molecules**

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I present a response to Vollmer's review of the book *Of Minds and Molecules,* and especially her comments on my own article therein. This provides an opportunity to discuss two central ideas in the philosophy of chemistry. These are the distinction between elements as simple substances (element-1) and elements as basic substances (element-2) and Paneth's proposed intermediate position for philosophy of chemistry. The response also discusses the question of isotopes in relationship to the nature of the elements and their classification as well as the philosophical status of atomic orbitals.

1. While it is gratifying that the book "Minds and Molecules" has been reviewed in this journal it is disappointing that the reviewer seems to show a misunderstanding of most of the central issues in philosophy of chemistry upon which she comments (Vollmer 2003). In this brief response I will restrict myself to Sara Vollmer's critique of my article in this book although I believe she is also mistaken in her comments regarding other contributors.

Vollmer correctly reports that my article includes an analysis of Paneth's writings on the concept of an "element." This issue concerns the ancient conundrum of how the elements survive, if at all, when they form compounds. Paneth resolves the conundrum by appealing to a dual sense of the term element. An element can be regarded as a "simple substance" that can be isolated and that can take several different structural forms, such as diamond or graphite, in the case of carbon (Paneth 1962). Let me call this element-1 in the interest of clarity. In addition, an element can also be regarded, more fundamentally, as a "basic substance," which is

*Received December 2002; revised February 2003.

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Philosophy of Science, 70 (April 2003) pp. 391–398. 0031-8248/2003/7002-0010$10.00

the bearer of properties while at the same time being devoid of properties per se.[1] This will be called element-2 in the interest of clarity.

Paneth claims that it is only the element, in the second sense, as element-2, that survives when, for example, sodium and chlorine combine to create sodium chloride. On the other hand, sodium and chlorine, as forms of element-1, consist of a gray metal and a green gas respectively. These properties clearly do not survive when sodium and chlorine, as elements-1, combine together to form sodium chloride. Unfortunately, very little of what Paneth or I have written on the basic substance/simple substance distinction is even mentioned by the reviewer. Instead, Vollmer discusses this question by claiming that it is the *atoms* of any element that remain unchanged on compound formation. She is thus substituting her own version of the question of the survival of elements in compounds, which as I will argue is irrelevant to this discussion. Vollmer writes,

> Paneth notes that the creation of a new substance by mixing[2] two known substances is prima facie incomprehensible. However, what looks like coming into being and ceasing to be, as the atomists first realized, can be reduced to a logic that retains an underlying, unchanging substratum—permanent atoms. The account Paneth offers requires, surprisingly, the existence of a strange kind of entity: the qualityless atom. (footnote added)

In fact it is not *atoms* that Paneth claims to be property-less but the elements themselves. The view that atoms lack such properties as color is held quite universally and did not need to be introduced by Paneth. It is a scientific commonplace that atoms have no color, smell etc.

Vollmer also claims that,

> What Paneth means by properties in this context are all the properties of interest to chemists, including taste, odor, feel, color, and valence (1965, 8). These are the properties, he says, that are generated only by "the coming together of many atoms" and that are, therefore, not discernible in the individual atom, such as an individual atom of gold. (1965, 13)

Although Paneth does indeed mention earlier debates regarding whether or not atoms have properties, this occurs in an opening historical preamble

1. Although this sense of the term element may sound somewhat mysterious it should be pointed out that it was crucial to Mendeleev's ordering of the elements in the periodic system. For example, if he had restricted himself to the properties in the sense of element-1 he might not have grouped together fluorine, chlorine, bromine and iodine which are respectively a yellow gas, a green gas, a brown liquid and a violet-black solid.

2. The issue is not one of physical mixing but chemical combination.

on Greek atomism and as a way of criticizing the view of Epicurus. Paneth believes that Epicurus was wrong in emphasizing the fact that atoms are propertyless, while maintaining that the properties of macroscopic substances are invariably real.

> Epicurus rightly sought to overcome this difficulty by shifting to the realm devoid of qualities, although in developing this idea he did not quite arrive at our present standpoint. . . .
>
> In principle Epicurus would have already reached the present standpoint, had he not considered the qualities of substances to be objectively real. Epistemologically this constitutes a step backwards from Democritus. (Paneth 1965, 13)

For Paneth the distinction is not between one, or many, atoms but rather between macroscopic elements in the form bearing properties (element-1) and macroscopic elements in the form where they do not bear properties (element-2).

Vollmer's move to discuss the persistence of the color of elements in terms of microscopic atoms is thus quite unwarranted although it appears that she genuinely believes that she is referring to Paneth's own discussion of the persistence of the elements. But no philosophical argument for the persistence, or otherwise, of elemental properties in compounds can be made in terms of atoms, particularly these days, when it is generally accepted that atoms do not show properties like color.

Vollmer further misinterprets Paneth when she claims that he realized that atomic weight explained the persistence of elements in the "wake of Rutherford and Bohr." In fact all that Paneth is saying, to cite him more fully, is,

> The atomic theory of Rutherford and Bohr allows us *to picture particularly vividly* how we are to understand the persistence of the elements in its compounds . . ." (Paneth 1962, 152 n. 3; emphasis added)

Paneth's view on the nature of elements does not depend on the discoveries of Rutherford and Bohr since, as he repeatedly states, it comes directly from the view of Mendeleev, for whom the element-1/element-2 distinction was crucial in the development of the periodic system.[3] Vollmer continues,

> A puzzle, then, arises. The persisting properties, which explain the persistence of an element and therefore the identity of a chemical element are, Paneth's implication seems to be, properties that are not of interest to chemists!

3. Admittedly, the move from atomic weight to atomic number is a modern development but one that does not fundamentally alter the distinction between element-1 and element-2. This move is discussed later in this response.

But Paneth does not claim to have personally solved the puzzle. Throughout his article Paneth readily concedes that his talk of the dual nature of the elements and the resolution of the puzzle was already carried out by the likes of Mendeleev.

Moreover, contrary to Vollmer's statement, atomic weight is of great interest to chemists since many of them, including Mendeleev, used it to develop their periodic systems. Indeed atomic weight continues to be of interest to chemists, although not for the purposes of ordering the elements in the periodic system. The point that Paneth is making about the puzzle of the persistence of elements is that it can be resolved provided that the chemist ceases to be a realist but rather embraces the property-less aspect of elements in the sense of elements-2.

2. Paneth's Other Contribution—The Chemist's Intermediate Position. The far more significant contribution offered by Paneth's paper, and something that I try to apply to the case of modern chemistry, is entirely missed by the reviewer. Paneth's main philosophical message is to suggest that chemists adopt an intermediate position between what Paneth terms realism and reductionism. In the case of most properties shown by elements, Paneth contends that the chemist can afford to take a realistic attitude. For example, the ore of mercury, called cinnabar, can be regarded as just being red even though the chemist knows that the red color can be further reduced to a specific range of frequencies of reflected light.

But such a form of realism, as accepting elemental properties at face value, breaks down when the chemist is confronted with the question discussed earlier regarding the persistence of elements in compounds. In such a case the chemist is forced to abandon the realistic view of elements, as simple substances (element-1), and must instead maintain an anti-realistic, or as Paneth prefers to call it, a reductionist view of elements as unobservable basic substances (element-2). Paneth suggests that chemists operate at an intermediate position, which is neither fully realistic nor reductionist, in trying to encompass these apparently different ways in which elements behave.

It is not difficult to see why contemporary philosophers of chemistry are interested in this idea. Paneth's notion, and before him Mendeleev's, comes close to resolving the central question in modern philosophy of chemistry, namely how to accept the findings of quantum mechanics while still retaining the autonomy of chemistry? According to Mendeleev and Paneth the answer lies in adopting an intermediate position between regarding the manifest chemical properties of elements and compounds realistically, on one hand, and the reductive view from physics that tells us that many of these properties are not in fact real, on the other hand.

3. The Question of Isotopes as "Atoms." In the 1920s Paneth drew on this intermediate view to save the periodic system from the major crisis that it was facing. Over a short period of time many new isotopes of the elements were discovered, such that the number of "atoms" or most fundamental units suddenly seemed to have multiplied. Should the periodic system continue to accommodate the traditionally regarded atoms of each element or should it be restructured to accommodate the more elementary isotopes of all the elements that might now be taken to constitute the true "atoms"? Paneth's response was that the periodic system should continue as it had done before, in that it should accommodate the traditional chemical atoms and not the separate isotopes of the elements. In this case the chemist should adopt a form of naïve realism by treating isotopes of the same element as being identical, even though the physicists of the day had revealed some specific differences between them.

Moreover, Paneth along with Hevesy, provided experimental evidence in support of this choice for chemists.[4] They showed that the chemical properties of isotopes of the same element were for all intents and purposes identical. As a result the chemist could maintain the elementary nature of atoms of the same element even though such atoms might occur in different isotopic forms.

It is essential to realize that in the case of this isotope controversy Paneth's recommendation was that the chemist should lean towards the naive realist view and should turn a blind eye to the reductive view afforded by the physics of the day. This is quite unlike the case of the persistence of the elements in compounds, a situation in which the chemist must abandon realism in order to rationalize the situation.

Nowhere in my own article do I disagree with Paneth as Vollmer seems to believe, especially not over the distinction between chemical and physical properties. For example, I do not imply that the new criterion for identifying a basic element (element-2), namely atomic number, should be considered as a chemical property. Atomic number is just as much a physical property as atomic weight. It just so happens that atomic number does not discriminate between the differences in weights of the isotopes of an element and this reflects the finding of Paneth and Hevesy that isotopes of the same element showed identical chemical behavior.

After claiming that neither Paneth nor I have resolved the "puzzle" Vollmer then offers her own solution which unfortunately reveals further confusion.

4. Paneth and Hevesy showed that the electrochemical potential from two cells made from different isotopes of the metal bismuth was the same as far as experimental techniques of the day could distinguish (Scerri 2000).

> "Sodium," for example, can refer to either individual Na atoms as they exist in metallic Na (or NaCl) or to the elemental substance Na with its metallic properties. In the former case "sodium" refers to such properties as atomic number and weight; in the latter case, it refers to the ordinary secondary properties of elemental sodium.

The contrast that Vollmer is trying to express is once again that of sodium as a simple substance (element-1) that can be isolated, and is metallic, as opposed to sodium as element-2 that lacks properties with the exception of its atomic weight, or atomic number. Again Vollmer fails to appreciate the correct contrast between element-1 and element-2 but now incorrectly makes sodium, as element-1, play *both* roles in her supposed contrast. But what is supposed to be the epistemological difference between "sodium in metallic form" and "elemental sodium"?

She then continues,

> One possible way to clarify our terminology would be to think of the nuclei and inner electrons, or "kernel," of sodium as the real sodium itself—this is the part of sodium that is both unique to Na and persists, more or less, through chemical change. Alternatively, "Na" could refer to the entire Na atom, including its outer electrons . . .

This is a category mistake since the question is not one of the constitution of atoms but of the nature of elements such as sodium. The question is rather whether one should intend the term "sodium" to mean a substance that can be isolated or whether one intends the term to mean that which occurs in compounds like sodium chloride.

4. Vollmer on Orbitals. Vollmer's final critique of my work concerns what I have written about atomic orbitals. She correctly reports that I deny the physical reality of atomic orbitals because they cannot be strictly defined in quantum mechanics (Scerri 2001). Vollmer's response to this is to say that, "However . . . being well defined is not a standard condition for reference." She then provides what she takes to be a counter-example, namely something that is not well defined and yet genuinely refers. Her example is,

> . . . a stellar phenomenon, if it existed long ago and far away, may be only approximated, yet reference would not be denied on this basis.

Given that Vollmer's example is rather vague it is difficult to know quite how to respond. But it seems clear that she intends this stellar phenomenon to have actually taken place at some time. If so, then whether or not we may have an approximate knowledge of this event is an epistemological and not an ontological question.

The case of atomic orbitals is altogether different. There are no such objects in the world in spite of the rather misleading term that harks back to the term "orbit" in Bohr's old quantum theory or in astronomy. An orbital, as opposed to an orbit, does not refer to the trajectory of an electron. It is merely a mathematical fiction that is used to perform atomic calculations. Atomic orbitals, unlike stellar phenomena, have no ontological status whatsoever. The manner in which this is established is indeed by recourse to the formalism of quantum mechanics. There is nothing in the furniture of atomic physics that corresponds to an atomic orbital, whereas if I understand Vollmer's example there is no debate over whether or not the stellar phenomenon in her example actually occurred or not. The only issue is that the stellar phenomenon is not "well defined," whatever that might mean.

I think that even a contemporary realist would be prepared to accept that the one instance when a theoretical term should not be taken to refer is precisely when the theory in question dictates as much.[5] Of course one could also debate whether quantum mechanics describes the world or our knowledge of the world, that is whether it provides an ontological or an epistemological description. But according to the Copenhagen interpretation quantum mechanics provides an ontological description. The breakdown of determinism, for example, is seen as a feature of the world rather than as some deficiency of our theoretical description. Consequently according to the standard interpretation, atomic orbitals indeed do not exist in the world precisely because quantum mechanics tells us so.

Of course the supporters of Bohm's interpretation of quantum mechanics might want to argue that the Copenhagen interpretation is actually an epistemological theory and that no serious ontological account could claim that the world itself is indeterministic. But this is altogether another issue from what Vollmer has raised in her critique of my views on atomic orbitals.

Let me conclude very briefly by saying that philosophers of chemistry are interested in trying to break new ground on questions of ontology and reduction, particularly as they arise in chemistry. Unfortunately the errors in Vollmer's book review and her failure to appreciate the subtlety in the ideas discussed are likely to obscure these promising new developments. I can only hope that philosophers of science will take a close look at this book and see for themselves the wealth of ideas that are emerging from this new field.

REFERENCES.

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5. I am grateful to Stathis Psillos for discussion on this point.

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