Substance and Modality

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The Aristotelian distinction between actual and potential presence of a substance in a mixture forms part of a conception of mixture which stands in contrast to atomist and Stoic theories as propounded by the ancients. But the central ideas on which these theories are built need not be combined and opposed to one another in precisely the ways envisaged by these ancient theories. This is well illustrated by Duhem, who maintained the Aristotelian idea that the original ingredients are only potentially, and not actually, present in a mixture, but who sided with the Stoics and against Aristotle on the possibility of co-occupancy. I have argued that the Stoic theory cannot dispense with some such notion as the Aristotelian conception of potentiality in allowing the elements to be actually present in a mixture. Here I suggest that some such Aristotelian notion must be at work in a more modern atomic conception of matter if this is to allow elemental substances to be actually present in compounds, which I think is how compounds are usually understood. Analogous issues arise regarding the status of solutions and their components.

1. Introduction. Mixing substances of various kinds can lead to radical changes. White crystalline salt disappears from sight when mixed with liquid water and left to reach equilibrium, but it makes its mark on the resulting mixture by changing the taste. White anhydrous copper sulfate also disappears when mixed with liquid water, but not without turning the liquid blue. Loss of the solid phase in these cases is associated with the formation of a *solution*. This is contrasted with mixing leading to a chemical reaction and the generation of new substances at the expense of the original reactants. Iron disappears when plunged into blue vitriol solution, for example, and brownish-red copper appears in its place. What, if anything, remains permanent through changes of either kind? Do elements persist in their various compounds? Do compounds remain in solution? Contemporary understanding suggests, perhaps, affirmative answers in both cases. But how can that be squared with the radical changes undergone? Similar questions were addressed by the ancients, who gave somewhat different answers. The distinction between compounds and so-

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Philosophy of Science, 73 (December 2006) pp. 829–840. 0031-8248/2006/7305-0032$10.00
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https://doi.org/10.1086/518632 Published online by Cambridge University Press

lutions is foreign to their thought, and their conception of an element differs from ours. But that does not mean that their theorizing has no bearing on modern accounts of what is involved in mixing. Certainly Duhem thought so and provides a valuable bridge between ancient and modern views. A brief outline of the main features of two ancient views is given before moving on to the questions of elements in compounds and compounds in solutions in modern chemistry.

2. Ancient Theories of Mixture. Aristotle developed his theory of mixture in opposition to a number of views, but in particular to that of the atomists. According to the atomists, mixtures are mechanical juxtapositions of constituents which may or may not be perceptually distinguishable. Matter is held to comprise small corpuscles, whose various shapes, arrangements, and motions, rather than any variation in each particle's size, shape, and so forth, give the appearance of a whole range of different kinds of substance, each exhibited by an apparently homogeneous body of matter. Although the blending of apparently homogeneous bodies may well be relative to some standard of perception in many cases, Aristotle thought that the variety of different substances cannot be explained by the atomists' theory. When bodies mix, new substances often appear with properties radically different from the original ingredients'. There are no good grounds for denying that proper mixtures are genuinely homogeneous—their *every* part is of the same kind as the whole. Since their new properties distinguish them from the original constituents, homogeneity precludes that the original ingredients are to be found in any part of the mixture. But although the original constituents are not actually present in the mixture, they are said to be potentially recoverable.

The fundamental contention of the Stoics was that the original ingredients of a mixture could not be recovered unless they were actually present in the mixture. Later, minimists and atomists (e.g., Daniel Sennert and Boyle) came to think that separation presupposes actual presence. But the Stoic theory is generally in agreement with Aristotle on the explanatory inadequacy and general incoherence of atoms. Accordingly, the Stoics, too, recognized genuinely homogeneous mixtures alongside juxtapositions. But how can distinct substances be said to coexist in a body which is genuinely homogeneous, and not a juxtaposition as the atomists would have it? The feasibility of the Stoic theory depended upon their allowing that different substances can occupy the same place at the same time. Aristotle agreed with the atomists that two bodies cannot occupy the same place at the same time. The possibility of co-occupancy is the distinctive feature of the Stoic conception.

Co-occupancy is often dismissed directly. This was Aristotle's ploy. He offered no argument in support but simply fell back on the blatant as-

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sumption that co-occupancy is impossible when arguing for other points. Examples of bodies which do not (could not) occupy the same place are sometimes presented as though to argue against the co-occupancy thesis. But these are merely counterexamples to everything (necessarily) always being in the same place as everything else, which is not what the co-occupancy thesis claims. Against this gut reaction we have to consider that in thermodynamics, the energy of a multicomponent system subject to work in the form of change in volume is specified as a function $U(S, V, N_1, \ldots, N_r)$ of the entropy, S, the relative amount of each component substance, N_i, and the volume, V. Although the amounts of the several kinds of component substances are specified, only one term for the volume, that of the whole system, appears. Co-occupancy cannot simply be ruled out. It will transpire that the weakness in the Stoic view lies elsewhere.

Why did Aristotle think the atomist theory inadequate? Ultimately, his reason was that it could not explain how new substances, with new properties distinguishing them from the original ingredients, could arise as the result of mixing. This was transformation into new substances and not merely rearrangement of particles which themselves remained unchanged. It required that the original substances must be able to induce, and themselves be susceptible to, change—substantial change and not merely change in position relative to nearby particles—which the postulation of unchanging atoms precludes. He therefore saw no reason to question the apparent fact that although sufficiently large regions are filled with heterogeneous matter, these comprise homogeneous parts. He seems to have assumed that the uniformity implied by homogeneity is indicative of a single substance and that distinctions of what we would call phase are distinctions of substance. Thus, water is literally transformed into air, another substance, when it evaporates; compounds resulting from mixing are homogeneous, just like the elements: "if combination has taken place, the compound *must* be uniform—any part of such a compound is the same as the whole, just as any part of water is water" (Aristotle 1984, *DG* 1.10, 328^{a}10–11).

From the assumption that chemical transformation involves substantial change, or independently from the assumptions of homogeneity and the impossibility of co-occupancy, the doctrine that the original ingredients are not actually present in the mixture follows from Aristotle's definition of the elements. What is important here is the general character of the definitions, in terms of the actual possession of simple properties, as distinct from the disposition to possess them. (The simple properties may themselves have a dispositional character.) The simple properties defining Aristotle's elements are derived from the comparative qualities of being warmer or colder than something and being moister or dryer than something. He thought that there were maximal degrees of these comparative

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qualities, or "contrary extremes" (Aristotle 1984, *DG* 2.8, 335[a]8)—what is as warm as can be is hot, what is as cold as can be is cold, and similarly for moist and dry. And since "it is impossible for the same thing to be hot and cold, or moist and dry," there will be four couples: "Fire is hot and dry, whereas Air is hot and moist . . . ; and Water is cold and moist, while Earth is cold and dry" (Aristotle 1984, *DG* 2.3, 330[a]30–330[b]5). These formulations are clearly definitions. Accordingly, they specify necessary as well as sufficient conditions, so that anything lacking at least one of a given pair of compatible contrary extremes lacks the corresponding elemental property. Now by Aristotle's first assumption, bodies initially possessing some of these properties change on mixing (combining) with other bodies possessing them. In general, the result of mixing is a body with degrees of warmth and humidity intermediate between the original contrary extremes. So the elements disappear—what was an element ceases to be so after mixing. The point is reinforced by the homogeneity condition, according to which all the parts have the same (intermediate) degree of warmth and humidity as the whole. Homogeneity is naturally understood to refer just to spatial parts, but the assumption that co-occupancy is impossible excludes the possibility of distinct parts occupying the same place. Accordingly, no part of the resulting mixture has the defining properties of any of the elements.

In modern terminology, Aristotle defines each element in terms of properties it exhibits in isolation. This strategy of definition, together with the assumption of modification in the process of combination, allows only that the elements are potentially present in a mixture—that is, they might be recoverable by some process of recreation (decomposition). There can be no part of the mixture which is an element. Is this a substantial result or merely an artefact of Aristotle's procedure which could be circumvented by an alternative strategy?

At first blush, it seems that the Stoic theory of mixture offers an alternative. Allowing co-occupancy seems to open up the possibility of the elements actually being present in a mixture while maintaining homogeneity. Co-occupancy involves nonoverlapping parts of the mixture occupying the same place. Understanding homogeneity to govern specifically spatial parts—that is, every spatial part of a mixture is the same as the whole—there is then a possibility that a given spatial part comprises several elements as separate parts each occupying the same place, namely, that of the spatial part in question.

The elements must then be defined in terms of properties which they exhibit in a mixture. Which properties might these be? Extremes of warmth are not candidates, since the same region of space cannot contain matter which is hot and matter which is cold in stable union, and similarly for moist and dry. The reason is the one Aristotle gave for holding that no

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element could be defined as possessing contrary qualities. So the elements cannot be defined as Aristotle defined them. Hahm's (1985, 42ff.) suggestion, that elements were characterized by density, fares no better than the suggestions he rejects. Clearly, the density of a substance (amount of matter of that kind per unit volume) decreases, on the Stoic view, as more matter of other kinds co-occupies and expands the region occupied by the quantity of the substance in question. It is difficult to see how simple necessary and sufficient conditions might be specified in extensional terms.

We might turn from properties actually possessed to ones that would be possessed, for example, under conditions of isolation. But this would take us very close to Aristotle's position. (In fact, Aristotle is sometimes wont to say that the elements are present in a mixture—although only potentially!) The conclusion Duhem drew from this was that some notion of potential property is essential to any adequate characterization of chemical substances, although it is independent of whether co-occupancy holds. He maintained the Aristotelian view that substances are not actually present, but only potentially obtainable, from homogeneous mixtures (Duhem 1902). The problem facing the interpreter of Duhem is that he also upheld the possibility of co-occupancy (see passages cited in Needham [2002b]), with the help of which it seems the Stoics sought to avoid the Aristotelian idea of the potential, nonactual presence of components in a homogeneous mixture. Without going into the details of Duhem's view, suffice it to say that this shows that the atomist, Aristotelian, and Stoic theories do not exhaust the possibilities and may help to prepare the way for a combination of aspects drawn from the Aristotelian and atomistic views. The main brunt of the argument here is that, while some notion of potential property is essential to any adequate characterization of chemical substances, the normal way of speaking takes elements to be in compounds. This argues, I think, for incorporating the notion of potentiality into the definition of elements (or into the understanding of their central properties). The question of whether compounds are present in solution is taken up later.

3. Modern Ways of Specifying Elements. How does this bear on what modern writers say about the elements? An example of a modern author who proposes a definition of the general notion of an element which is unclear about whether elements are present in a mixture is provided by Ostwald. Elements are distinguished, Ostwald says, as "substances which have never been transformed into solutions or whose sphere of existence covers all accessible states of temperature and pressure," and elements are defined as "substances which never form other than hylotropic phases" (1904, 516–517). It seems blatantly false to say that elements "have never been transformed into solutions," however, and it is impossible to glean

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from the wording whether, on that definition, elements actually exist in compounds or not.

Modern textbooks list properties of specific elements, usually understood to apply to the isolated state. For example, specifying the melting and boiling points of sodium as 371 K and 1160 K, respectively, says nothing about the melting and boiling points of sodium in ordinary salt; they apply to sodium in isolation. Even then, the property is of a modal or dispositional character, to the effect that if isolated sodium were carried to a temperature of 1160 K at standard pressure, the liquid would boil. Similar comments apply to heats of fusion and vaporization. Likewise, density, electrical resistivity, specific heat capacity, and so on speak of the manifestation of a certain feature under specified circumstances at standard temperature and pressure. By contrast, when the abundance of sodium is specified as the sixth commonest element in the earth's crust, it is not the isolated element that is at issue. A typical textbook statement runs: "Sodium and K have high abundances (2.6 and 2.4%) in the lithosphere and occur in large deposits of rock salt, NaCl, and carnallite, $KCl \cdot MgCl_2 \cdot 6H_2O$. Lithium, Rb and Cs have much lower abundances and occur mainly in a few silicate minerals" (Cotton et al. 1999, 94). But is the same kind of stuff to be found in sodium in the isolated state and in common salt? And if so, what is it?

What bearing do atomic properties have? Nuclear properties do not vary with state of combination, and Paneth's suggestion of defining the elements by atomic number has been officially adopted. This provides a criterion for saying that an element is present in a quantity of matter regardless of state of combination, but not for distinguishing what is sodium from what is not. Although it gives a necessary condition, Paneth's definition—"a chemical element is a substance all of whose atoms have the same nuclear charge" (1962, 155 n. 1)—does not provide a sufficient condition for identifying the entities which, as he says, "have the same nuclear charge." Moreover, it departs from Aristotle's strategy of defining elements in terms of features accounting for their capacity to enter into combination. Addressing the latter two issues brings electrons into the picture, which surely must be done in a chemically interesting characterization of sodium.

Suppose we start with the atomist's general strategy of defining sodium:

> **Definition 1.** A quantity of matter is sodium iff it is comprised exclusively of sodium particles.

Then we proceed to define "sodium particle." For this purpose, a simple count will not do: arbitrary mereological sums of the appropriate number of elementary particles do not constitute sodium particles. Perhaps the

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electronic configuration, $[Ne]3s^1$, which in the circumstances entails an atomic number 11, provides the notion of structure required.

There are no particles with the configuration $[Ne]3s^1$ in salt, which is an ionic compound containing sodium cations with one less electron than this configuration attributes. So if sodium atoms and sodium cations are the same kind of thing—both sodium particles—it is not in virtue of a shared property described by their configuration $[Ne]3s^1$. But not even the isolated solid conforms, comprising as it does a close-packed lattice in which individual "atoms" are combined in a metallic structure where the single valence electron makes for weak binding energies and consequently a soft solid with a low melting point. The configuration describes an ideal condition of a single isolated atom ("infinitely separated" from its closest neighbor), thought to be approximated in the gas state, in terms of which it makes sense to speak of the process of removing a first electron and assigning a corresponding ionization potential, and forming the hydrated ion and assigning a corresponding heat of hydration. Nevertheless, the electronic configuration is listed alongside melting and boiling points, implying that what these properties are each characteristic of is a substance which is found in solid and liquid phases as well as the gas phase. Perhaps it should be considered to provide a (chemically relevant) defining property of sodium in the following sense:

> **Definition 2.** A sodium particle is one which can be transformed into, and may be considered to be derived from, an atom with the electronic configuration $[Ne]3s^1$.

On this construal, the world's sodium includes that in salt. Further, the definition discounts the fluoride anions in, for example, sodium fluoride, as sodium particles, despite F^- and Na^+ ions, as well as Ne atoms, being isoelectronic. This definition is not of the kind Aristotle proposed for the definition of his elements. It builds the notion of possible realization into the defining quality, which is not simply "having the electronic configuration $[Ne]3s^1$" but, rather, "being able to sustain the electronic configuration $[Ne]3s^1$." Were sodium to be defined in Aristotelian fashion by the following definition 3, then there is no sodium in salt.

> **Definition 3.** A sodium particle is one which actually has the electronic configuration $[Ne]3s^1$.

Nor in this case is there any sodium in the soft greyish metallic substance stored under paraffin in many labs in bottles misleadingly, on this proposal, labeled "sodium." This is also reminiscent of Aristotle's phase-dependent senses of the elements, according to which water, for example, is necessarily liquid. The fact that textbook writers rarely express themselves in the manner of definition 2 might suggest that definition 3 is what

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is usually intended. But the fact that the consequences hardly square with what is found in a textbook under the heading "sodium" provides a stronger case for understanding the text along the lines of definition 2.

A vagueness in the "can" of definition 2 should be addressed. The "can" is naturally understood to restrict the transformations in question to those involved in normal chemical processes. If a physical process of fusion of boron and carbon were possible that resulted in sodium atoms with the electronic configuration $[Ne]3s^1$, this would not mean that boron and carbon are each also sodium. The corresponding definition of francium, using its listed electronic configuration, would read:

> **Definition 4.** A francium particle is one which can be transformed into, and may be considered to be derived from, an atom with the electronic configuration $[Rn]7s^1$.

Francium is radioactive, the longest-lived isotope having a half-life of only 22 minutes. As part of the natural radioactive decay series, it disintegrates with the emission of β-rays yielding radium. Radium thus derived from "atoms with the electronic configuration $[Rn]7s^1$" would be counted as francium, however, as definition 4 stands, as would the 1.2% of the actinium-227 that disintegrates to form francium. (But which actinium atoms would be counted as francium before disintegration by loss of an α-particle?) Similar comments apply to the radioactive antecedents and disintegration products of ^{24}Na, with a half-life of 15 hours. The properties of being a particle of one or other element are mutually exclusive. These problems might be circumvented by making the restriction explicit as follows:

> **Definition 5.** A sodium particle is one which can be transformed into, and may be considered to be derived from, an atom with the electronic configuration $[Ne]3s^1$, where the transformation involves no nuclear disruption.

The point of the atomic number (number of protons) implied by the electronic configuration is to say that the nucleus remains intact in chemical change preserving elements.

It seems, then, that although important properties like electronic configuration are presented as though they are defining features in the Aristotelian manner, the usual un-Aristotelian way of speaking about the elements as occurring in several phases and in compounds suggests that a modal formulation along the lines of definition 5 is how they are normally understood. Far from discarding the Aristotelian notion of potential presence as irrelevant, this procedure incorporates it directly into the definition by appropriately qualifying the defining property.

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4. Are Compounds Preserved in Solution? As the examples given in the introduction suggest, analogous issues of preservation and potentiality arise concerning compounds in solution. Is there any salt in the sea?[1] The definition of salt given in the *Shorter Oxford English Dictionary* is ambiguous:

> The substance (sodium chloride, NaCl), which gives seawater its characteristic taste, a white or (when impure) reddish-brown mineral crystallizing in the cubic system; this substance as [*sic*] obtained by mining or by evaporation of seawater and used esp. for seasoning and preserving food.

Although salt gives seawater its characteristic taste and is obtained from seawater by evaporation, there is no direct commitment either way on whether salt is actually in the sea. It is unclear whether the definition requires salt to actually display the property of being a white (or reddish brown if impure) mineral or allows merely that it *can* have a crystalline structure. But let us say that absence of crystalline structure rules out the presence of salt in solution by the *phase criterion*.

The preservation of salt in aqueous solution seems to be particularly problematic because of its ionic character, leading to virtually complete dissociation in aqueous solution. In general, there is a degree of dissociation, which would suggest that a distinction is to be drawn between the undissociated substance and the components into which it dissociates. By the *dissociation criterion*, there is no salt in aqueous solution, in stark contrast to cases where there is no dissociation of the solute. A distinction is made between, on the one hand, aqueous solutions of polar covalent substances and solutions of nonpolar solutes in nonpolar solvents where there is some interaction with the solvent and, on the other hand, ideal solutions where solubility is entirely due to the entropy of mixing with no intermolecular forces. Solutions of naphthalene in benzene, or of carbon dioxide in chloroform, are examples of cases approaching ideality. But they resemble seawater inasmuch as the original phase of the isolated solute (solid or gas) is changed to liquid. So if phase were made a defining feature of substances, solutes would not even be preserved in ideal solutions either. Dissociation and change of phase as criteria for salt being preserved in solution yield different results in these other cases.

Although phase is a feature of certain common substance terms such as "calcite" and "arogonite," these are polymorphs of the substance calcium carbonate, which is what is described as composed of other substances. Calcium carbonate comprises carbon, oxygen, and calcium in

1. The question is raised by Joe Earley (2005).

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certain proportions; there is no question of any phase qualification (Needham 2000, 2002a). Phase is not a general feature of chemical substances but, rather, a possible feature under appropriate conditions. Loss of the white crystalline solid feature is therefore not sufficient grounds for salt not being preserved in seawater. Is dissociation?

The contrast suggests that since carbon dioxide forms a near-ideal solution in chloroform and is not dissociated, it is preserved, whereas salt, which does not, is not. It is not so clear what it is that is preserved in the one case but not in the other, however. Gaseous carbon dioxide is made up of covalently bonded molecules, which remain intact in chloroform solution. Solid sodium chloride, by contrast, is not made up of covalently bonded molecules. Since there are not any salt molecules to be disrupted, there is no dissociation of salt in solution. Why not say that the sodium and chloride ions responsible for the crystalline structure persist in solution where they continue to balance the total charge and thus *maintain* the ionic bonding of the solid? The presence of the ions in solution is as little an obstacle to the continued presence of sodium chloride in solution as it is in the solid state.

The term "dissociation" is something of a misnomer. Its chemical significance emerges from the colligative properties (freezing-point depression, etc.), which show in terms of the phase rule that there are three *independent* substances in a salt solution. But this does not mean that sodium cation, chloride anion, and water are the only substances present. By the same count, there are only two independent substances present when calcium carbonate is heated in a closed system and the equilibrium

$$CaCO_3 \rightleftharpoons CaO + CO_2$$

is established. Since this is a univariant system (there is a definite gas pressure for a given temperature), the phase law distinguishes three phases. Rather than forming a solid solution, calcium carbonate and calcium oxide form distinct solid phases, even though they are quite intimately mixed, and there is a third gas phase (Duhem 1898, 74). But then there would be no carbon dioxide constituting the gas phase if there were no more substances than the independent ones.

Even if dissociation is not sufficient grounds for denying the presence of electrolytes in solution, perhaps the changes wrought by interaction with the solvent provide a relevant difference. Although this is minimal in near-ideal solutions, polarized solutes and solvents do give rise to significant interaction, and ionic species enter into definite patterns of hydration. There is a parallel here with the earlier discussion of the electronic structure of sodium atoms. In that case, sodium particles were defined as particles which were related by processes of interaction to isolated particles with the ideal configuration. Sodium and chloride ions can be similarly

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considered to be preserved under modification in aqueous solution, as can covalent species. There are also changes in the distance of separation and orientation between neighboring element particles in the pure solute and in solution. But such features of the solid state are lost in liquid and gas phases anyway, and since isolated substances are not treated as phase bound, such changes hardly amount to disappearance of a substance.

5. Summary and Concluding Remarks. The Aristotelian notion of potentiality is not tied to other aspects of Aristotle's conception of mixture. Duhem has already severed it from the impossibility of co-occupancy, and it is argued here that it is not tied to a continuous view of matter but also arises on the modern, nonatomic theory of the atom. Aristotle's criticisms of classical atomism—the doctrine that matter comprises minimal particles which can only change in their spatial relation to one another and the patterns formed by suitable numbers—stand. His point was that what enters into genuine mixture or combination must be able to affect, and be affected by, other matter. These powers and susceptibilities are precisely what the variable electronic structure confers on the modern notion of the structured atom. And they must still be taken into account in understanding elements to be actually present in their compounds, as the modern view has it in contradistinction to the Aristotelian view which Duhem also held.

Analogous questions arise about the status of substances in solution. The argument developed here came down in favor of treating compounds in solution like elements in compounds. Lavoisier first "supposed that water existed ready formed in sugar" but became "convinced that sugar only contains the elements proper for composing it" (1965, 140–141). Hydrates, such as hydrated manganous chloride, $MnCl_2 \cdot H_2O$, are written as though there is water in them, however. The subject is not yet exhausted.

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