What Is a Chemical Element?

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A Collection of Essays by Chemists, Philosophers, Historians, and Educators

Edited by

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Foreword

It can come as a surprise to those not versed in the philosophy of science to discover how apparently shaky its roots can be. The classic deductive method supposes that there are some statements and concepts we can assume to be fundamental and precise, and that we can use these to construct theories and hypotheses amenable to experimental testing. But those concepts might, on closer inspection, prove rather less precise and secure than we had hoped or imagined. In biology this is true of "genes" and "species"; in physics there are several ways of thinking about the concept of "force," while the origin and nature of at least one of these—gravity—remain hazy and contentious. In chemistry it is possible to argue without resolution or consensus about what is meant by, for example, "element," "bond," and "molecule"—concepts that even school pupils are taught at the early stages of instruction in the subject.

Yet there is nothing truly problematic about such fuzziness surrounding fundamental concepts. On the contrary, the debates and ambiguities reflect the provisional nature of science, which is not so much a progressive elaboration of the implications of a few timeless truths, but an ever deeper inquiry into the nature of physical reality. Put simply, it works in both directions: starting from what we can observe, at a scale intermediate between atoms and cosmos, and venturing out into the extremes beyond perception and—at least so it can often feel—beyond intuition.

The idea of a chemical element is, then, one of those scientific concepts that exists first and foremost because it is good for thinking with. And so has it always been, since long before we had any notion of an element in its modern sense, before there was any reason to think of atoms as real and tangible objects, before even the idea of science as a self-consistent process of deductive, inductive, and abductive reasoning was adduced. The element is a way of simplifying the world: reducing the bewildering diversity of experience to some countably small number of underlying principles. No one supposes now that what Empedocles and Aristotle understood by an element bears much relation to what Boyle, Lavoisier, and Mendeleev understood it to mean (or that those latter three individuals had a shared definition either). But supposing the physical world to be made up of elemental substances was useful to them all.

Likewise, the fact that it is possible to compile a book like this, in which the definition of an element is interrogated and contested, does not imply that the

discipline of chemistry is unstable at its base. The element is a "good enough" organizing principle for the daily practice of chemists. They know what they mean by it, and even if they do not always mean the same thing (from one day to another, and one chemist to another), any confusion does not take long to resolve. In this respect, the language and discourse of scientists is not so different from that of anyone else: it has rules, but they often work best when there is some latitude, some room for maneuver, some flux. We can use the concept of an element as effectively (and as loosely) as we can speak of "love" or "money," "life" (another of biology's usefully vague words) or "liberty."

A chemist working at the bench with solvents and retorts might, then, be forgiven for asking, what is the point? Why debate a word that works perfectly well for my colleagues and me? And indeed one answer can be "fair enough, there's no obligation." But there are more than enough justifications all the same. First, because it is interesting, in the same way that the history of the subject is interesting (and one can't discuss the meaning of "element" without discussing the history of the term). But also because it is always a little dangerous in science to overconfidently assume that because you can use a word or concept without being challenged, you and others know what it means and agree on that. And it's important to realize that there are very real consequences of ambiguity, as some of the contributions in this volume point out. In an age when "new elements" are made one ephemeral atom at a time, with little prospect of ever establishing their chemical behavior, it seems imperative to think about how to judge and codify such claims. What are our criteria for existence? Does element 119 "exist" even in 2020 (although at the time of writing no one has claimed to have made it)? Does even element 118 (which has been reported and verified) truly exist, except for a few fleeting moments? Does it exist right now, if its atoms do not?

What's more, if we are not united on what are the defining properties of a chemical element, then we have to confront uncertainties about how to arrange and structure these entities in the periodic table. We have to acknowledge and deal with the possibility that students will be confused and even misled. The terms and names used in science encode assumptions, often invisibly. To be a good chemist, it is not a requirement that you know the name "oxygen" falsely imputes the element's ubiquity in acids, or that sodium and nitrogen share similar chemical symbols because they share a linguistic root (*natro*/*nitro*). But sometimes implications lie dormant in etymologies and terminologies that, brought to light, not only can deepen our appreciation of the subject and its heritage but might also alert us to notions we might too readily take for granted. As the disputes between the oxygen and phlogiston theories of combustion showed, words and terminology can dictate thinking, and so are worth taking seriously. By defining our terms, we state what we think is important.

There's a very real danger in science today, when the literature and the broader boundaries of scientific knowledge are so unmanageably vast, that the working scientist becomes too preoccupied with the question "is this information useful to me?" If the issue of utility is simply about getting an experimental result, a paper published, a grant secured, science itself risks becoming a pinched, pragmatic enterprise. But perhaps more important, scientists risk doing their job less well, trapped as they are in the valley of the familiar. I believe that these contributions, as well as being entertaining, intriguing, and challenging discussions in their own right, can have the value to chemical practitioners of re-engaging them with the core of their craft: to the intersection of ideas and substance, of the microscopic to the macroscopic, of concepts to the objects they are supposed to describe (or might that be: to create?). These essays prompt more general questions: Why do I do what I do? How do I know what I know (and is it right)? Are words tools or traps?

The questions faced by the chemists of past times struggling to refine the concept of an element apply equally elsewhere in chemistry today: To what extent is a mechanism a convenient model rather than a description of events? Are there natural boundaries of categories in nature (is this a bond or not?), and if so, where? What makes particles indistinguishable, and what is their status if they are? Can we live with the tension of multiple, overlapping and sometimes conflicting definitions and theories, or must it all dovetail perfectly? It's fun to think about these things, but it's also useful, and sometimes it will be essential.

Philip Ball
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