Mixtures and Mass Terms*

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Abstract

In this article, I show that the semantics one adopts for mass terms constrains the metaphysical claims one can make about mixtures. I first expose why mixtures challenge a singularist approach based on mereological sums. After discussing an alternative, non-singularist approach based on plural logic, I take chemistry into account and explain how it changes our perspective on these issues.

Keywords: chemistry, mass term, mereology, mixture, plural logic

Let me prepare my favorite drink. I pour lemon juice, water, and sugar in a glass, and mix them with a spoon. I soon obtain some refreshing lemonade. (Better but more complicated recipes are easy to find.) Have I thereby created something new? Before answering the question, notice that I have used mass terms such as *water* and *lemonade* in order to describe what happened. A central aim of this article is to show that the semantics one adopts for mass terms constrains the metaphysical claims one can make about mixtures like lemonade.

So, in section 1, I present the two main accounts that have been proposed of their semantics. The singularist approach treats them as singular terms referring to mereological sums (e.g. Link 1983). The non-singularist approach is based on the idea that, together with plurals, mass terms have the ability to refer to one or several entities at once (e.g. Nicolas 2008).

In section 2, I present Barnett (2004)'s case for arguing that mereological sums are inadequate to capture our intuitions concerning the identity of mixtures over time. His conclusion is that a mixture is indeed something new, a 'rigid embodiment'. In section 3, I discuss how the non-singularist approach can deal with mixtures. I show that it must treat nouns of mixtures as collective, temporary predicates. On this approach, a mixture is not something new; it is just the plurality of its constituents when they stand in the appropriate relation.

Then, in section 4, I turn to chemistry, the science of matter and its transformations. My guide is the work of Needham (2010). Once his perspective on chemistry is adopted, the metaphysical issues raised by Barnett concerning mixtures appear in a very different light. This leads me to compare, in section 5, two approaches according to which all portions of matter are nuclei and electrons, or sums thereof.

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1 Two approaches to the semantics of mass terms

Two types of account have been proposed for the semantics of mass terms, such as *water*, *gold*, *lemonade*, and *succotash*: the singularist and the non-singularist approaches (see Nicolas 2018 for an overview).

1.1 The singularist approach

The singularist approach is very popular in linguistics and philosophy (e.g. Link 1983, Zimmerman 1995). The key idea is that a mass term is a singular term: whenever it is used to refer, it refers to a single entity, since it is used in the singular. This entity is usually identified with a mereological sum (see Steen 2016 for discussion of alternatives).

The notion of sum belongs to mereology, the study of relations between parts and wholes (Cotnoir and Varzi 2021). It can be characterized in different ways, for instance as a least upper bound with respect to the relation of part:

• s is the SUM of some entities :≡ s is part of anything that has these entities as parts.

A well-known set of axioms yields *classical mereology*, with in particular:

• UNRESTRICTED SUMS: any entities have a sum.[1]

Now, let *M* be a mass term and *P* a predicate. If there is some M that P, then the definite description *the M that P* designates something, namely the sum of the M that P. Thus, *the water in the two bottles* refers to an entity, the sum of everything which is water in the two bottles. And *the gold in the safe* designates the sum of the gold in the safe — for instance, the sum of three gold nuggets.

1.2 The non-singularist approach

The non-singularist approach is put forward by Nicolas (2008), drawing inspiration from Laycock (2006). Mass terms do not admit the grammatical contrast between singular and plural, so one may argue that their use in the singular has no semantic significance. Mass terms are not singular terms, but non-singular terms: just like plurals, they may refer to one or several entities at once.[2]

Let *M* be a mass term and *P* a predicate. The definite description *the M that P* refers collectively to the entities that are some M that P. Thus, *the water in the two bottles* refers collectively to two entities, the water in the first bottle and the water in the second one. And *the gold in the safe* refers collectively to three gold nuggets if this is what the safe contains.

Nicolas proposes a semantics of mass terms based on this idea. This semantics is developed in non-singular or plural logic. In usual logics, such as predicate logic, terms are singular in the following sense. Under any interpretation, a constant is interpreted as one entity, and under any assignment, a variable is interpreted as one entity. By contrast, plural logic has both singular and non-singular terms (Florio and Linnebo 2021). Under any interpretation and assignment, a non-singular term (a constant or a variable) can

1 Classical mereology is often formulated in first-order logic, using axiom schemas. Here, for ease of exposition, plural logic is implicitly used. Compare sections 2.1 and 6.1.2 from Cotnoir and Varzi (2021).

2 By contrast, according to Laycock (2006) and McKay (2015), mass terms come with their own primitive form of non-singular reference.

be interpreted as one or several entities in the domain of interpretation. In particular, a formula consisting of a predicate whose argument is a non-singular term is true if and only if the term is interpreted as one or more entities which collectively satisfy the predicate.

Two things should be stressed. First, the claim is not that mass terms are plurals. It is that mass terms and plurals share a common property, namely the ability to refer non-singularly. Second, in this approach, one does not need to postulate that any entities have a sum, since one can directly refer to these entities themselves.

2 Mixtures and the singularist approach

A mixture is obtained by mixing portions of different types of matter, without creating a new chemical bond between elements. Thus, one obtains lemonade by mixing lemon juice, water, and sugar.

As we shall now see, Barnett (2004) argues that the identity of mixtures over time presents a problem for a singularist approach based solely on mereological sums. Indeed, according to him, a portion of a mixture cannot be a sum.

Barnett adopts the following definitions:

• p is a PORTION of a type of matter M :≡ p is some M.
• q is a SUBPORTION of p of type M :≡ p is some M, q is some M, and q is part of p.
• p is a LEAST PORTION of M :≡ p is some M and p has no proper part which is also some M.

Thus, the water in a bottle is some water (a portion of water), and the water in the lower half of the bottle is a subportion of water. Like many authors, Barnett supposes that a least portion of water is an H_2O molecule.

Barnett holds that sums exist unrestrictedly, and moreover, that they are mereologically constant:

• MEREOLOGICAL CONSTANCY: a sum of entities exists when, and only when, these entities exist.[3] Thus, the sum of all the H_2O molecules exists when, and only when, these molecules exist. If one molecule ceases to exist, so does the sum.

Now, according to Zimmerman (1995, sec. 8), a portion of a type of matter M is the sum of its subportions, so it should satisfy a more specific property:

• SUBPORTION CONSTANCY: a portion of a type of matter M exists when, and only when, its subportions exist.

Barnett disagrees, distinguishing two types of matter, discrete and non-discrete:

• DISCRETE MATTER: least portions have no part in common. Discrete matter satisfies SUBPORTION CONSTANCY. Thus, take a portion of water. It is the sum of a great many least portions (H_2O molecules), which have no part in common. This portion of water exists when, and only when, these molecules exist. This portion has always the same subportions, each subportion being the sum of certain H_2O molecules.
• NON-DISCRETE MATTER: least portions can share parts. Non-discrete matter does not satisfy SUBPORTION CONSTANCY. Thus, take a portion of lemonade in a glass. Its subportions contain lemon juice, water, and sugar, and two least portions can share, for instance,

3 While MEREOLOGICAL CONSTANCY is a popular thesis, it remains controversial. For instance, van Inwagen (2006) argues vigorously that sums can change their parts. Consequently, one might prefer to adopt a weak mereology which says little about what happens to sums over time (Donnelly and Bittner 2009).

some lemon. When one stirs the lemonade in a glass, at least one of its subportions will disappear because its own constituents (certain portions of lemon juice, water, and sugar) are separated and do not form lemonade together anymore.

For non-discrete matter, Barnett proposes to use the notion of rigid embodiment from Fine (1999, sec. 3):

• An entity o is a RIGID EMBODIMENT of a relation R in some constituents p, q, … :≡ o exists when, and only when, p, q, … stand in the relation R. Thus, a portion of lemonade exists when, and only when, its constituents (lemon juice, water, and sugar) stand in the relation Appropriately Mixed.

Overall, according to Barnett, the ontology of matter involves entities of two different kinds: mereological sums *and* rigid embodiments. This may be worrisome if one wants to minimize ontological commitments or if one is suspicious of rigid embodiments.

At this point, let's reflect about the relation between metaphysics and language in this discussion. Barnett's hypotheses about mixtures and matter are metaphysical claims which are expressed using mass terms. In particular, the notions of portion and subportion of M are defined using the mass expression *some M*. Moreover, these hypotheses are motivated by a particular understanding of general features of our use of mass terms. As Zimmerman (1995, p. 55) puts it: "Attention to the presuppositions of our ordinary use of mass terms reveals a 'proto-theory' of masses", involving "central proto-theoretical assumptions about the referents of mass expressions of the form" *the M* and *some M*. The 'proto-theory' in question is an instance of the singularist approach; it presupposes in particular that, for many nouns of matter, a definite description of the form *the M* denotes a mereological sum. In the next section, I turn to the non-singularist approach, which makes different presuppositions. As we shall see, it offers a different view on mixtures, one that incurs simpler ontological commitments.

3 Mixtures and the non-singularist approach

Two broad conceptions concerning the relation between mixtures and their constituents can be distinguished:

• NOVELTY: a mixture is something *new* compared to its constituents — e.g. a rigid embodiment for Barnett.

• MERE RELATEDNESS: a mixture is *just* the sum or plurality of its constituents *when* they stand in the appropriate relation — cf. Burge (1977, pp. 109–112), for whom a mixture is a temporal phase of an 'aggregate'.

Thus, when one mixes lemon juice, water, and sugar appropriately:

• According to NOVELTY, one creates something new (some lemonade), which did not exist before.

• According to MERE RELATEDNESS, one does not create anything new; one merely puts certain constituents in an appropriate relation with one another.

As explained below, the non-singularist approach, as developed by Nicolas (2008), is incompatible with NOVELTY, given the following, extremely plausible assumption about pluralities (Florio and Linnebo 2021, ch. 10):

• PLURAL CONSTANCY: a plurality of entities exists when, and only when, these entities exist. Relatedly, two pluralities are identical if and only if they have the same members.

Thus, the chairs that are in the office are the same as the chairs that were in the living-room if and only if these two pluralities of chairs have the same members.

Following Sharvy (1979), let's consider the case of succotash (idealized below), an American dish made of Lima beans and kernels of green corn cooked and served together. Imagine the following scenario:

• At t_0, beans b_1 and b_2 and kernels of corn k_1 and k_2 are cooked together.
• At t_1, b_1 and k_1 are served in one cup, b_2 and k_2 in another. So, each cup contains succotash.
• At t_2, b_1 and k_2 are served in a bowl, b_2 and k_1 in another. So, each bowl contains succotash.

Given this, the following statement of identity over time seems true:

The succotash (which was in the cups) at t_1 is identical to the succotash (which was in the bowls) at t_2.

Can we explain this intuition if we combine the non-singularist approach with the first or the second conception above?

If we combine the non-singularist approach with NOVELTY, we get this:

• The term *the succotash at t_1* denotes the succotash s_1 (made of b_1 and k_1) and the succotash s_2 (made of b_2 and k_2).
• The term *the succotash at t_2* denotes the succotash s_3 (made of b_1 and k_2) and the succotash s_4 (made of b_2 and k_1).
• s_3 is distinct both from s_1 and s_2, and s_4 is distinct both from s_1 and s_2.

If we combine the non-singularist approach with MERE RELATEDNESS, we get that:

• The term *the succotash at t_1* directly denotes b_1, k_1, b_2 and k_2; there are no new entities s_1 and s_2.
• The term *the succotash at t_2* directly denotes b_1, k_1, b_2 and k_2; there are no new entities s_3 and s_4.

Given PLURAL CONSTANCY, the non-singularist approach is actually incompatible with NOVELTY. Indeed, the identity of succotash over time would correspond to the fact that s_1 and s_2 are identical to s_3 and s_4, and so that s_1 is identical to s_3 or s_4 (and likewise for s_2), contrary to the scenario. The non-singularist approach must therefore adopt MERE RELATEDNESS.

For the non-singularist approach, mass terms designating mixtures turn out to be temporary, collective predicates: they hold collectively of certain entities when, and only when, certain conditions are satisfied. (Similarly, the temporary predicate *child* holds of a person when, and only when, certain conditions of age are satisfied.)

Here, it seems fair to recognize that, according to common sense, when one mixes lemon juice, water, and sugar, one *does make* something new, some lemonade which did not exist before, and which one can now drink, give, or sale. Being at odds with common sense may appear as a disadvantage for the non-singularist approach.

At the same time, as we saw, Barnett is led to distinguish two kinds of matter, mereological sums and rigid embodiments. The ontological commitments of the singularist approach, on Barnett's analysis, are thus more costly than those of the non-singularist approach, which is only committed to pluralities.

In order to make progress, in the next section, I present the conception of chemistry put forward by Needham (2010). As I explain, this conception has important consequences for the issues just discussed.

4 The perspective from chemistry

4.1 Constancy of matter

In a chemical reaction, the mass of the reactants before reaction is identical to the mass of the products after reaction. Chemists think that constancy of mass is due to something deeper, namely constancy of matter. Thus, according to 19^{th} century chemistry:
• Elements (like oxygen and hydrogen) are permanent.
• When put together, they form compounds (like water) and solutions (like lemonade), in which they are actually present. Compounds and solutions are impermanent. The constancy of elements in chemical reactions explains the constancy of mass.

And according to 20^{th} century chemistry:
• In a chemical reaction, electrons are gained, lost, or shared by elements and compounds (cf. ions, metals, etc.).
• So, what remains constant is nuclei (not atoms) and the overall number of electrons.

This leads Needham (2010, sec. 2) to defend the idea that all nouns of matter are temporary predicates, which apply to portions of matter when, and only when, they have certain properties. For instance, let's consider the combustion of hydrogen in oxygen, which gives water:

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

Before reaction, at time t_1, there are two portions of matter, p and q, and their sum, p+q. The temporary predicates *hydrogen* and *oxygen* apply to p and q, respectively: hydrogen(p,t_1) $\wedge$ oxygen(q,t_1). After reaction, at time t_2, we have still the same portions of matter.[4] The temporary predicate *water* now applies to their sum: water(p+q,t_2). The common-sense preconception spelled out as NOVELTY in the previous section is thus rejected, not only for mixtures, but for matter of any kind.

4.2 Liquid water in constant reaction

A liquid portion of water undergoes constant chemical reactions, and this explains important properties of water.

Thus, there is a continual association of H_2O molecules into larger polymeric species (due to hydrogen bonding), and a continual dissociation (Needham 2010, sec. 6):

$$H_2O + H_2O \longleftrightarrow (H_2O)_2$$
$$H_2O + (H_2O)_n \longleftrightarrow (H_2O)_{n+1}$$

And there is also a continual dissociation of H_2O molecules into hydrogen and hydroxide ions, and a continual recombination, together with the hydrogen-bonded clusters:

$$H_2O \longleftrightarrow H^+ + OH^-$$
$$(2n+1)\,H_2O \longleftrightarrow (H_2O)_nH^+ + (H_2O)_nOH^-$$

The conductivity of water is due to this: a hydrogen ion attaches at one point of a polymeric cluster, this induces a transfer of charge across the cluster, and ultimately a hydrogen ion is released. Other properties of water (boiling at a given temperature, for instance) are also due to such reactions and hydrogen bonding.

So, the microstructure of water cannot be simply characterized as a collection of H_2O molecules. And the subportions of a liquid portion of water constantly change, similarly

4 For Needham, a given portion of matter is the constant sum of certain nuclei and electrons.

to what happens in the case of a mixture like lemonade.

5 Conclusion

I have examined three approaches about mixtures and mass terms. For two of them, mass terms are singular terms; for one, they are non-singular terms which may refer to one or several entities at once. As explained:

• Barnett distinguishes between discrete matter (a portion of water for instance), which is the sum of its subportions; and non-discrete matter (a portion of lemonade for instance), which is not a sum but something new, a rigid embodiment.

• According to the non-singularist approach, a mixture is not something new; it is just the plurality of its constituents when they stand in the appropriate relation. Nouns of mixtures are temporary predicates.

• From the perspective of chemistry, according to Needham, any portion of matter is the sum of some nuclei and electrons. All nouns of matter are temporary predicates, not just nouns of mixtures.

The non-singularist approach can readily accommodate Needham's perspective. It suffices to take a portion of matter to be the plurality of some nuclei and electrons. The two views then end up being similar. However, their ideologies differ, as do the formal apparatus they use: classical mereology for the former, plural logic for the latter. Are there reasons to prefer one approach over the other? Five come to mind, but none seems decisive.

First, plural logic is a form of higher-order logic, which in its simplest form is similar to monadic second-order logic. So, the fact that mereology can remain first-order may be taken as an advantage: being incomplete, such a theory would be less demanding than plural logic. But this is disputable, since such a theory lacks the resources to say everything a mereologist would like to say. For instance, it cannot say that any entities have a sum. Consequently, several philosophers prefer to characterize mereology using second-order or plural logic (Cotnoir and Varzi 2021, sec. 6.1). Indeed, this is what was done in section 1.1 for ease of exposition.

Second, the non-singularist approach requires one to identify which entities are non-singularly quantified over. Given what we know about chemistry, it is natural to identify these entities with nuclei and electrons. The mereological approach is consistent with this kind of identification, but at the same time, it does not necessarily force one to make an identification. In this respect, the mereological approach may appear as ontologically less restricting. However, Needham's argumentation, summarized earlier, *does* rely crucially on an identification of this kind, namely, to sums of nuclei and electrons. So, both approaches are on a par with respect to the assumptions they make about chemistry.

Third, and relatedly, what about the possibility of 'gunk', i.e. indefinitely divisible matter? It is in fact easily accommodated by both approaches (putting aside assumptions about chemistry for the purpose of discussion). Say that a predicate M is 'gunky' if, whenever it is true of something, it is also true of a proper part of it. Using sets, there is no difficulty in specifying its denotation: it is the set of entities the predicate M is true of. Mutatis mutandis, the same is true in plural logic. The denotation of the predicate M is just those entities it is true of. This can then be combined with an independently motivated relation of part without assuming UNRESTRICTED SUMS (Nicolas 2008, sec. 5).

Fourth, one may wonder whether questions concerning the determinacy of electrons are particularly pressing for the non-singularist approach. If, as argued by French and Krause (2006), electrons are not subject to the law of identity, how could one refer plurally to some electrons? However, this would also be a difficulty for the mereological approach as articulated by Needham. According to him, a portion of matter is the sum of some nuclei and some electrons. In classical mereology, a sum of entities requires these entities to be determinate. So, the indeterminacy of electrons seems inconsistent with both approaches.

Fifth, while classical mereology postulates that any entities have a sum, plural logic is, by itself, silent about this. A thirst for ontological simplicity may then lead one to the non-singularist approach. There is no need to postulate that any entities have a sum when it is possible to refer directly to these entities themselves. But of course, this is unlikely to convince a friend of classical mereology.[5]

Overall, it remains hard to adjudicate between the two approaches. A related way to consider this debate is the following. One-sorted plural logic and atomistic, classical mereology are mutually interpretable (Florio and Linnebo 2021, sec. 5.3): each theory can be interpreted in terms of the other. How, then, should one understand their ideological differences?

What is the relationship between these metaphysical issues and language? The scientific knowledge of chemistry and the theoretical considerations that have been invoked are largely foreign to ordinary speakers. They are the concern of metaphysicians. Still, metaphysicians routinely *use mass terms* when making theoretical claims about mixtures and matter. According to semanticists, mass terms are either singular terms that refer to mereological sums; or they are non-singular terms that can refer to one or several entities at once. As we have seen, notably in sections 2 and 3, adopting either of these approaches constrains the metaphysical claims one can make about mixtures.

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5 See Cotnoir and Varzi (2021, sec. 5.2.1) for a short survey of arguments about UNRESTRICTED SUMS.

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