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Using the disperse system formalism, DSF, to determine the first two classes of complex suspensions

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Abstract

The “disperse system formalism” (DSF) can be used to describe the structure of physical and chemical systems at any scale. It is particularly useful for describing the microstructure of colloidal systems that are ubiquitous in food. Adapting a computer program that was already used for the study of complex gels, the whole set of possible suspensions was determined for the first “classes”, *i.e.*, groups of systems ordered by increasing number of complexity. Here a detailed discussion of the impossible formulae is given, and it is explained how the classes were obtained. It is shown that 6 possibilities exist for the class 1.1 suspensions (one solid phase only dispersed in one monophasic liquid phase); for the class 2.1, there are 362 systems. A generalization to complex solid suspensions, and to emulsions, foams and aerosols is proposed.

Keywords

DSF, colloidal suspensions, classes, number, emulsions, foams, gels, solid suspensions.

Introduction

Suspensions are systems made of “a liquid in which solid particles are dispersed”, and solid suspensions are systems for which solid particles are dispersed in a solid phase (IUPAC, 2019a). Among such systems, colloidal suspensions are suspensions for which the sizes of the particles lie in the colloidal range, with the definition of “colloidal”: “The term refers to a state of subdivision, implying that the molecules or polymolecular particles dispersed in a medium have at least in one direction a dimension roughly between 1 nm and 1 μ m, or that in a system discontinuities are found at distances of that order” (IUPAC, 2019b)

Such systems are ubiquitous in food. For example, many sauces, such as hollandaise, béarnaise, veloutés or custard, are suspensions (This, 2021a), but also fruit or vegetable purees, and smoothies are more or less concentrated suspensions of deformable particles (Leverrier *et al.*, 2021); pastes and

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doughs also fall in the suspension category (Zhang *et al.*, 2020).

In order to describe the colloidal systems, and the gels in particular, a formalism was introduced in 2001 (This, 2021b). It was first named “complex disperse system formalism” (CDS), but it was later mixed with another proposal called “non periodical organization systems” (NPOS) to become finally the “dispersed system formalism” (DSF). In this description of the topological and physical organization of structures, letters describe the phases (gas, oil, solids, water, etc.). As frequently in physical chemistry (Dickinson, 1986), “oil” (O) stands for any liquid fat, and “water” (W) for any aqueous solution; the letters G and S apply respectively to gas and solids. In other contexts of formulation, such as cosmetics, drugs, paintings and varnishes, etc., other symbols could be used if needed, such as E for pure ethanol, P for poly(oxyethylene) (“polyethylene glycol”) or any other letter that would be the abbreviation of a specific solvent.

The “dimensions” of the various objects making up a system are defined after a size of reference λ has been introduced: it can be any length, either the size of the overall system, or another smaller size, when the description focuses on the microscopic, the nanoscopic or the molecular level (This, 2016a).

The D_3 objects are defined as having their dimensions in the three directions of space of the same order of magnitude (this being defined rigorously) as the size of reference λ ; D_2 , D_1 and D_0 objects are defined as having respectively one, two or three of their dimensions more than one order of magnitude smaller as the size of reference λ .

Finally, operators (+, /, x, @, σ) indicate how all the phases are topologically arranged:

- “+” is used when two phases or more are directly inside another phase ;
- “/” stands for a random dispersion of elements from one phase into another phase;
- “x” stands for the intermixing of two continuous phases ;

- “@” stands for inclusion ;

- σ stands for superpositions (with possibilities of adding a direction x, y or z).

Using this formalism, all possible gels were previously determined for classes 1 and 2 (This, 2016b). Here we give the results of the same kind for suspensions.

Describing the simplest suspensions is easy, as they have the formula $D_0(S)/D_3(L)$, corresponding to the random dispersion of solid particles S in a liquid L. However, in this formula $D_0(S)/D_3(L)$, various cases can be envisioned for food systems, as the liquid L could be an aqueous solution (W) or melted fat (O) (most simple cases), but also an emulsion or a foam (more complex cases), because the random dispersion of solid particles in a liquid is not the sole possibility for systems deserving the name “suspension” as defined by IUPAC (2019a).

The question discussed here is to know how many kind of suspensions can exist (avoiding to forget anyone), and what they are. To this end, the DSF can be used within a simple computer program, to solve this first question, as it was already done formerly for gels.

For suspensions as for gels, “classes” of systems need to be defined. For class 1, only one solid phase is suspended in the liquid, but this liquid can either be monophasic (oil, water ; class 1.1) or biphasic, such as in simple emulsions or simple foams (class 1.2). For suspensions of class 2, two phases are suspended, with at least one solid phase (in order to deserve the IUPAC name of “suspension”), and so on.

In this article, such organizations are explored, focusing on systems of classes 1 (C1) and 2 (C2). Such a discussion can be the basis for the recognition of various natural and artificial systems as suspensions, but it can also be used for technical innovation: any formula corresponding to a suspension can be turned into a formulated system, used in the industry, with specific properties (flavour release, rheology, optical properties, etc.).

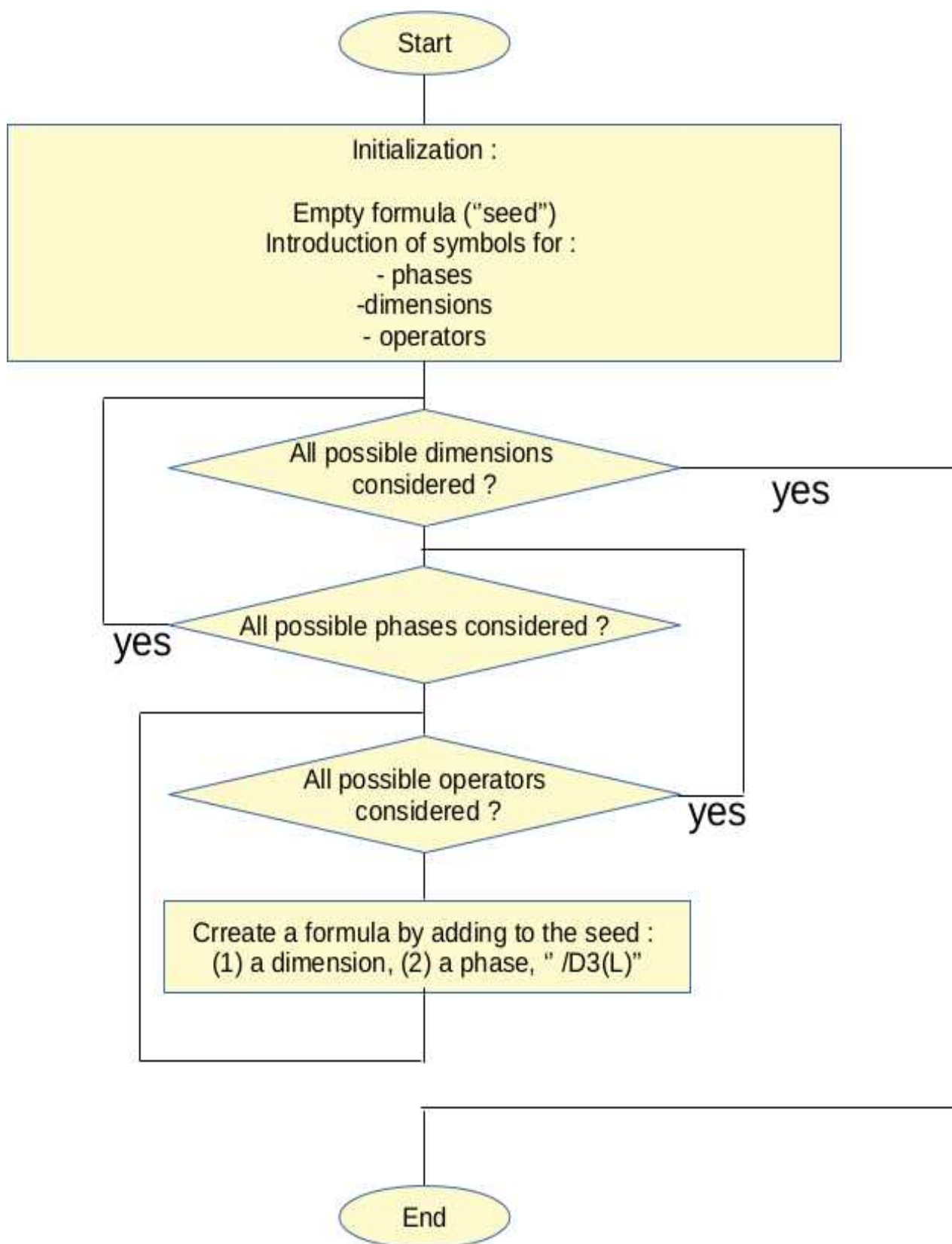


Figure 1. The simplest program for producing all possible C1 formulae for dispersions in a liquid (L). For suspensions, the first phase must be a solid (S), and the continuous phase (D₃) must be liquid (O, or W). The Maple code is given in Supplemental Material 1.

Materials and methods

As said, C1 suspensions are dispersions in a liquid continuous phase (L). All the systems in this class can be found manually, but the use of a simple computer program (Figure 1) makes sure to get all possibilities without forgetting any of them.

This program introduces first the dimension of the dispersed phase, then the nature of the dispersed phase, an operator for dispersion, another dimension that has to be 3 (continuous liquid phase), and the liquid phase L, which, as said before, can be oil (O), water (W), oil-in-water emulsion (O/W), water-in-oil emulsion (W/O), oleofoam (G/O), or aqueous foam (G/W). A more elaborate program can eliminate redundancies due to some operators that have commutative properties, and it can also eliminate impossible systems.

Let us consider these impossibilities now, keeping in mind the idea that the D_0 , D_1 , D_2 and D_3 objects are physical objects, and not mathematical ones, according to the definitions given above; as a consequence, D_2 objects have a thickness, D_1 objects have a radius, as well as D_0 objects.

For the σ operator (superposition) and for the $+$ operator (coexistence of phases), there is no problem of associating objects of various dimensions, but the question holds for the operators $@$, $/$ and \times . For example, about the $@$ operator, it appears that, whatever the nature of the phases, systems with a phase of a certain dimension can be included in a phase of higher dimension: this is the case for $D_0@D_3$, $D_1@D_3$, $D_2@D_3$, $D_0@D_2$, $D_1@D_2$, $D_0@D_1$: for all these cases, one can express this possibility through the mathematical conditions for the respective volumes of the objects on both side of the $@$ operator. For example, in the first case, assuming a D_0 system with dimensions $a < \lambda/10$, $b < \lambda/10$, $c < \lambda/10$ (whatever the units), the volume $a \times b \times c$ is less than $(\lambda/10)^3$, which would be the smallest volume for a D_3 object.

When the two dimensions are equal ($D_0@D_0$,

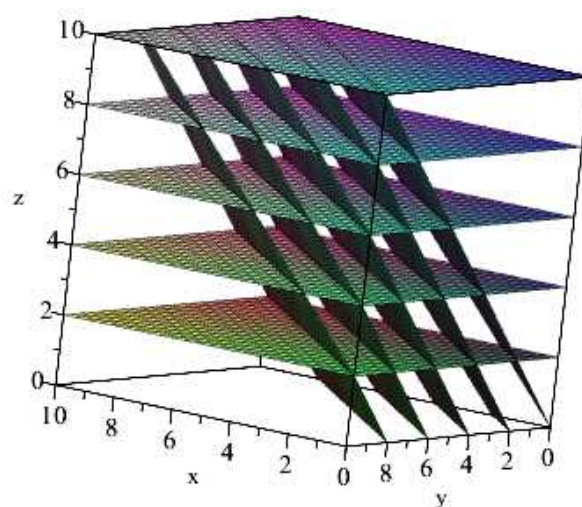


Figure 2. A lamellar network D_2 in a D_3 system (the whole cube), corresponding to the formula $D_2 \times D_3$.

$D_1@D_1$, $D_2@D_2$, $D_3@D_3$), there is no impossibility, as well, as shown by the following specific algebraic conditions: for all four cases, if a , b , c , and a' , b' , c' respectively represent the dimensions of the first and the second object, the inclusion is possible if $a < a'$, $b < b'$, $c < c'$.

The algebraic treatment is different when the dimension of the included phase is higher than the dimension of the including phase. Firstly, for $D_1@D_0$, one can fit a line D_1 of a certain length l in a D_0 system as long as the volume of the D_1 object is less than the volume of the D_0 system: with a reference size λ , the maximum volume for a D_0 system would be $\sim (\lambda/10)^3$, to be compared with the volume of the D_1 object, that could be $l r^2$. As the D_1 object needs to have a length more than $\lambda/10$ (otherwise it would be a D_0 system), the limit for the radius is given by the equation:

$$l r^2 = (\lambda/10)^3$$

with $l = \lambda/10$.

Finally, the radius has to be:

$$r < (\lambda/10)^2.$$

The same kind of calculations can be performed for other systems with formulae $D_2@D_0$, $D_2@D_1$.

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In the first case, one has to consider a crumpled sheet, and its volume, equal to $a \cdot e$ (where a is the area, and e the thickness), has to be lower than $(\lambda/10)^3$, again with the condition that \sqrt{a} should be higher than $(\lambda/10)$, so that this object is really a D_2 one. Here, the condition is:

$$\left(\frac{\lambda}{10}\right)^2 < a < \frac{\left(\frac{\lambda}{10}\right)^3}{e}$$

And a similar calculation can be done for the second case.

Two impossible systems remain: $D_3@D_0$ and $D_3@D_1$, because:

- for the first one, the equation expressing the volumes $(\lambda/10)^3 < (\lambda/10)^3$ has no solution,

- for the second one, the condition on volume, for the direction of the line, would be: $(\lambda/10)^3 < (\lambda/10)$, which is impossible.

On the contrary, objects with a $D_3@D_2$ formula can exist: simply consider a ball inside a "skin".

For the / operator (random dispersion of one phase into another), the algebraic treatment is the same as for @, but it has to include a number n of dispersed objects higher than 1 (in other words, if the volume found for one included object is v , the volume for n included objects is v/n).

To begin with, whatever the phase, objects of a particular dimension can be randomly dispersed in a phase of a higher dimension, such as in D_0/D_3 , D_0/D_2 , D_0/D_1 , D_1/D_3 , D_1/D_2 , D_2/D_3 . Now the question is about dispersing a phase of higher dimension in a phase of equal or lower dimension, but the analysis made above can be used here again (introducing in the equations a number n for the number of dispersed systems) to show that formulae such as D_0/D_0 , D_1/D_0 , D_1/D_1 , D_2/D_0 , D_2/D_1 , D_2/D_2 , D_3/D_2 or D_3/D_3 are possible. Only the cases D_3/D_0 and D_3/D_1 cannot exist.

Finally we have to consider the x operator, corresponding to the intermixing of two continuous systems. The $D_0 \times D_3$ system cannot exist because a phase can be "continuous" only if one of its dimension is of the order of the size of reference, i.e., D_0 objects are excluded. This

operator x was defined (This, 2007) as commutative, so that the list of formulae that can be built using it is reduced to $D_0 \times D_0$, $D_0 \times D_1$, $D_0 \times D_2$, $D_0 \times D_3$, $D_1 \times D_2$, $D_1 \times D_3$, $D_2 \times D_3$, $D_3 \times D_3$.

The $D_0 \times D_0$ and the $D_3 \times D_3$ systems are alike. The $D_0 \times D_1$ and $D_0 \times D_2$ systems correspond respectively to a network of holes in a D_1 or a D_2 system. The $D_1 \times D_2$ and $D_1 \times D_3$ are made of "filamentous" networks within respectively a D_2 and a D_3 object (in this last case, we have the formula correspond to gelatin gels, for example). The formula $D_2 \times D_3$ corresponds to a lamellar network in a D_3 system (Figure 2).

Dropping the impossibilities, we obtain finally 24 formulae (Figure 3).

$D_0(W) \times D_3(W)$
$D_0(W)/D_3(W)$
$D_0(O) \times D_3(W)$
$D_0(O)/D_3(W)$
$D_0(S) \times D_3(W)$
$D_0(S)/D_3(W)$
$D_1(W) \times D_3(W)$
$D_1(W)/D_3(W)$
$D_1(O) \times D_3(W)$
$D_1(O)/D_3(W)$
$D_1(S) \times D_3(W)$
$D_1(S)/D_3(W)$
$D_2(W) \times D_3(W)$
$D_2(W)/D_3(W)$
$D_2(O) \times D_3(W)$
$D_2(O)/D_3(W)$
$D_2(S) \times D_3(W)$
$D_2(S)/D_3(W)$
$D_3(W) \times D_3(W)$
$D_3(W)/D_3(W)$
$D_3(O) \times D_3(W)$
$D_3(O)/D_3(W)$
$D_3(S) \times D_3(W)$
$D_3(S)/D_3(W)$

Figure 3. The possible C1 dispersions. With the simplest program of figure 1, dispersions -and not only suspensions- are produced.

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In this list of dispersions, in order to isolate only suspensions, we have to drop off emulsions, foams and gels, and focus on a solid dispersed into a liquid. To this aim, it is easy to change the program of figure 1, and limit it to writing the formulae of a solid phase dispersed in a liquid (L). Of course, this letter L can be replaced by W (aqueous solution) or O (melted fat), in class 1.1 (C1.1) systems, and by L₁/L₂ and G/L for emulsions and foams respectively (class 1.2, C1.2).

Now, for C2 systems, a similar program can be used (Figure 4), but again impossibility rules have to be applied: whatever the phases making up the various objects, the formulae D₃@D₀, D₃@D₁, D₃/D₀, D₃/D₁, D₀xD₃ or D₃xD₀ are impossible. Also, symmetries have to be taken into account for the operators σ, x, +.

Results

Using the modified program for C1 dispersions, the list of all possible suspensions can be established for this class. The results are:

- D₀(S)/D₃(W) : simple classic dispersion in an aqueous solution,
- D₁(S)/D₃(W) : dispersion of filaments in an aqueous solution,
- D₂(S)/D₃(W) : dispersion of sheets in an aqueous solution,
- D₀(S)/D₃(O) : dispersion in oil,
- D₁(S)/D₃(O) : dispersion of filaments in oil,
- D₂(S)/D₃(O) : dispersion of sheets in oil.

For emulsions, *i.e.*, class 1.2.1 (O/W or W/O), or for foams, *i.e.*, class 1.2.2 (G/O or G/W), the list is:

- D₀(S)/D₃(O/W)
- D₁(S)/D₃(O/W)
- D₂(S)/D₃(O/W)
- D₀(S)/D₃(W/O)
- D₁(S)/D₃(W/O)
- D₂(S)/D₃(W/O)
- D₀(S)/D₃(G/O)
- D₁(S)/D₃(G/O)

- D₁(S)/D₃(G/O)
- D₀(S)/D₃(G/W)
- D₁(S)/D₃(G/W)
- D₁(S)/D₃(G/W).

Of course, there are various possibilities for the A/B formulae used here in the dispersing medium because of dimensions.

For C2 suspensions, there are 362 results (Supplemental Material 2 and 3). This number holds for any "liquid" L, and, again, we can distinguish various cases: (1) class 2.1 (C2.1) when the suspension is in a monophasic liquid (L = O or L = W), (2) class 2.2 (C2.2). when it is in a more complex biphasic system, emulsions (C2.2.1) or foams (C2.2.2).

Discussion

Before considering the results, the issue of the coherence and completeness of the DSF is to be discussed. Up to now, no contradiction was found, but no mathematical demonstration has been showing that the system is coherent, and there is still the possibility of incompleteness of the formalism, and, hence, a possibility to have missed some systems, even if the number already produced is high. On the other hand, it can be observed that up to now, no physical system that was analyzed escaped a description by the DSF. The x operator was introduced in 2003 because some gels were not correctly described using the / operator, but since no other modification of the formalism was needed.

In the assumption of completeness, one has also to observe that colloidal systems are often out of equilibrium, and only metastable, so that their making is a question of smartness rather than thermodynamic stability (Poon, 2000).

As said, the programs shown here were already applied for gels (This, 2016b), and they are simple to write. The adaptation to suspensions is straightforward. Here we focused on liquid suspensions, *i.e.*, suspensions in a liquid phase, but replacing the letter L by S produces all

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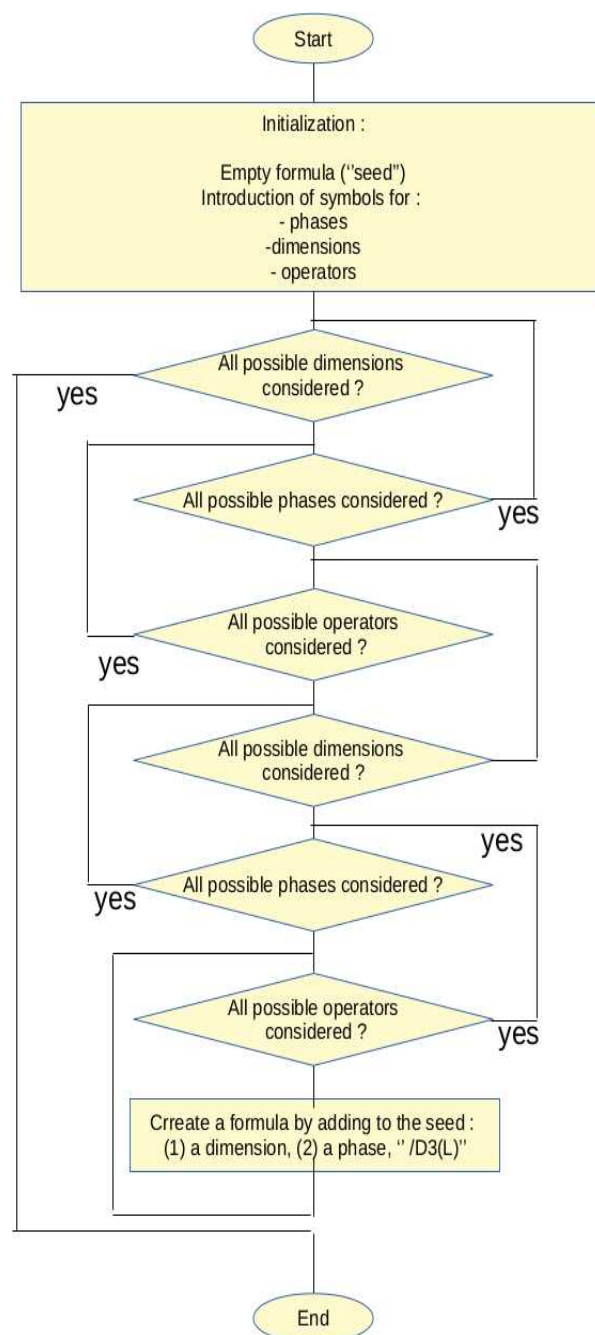
possible solid suspensions as well. Of course, using the same kind of work, one could envision complex emulsions, complex foams, complex aerosols: for complex emulsions, one has to replace the dispersed phase of suspensions (S) with a liquid (L= O or W); for foams, one has to replace the dispersed phase of suspensions (S) with a gas (G); for complex aerosols, one has to replace the dispersing phase of suspensions (L) with a gas (G).

Coming back to liquid suspensions, it would be much too long to discuss them all one by one, and to try to guess what they can be. This is not a difficult work, and some hours of training are enough to describe formulae in natural language. For example, the formula $[D_0(G)@D_0(S)]/D_3(L)$ corresponds to suspensions in a liquid L of solids with gaseous core; $[D_0(G)@D_1(S)]/D_3(L)$ corresponds to suspensions in a liquid L of filaments including a gaseous zero dimensional core; and $[D_0(G)@D_2(S)]/D_3(L)$ corresponds to suspensions of sheets having each a gaseous core of dimension 0 ; and so on.

With the three considered examples, one can observe that there are many different systems corresponding to each case: not only the chemical material of the solid, the gas and the liquid can be anyone, as long as they remain in this physical state, but the shape and size of the dispersed solids (and their core) can also be different: they can be cube, spheres, or any irregular shape, and the size is simply smaller than 1/10 of the reference size (of the liquid).

About these systems, one question is to know which ones can be found in the natural world. For example, milk has been said to be an emulsion, but this would be true only when all the fat is melted ($T > 55\text{ }^\circ\text{C}$) (Lopez and Ollivon, 2009); at lower temperatures, the system is a dispersion -in an aqueous solution W- of structures made of a solid core ($D_0(S)$) in a liquid shell ($D_0(O)$), i.e., a complex suspension.

Another question is to understand how the formulae of possible systems can be grouped from shared properties: flavour release, optical,



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rheology, etc. For technology, it is now possible to envision existing systems of a certain set (sauces, cosmetics, paintings, etc.), and to look for absent formulae within this set after it was ordered by order of complexity. For example, about sauces, the full set of classical French sauces was explored by optical microscopy, (size cutoff $d > 10^{-7}$), and 23 categories were found, some of them being suspensions. Surprisingly some simple types are missing, such as “foamed veloutés” ($D_0(G) + D_0(W/S)/D_3(W)$). Such systems are not difficult to produce practically. This led to a separate study on the number of different kinds of sauces as a function of time, using some traditional French culinary books (This, 2009). The increasing number of types of sauces with time shows that culinary empiricism has probably not had enough time yet to develop all possible kinds of sauces.

Conclusions and perspectives

Using an adaptation of a work done before for gels, we showed here that the number of possible liquid suspensions is great, but limited within each particular class. This is the first step before the analysis of their properties, in view of their grouping in categories. All the work done was obtained for liquids suspensions, but it is obvious to get the same result for solid suspensions (only replace the “L” symbol with the symbol “S”).

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Supplemental Material :

1. The Maple code for creating all C1 dispersions.

```
A := [];  
phase := [W, O, S];  
dimension := [D0, D1, D2, D3];  
operator := ["X", "/", "@", "σ;"];  
formula := "";  
seed := "";  
for dim1 to 4 do  
  for phas1 to 3 do  
    for ope to 2 do  
      formula := cat(seed, dimension[dim1], "(",  
phase[phas1], ")", operator[ope], dimension[4], "(",  
phase[1], ")");  
      A := [op(A), formula];  
    end do;  
  end do;  
end do;  
formula;  
writedata("suspensions_class_1_in_W_simplistic"  
, A, string);
```

2. The Maple program for finding all formulae of C2 suspensions in water or in oil. Here the impossibilities and symmetries have to be cropped off manually, but conditions can be used for calculating them.

```
A := [];  
dimension := [D0, D1, D2, D3];  
phase := [W, O, S];  
operator := ["X", "/", "@", "s"];
```

```
formula := "";  
seed := "";  
for dim1 to 4 do  
  formula := cat(seed, dimension[dim1], "(", "S",  
")", "/", dimension[4], "(L)");  
  A := [op(A), formula];  
end do;  
formula;  
writedata("suspensions_class_1_in_L", A,  
string);
```

2. The Maple code for creating C1 suspensions.

```
A := [];  
dimension := ["D0", "D1", "D2", "D3"];  
phase := ["G", "O", "S", "W"];  
operator := ["X", "/", "@", "&sigma;", "+"];  
formula := "";  
seed := "";  
for dim1 to 3 do  
  for phas1 to 4 do  
    for ope to 5 do  
      for dim2 to 3 do  
        for phas2 to 4 do  
          for phas3 to 4 do  
            if phase[phas3] = "O" or phase[phas3] = "W"  
then  
if phase[phas1] = "S" or phase[phas2] = "S" then  
formula := cat(seed, "[", dimension[dim1], "(",  
phase[phas1], ")", operator[ope],  
dimension[dim2], "(", phase[phas2], ")",  
phase[phas3], ")"); A := [op(A), formula];  
end if;  
end if;  
end do;  
end do;  
end do;  
end do;  
end do;  
end do;  
writedata("dispersions_class_2", A, string);
```

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3. The generic formulae for C2 suspensions.

[D0(G) @ D0(S)] / D3(L)	[D0(S) @ D2(W)] / D3(L)	[D0(S) X D0(S)] / D3(L)
[D0(G) @ D1(S)] / D3(L)	[D0(S) @ D3(G)] / D3(L)	[D0(S) X D0(W)] / D3(L)
[D0(G) @ D2(S)] / D3(L)	[D0(S) @ D3(O)] / D3(L)	[D0(S) X D1(G)] / D3(L)
[D0(G) @ D3(S)] / D3(L)	[D0(S) @ D3(S)] / D3(L)	[D0(S) X D1(O)] / D3(L)
[D0(G) / D0(S)] / D3(L)	[D0(S) @ D3(W)] / D3(L)	[D0(S) X D1(S)] / D3(L)
[D0(G) / D1(S)] / D3(L)	[D0(S) / D0(G)] / D3(L)	[D0(S) X D1(W)] / D3(L)
[D0(G) / D2(S)] / D3(L)	[D0(S) / D0(O)] / D3(L)	[D0(S) X D2(G)] / D3(L)
[D0(G) / D3(S)] / D3(L)	[D0(S) / D0(S)] / D3(L)	[D0(S) X D2(O)] / D3(L)
[D0(G) + D0(S)] / D3(L)	[D0(S) / D0(W)] / D3(L)	[D0(S) X D2(S)] / D3(L)
[D0(G) + D1(S)] / D3(L)	[D0(S) / D1(G)] / D3(L)	[D0(S) X D2(S)] / D3(L)
[D0(G) + D2(S)] / D3(L)	[D0(S) / D1(O)] / D3(L)	[D0(W) @ D0(S)] / D3(L)
[D0(G) + D3(S)] / D3(L)	[D0(S) / D1(S)] / D3(L)	[D0(W) @ D1(S)] / D3(L)
[D0(G) s D0(S)] / D3(L)	[D0(S) / D1(W)] / D3(L)	[D0(W) @ D2(S)] / D3(L)
[D0(G) s D1(S)] / D3(L)	[D0(S) / D2(G)] / D3(L)	[D0(W) @ D3(S)] / D3(L)
[D0(G) s D2(S)] / D3(L)	[D0(S) / D2(O)] / D3(L)	[D0(W) / D0(S)] / D3(L)
[D0(G) s D3(S)] / D3(L)	[D0(S) / D2(S)] / D3(L)	[D0(W) / D1(S)] / D3(L)
[D0(G) X D0(S)] / D3(L)	[D0(S) / D2(W)] / D3(L)	[D0(W) / D2(S)] / D3(L)
[D0(G) X D1(S)] / D3(L)	[D0(S) / D3(G)] / D3(L)	[D0(W) + D1(S)] / D3(L)
[D0(G) X D2(S)] / D3(L)	[D0(S) / D3(O)] / D3(L)	[D0(W) + D2(S)] / D3(L)
[D0(O) @ D0(S)] / D3(L)	[D0(S) / D3(S)] / D3(L)	[D0(W) + D3(S)] / D3(L)
[D0(O) @ D1(S)] / D3(L)	[D0(S) / D3(W)] / D3(L)	[D0(W) s D1(S)] / D3(L)
[D0(O) @ D2(S)] / D3(L)	[D0(S) + D0(S)] / D3(L)	[D0(W) s D2(S)] / D3(L)
[D0(O) @ D3(S)] / D3(L)	[D0(S) + D0(W)] / D3(L)	[D0(W) s D3(S)] / D3(L)
[D0(O) / D0(S)] / D3(L)	[D0(S) + D1(G)] / D3(L)	[D0(W) X D1(S)] / D3(L)
[D0(O) / D1(S)] / D3(L)	[D0(S) + D1(O)] / D3(L)	[D0(W) X D2(S)] / D3(L)
[D0(O) / D2(S)] / D3(L)	[D0(S) + D1(S)] / D3(L)	[D1(G) @ D0(S)] / D3(L)
[D0(O) / D3(S)] / D3(L)	[D0(S) + D1(W)] / D3(L)	[D1(G) @ D1(S)] / D3(L)
[D0(O) + D0(S)] / D3(L)	[D0(S) + D2(G)] / D3(L)	[D1(G) @ D2(S)] / D3(L)
[D0(O) + D1(S)] / D3(L)	[D0(S) + D2(O)] / D3(L)	[D1(G) @ D3(S)] / D3(L)
[D0(O) + D2(S)] / D3(L)	[D0(S) + D2(S)] / D3(L)	[D1(G) / D0(S)] / D3(L)
[D0(O) + D3(S)] / D3(L)	[D0(S) + D2(W)] / D3(L)	[D1(G) / D1(S)] / D3(L)
[D0(O) s D0(S)] / D3(L)	[D0(S) + D3(G)] / D3(L)	[D1(G) / D2(S)] / D3(L)
[D0(O) s D1(S)] / D3(L)	[D0(S) + D3(O)] / D3(L)	[D1(G) / D3(S)] / D3(L)
[D0(O) s D2(S)] / D3(L)	[D0(S) + D3(S)] / D3(L)	[D1(G) + D1(S)] / D3(L)
[D0(O) s D3(S)] / D3(L)	[D0(S) + D3(W)] / D3(L)	[D1(G) + D2(S)] / D3(L)
[D0(O) X D0(S)] / D3(L)	[D0(S) s D0(S)] / D3(L)	[D1(G) + D3(S)] / D3(L)
[D0(O) X D1(S)] / D3(L)	[D0(S) s D0(W)] / D3(L)	[D1(G) s D1(S)] / D3(L)
[D0(O) X D2(S)] / D3(L)	[D0(S) s D1(G)] / D3(L)	[D1(G) s D2(S)] / D3(L)
[D0(S) @ D0(G)] / D3(L)	[D0(S) s D1(O)] / D3(L)	[D1(G) s D3(S)] / D3(L)
[D0(S) @ D0(O)] / D3(L)	[D0(S) s D1(S)] / D3(L)	[D1(G) X D1(S)] / D3(L)
[D0(S) @ D0(S)] / D3(L)	[D0(S) s D1(W)] / D3(L)	[D1(G) X D2(S)] / D3(L)
[D0(S) @ D0(W)] / D3(L)	[D0(S) s D2(G)] / D3(L)	[D1(G) X D3(S)] / D3(L)
[D0(S) @ D1(G)] / D3(L)	[D0(S) s D2(O)] / D3(L)	[D1(O) @ D0(S)] / D3(L)
[D0(S) @ D1(O)] / D3(L)	[D0(S) s D2(S)] / D3(L)	[D1(O) @ D1(S)] / D3(L)
[D0(S) @ D1(S)] / D3(L)	[D0(S) s D2(W)] / D3(L)	[D1(O) @ D2(S)] / D3(L)
[D0(S) @ D1(W)] / D3(L)	[D0(S) s D3(G)] / D3(L)	[D1(O) @ D3(S)] / D3(L)
[D0(S) @ D2(G)] / D3(L)	[D0(S) s D3(O)] / D3(L)	[D1(O) / D0(S)] / D3(L)
[D0(S) @ D2(O)] / D3(L)	[D0(S) s D3(S)] / D3(L)	[D1(O) / D1(S)] / D3(L)
[D0(S) @ D2(S)] / D3(L)	[D0(S) s D3(W)] / D3(L)	[D1(O) / D2(S)] / D3(L)

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[D1(O) / D3(S)] / D3(L)	[D1(S) s D1(S)] / D3(L)	[D2(O) / D0(S)] / D3(L)
[D1(O) + D1(S)] / D3(L)	[D1(S) s D1(W)] / D3(L)	[D2(O) / D1(S)] / D3(L)
[D1(O) + D2(S)] / D3(L)	[D1(S) s D2(G)] / D3(L)	[D2(O) / D2(S)] / D3(L)
[D1(O) + D3(S)] / D3(L)	[D1(S) s D2(O)] / D3(L)	[D2(O) / D3(S)] / D3(L)
[D1(O) s D1(S)] / D3(L)	[D1(S) s D2(S)] / D3(L)	[D2(O) + D2(S)] / D3(L)
[D1(O) s D2(S)] / D3(L)	[D1(S) s D2(W)] / D3(L)	[D2(O) + D3(S)] / D3(L)
[D1(O) s D3(S)] / D3(L)	[D1(S) s D3(O)] / D3(L)	[D2(O) s D3(S)] / D3(L)
[D1(S) @ D0(G)] / D3(L)	[D1(S) s D3(S)] / D3(L)	[D2(O) X D2(S)] / D3(L)
[D1(S) @ D0(O)] / D3(L)	[D1(S) s D3(W)] / D3(L)	[D2(O) X D3(S)] / D3(L)
[D1(S) @ D0(S)] / D3(L)	[D1(S) X D1(O)] / D3(L)	[D2(S) @ D0(G)] / D3(L)
[D1(S) @ D0(W)] / D3(L)	[D1(S) X D1(S)] / D3(L)	[D2(S) @ D0(O)] / D3(L)
[D1(S) @ D1(G)] / D3(L)	[D1(S) X D1(W)] / D3(L)	[D2(S) @ D0(S)] / D3(L)
[D1(S) @ D1(O)] / D3(L)	[D1(S) X D2(G)] / D3(L)	[D2(S) @ D0(W)] / D3(L)
[D1(S) @ D1(S)] / D3(L)	[D1(S) X D2(O)] / D3(L)	[D2(S) @ D1(G)] / D3(L)
[D1(S) @ D1(W)] / D3(L)	[D1(S) X D2(S)] / D3(L)	[D2(S) @ D1(O)] / D3(L)
[D1(S) @ D2(G)] / D3(L)	[D1(S) X D2(W)] / D3(L)	[D2(S) @ D1(S)] / D3(L)
[D1(S) @ D2(O)] / D3(L)	[D1(S) X D3(G)] / D3(L)	[D2(S) @ D1(W)] / D3(L)
[D1(S) @ D2(S)] / D3(L)	[D1(S) X D3(O)] / D3(L)	[D2(S) @ D2(G)] / D3(L)
[D1(S) @ D2(W)] / D3(L)	[D1(S) X D3(S)] / D3(L)	[D2(S) @ D2(O)] / D3(L)
[D1(S) @ D3(G)] / D3(L)	[D1(S) X D3(W)] / D3(L)	[D2(S) @ D2(S)] / D3(L)
[D1(S) @ D3(O)] / D3(L)	[D1(W) @ D0(S)] / D3(L)	[D2(S) @ D2(W)] / D3(L)
[D1(S) @ D3(S)] / D3(L)	[D1(W) @ D1(S)] / D3(L)	[D2(S) @ D3(G)] / D3(L)
[D1(S) @ D3(W)] / D3(L)	[D1(W) @ D2(S)] / D3(L)	[D2(S) @ D3(O)] / D3(L)
[D1(S) / D0(G)] / D3(L)	[D1(W) @ D3(S)] / D3(L)	[D2(S) @ D3(S)] / D3(L)
[D1(S) / D0(O)] / D3(L)	[D1(W) / D0(S)] / D3(L)	[D2(S) @ D3(W)] / D3(L)
[D1(S) / D0(S)] / D3(L)	[D1(W) / D1(S)] / D3(L)	[D2(S) / D0(G)] / D3(L)
[D1(S) / D0(W)] / D3(L)	[D1(W) / D2(S)] / D3(L)	[D2(S) / D0(O)] / D3(L)
[D1(S) / D1(G)] / D3(L)	[D1(W) / D3(S)] / D3(L)	[D2(S) / D0(S)] / D3(L)
[D1(S) / D1(O)] / D3(L)	[D1(W) + D2(S)] / D3(L)	[D2(S) / D0(W)] / D3(L)
[D1(S) / D1(S)] / D3(L)	[D1(W) + D3(S)] / D3(L)	[D2(S) / D1(G)] / D3(L)
[D1(S) / D1(W)] / D3(L)	[D1(W) s D2(S)] / D3(L)	[D2(S) / D1(O)] / D3(L)
[D1(S) / D2(G)] / D3(L)	[D1(W) s D3(S)] / D3(L)	[D2(S) / D1(S)] / D3(L)
[D1(S) / D2(O)] / D3(L)	[D2(G) @ D0(S)] / D3(L)	[D2(S) / D1(W)] / D3(L)
[D1(S) / D2(S)] / D3(L)	[D2(G) @ D1(S)] / D3(L)	[D2(S) / D2(G)] / D3(L)
[D1(S) / D2(W)] / D3(L)	[D2(G) @ D2(S)] / D3(L)	[D2(S) / D2(O)] / D3(L)
[D1(S) / D3(G)] / D3(L)	[D2(G) @ D3(S)] / D3(L)	[D2(S) / D2(S)] / D3(L)
[D1(S) / D3(O)] / D3(L)	[D2(G) / D0(S)] / D3(L)	[D2(S) / D2(W)] / D3(L)
[D1(S) / D3(S)] / D3(L)	[D2(G) / D1(S)] / D3(L)	[D2(S) / D3(G)] / D3(L)
[D1(S) / D3(W)] / D3(L)	[D2(G) / D2(S)] / D3(L)	[D2(S) / D3(O)] / D3(L)
[D1(S) + D1(S)] / D3(L)	[D2(G) / D3(S)] / D3(L)	[D2(S) / D3(S)] / D3(L)
[D1(S) + D1(W)] / D3(L)	[D2(G) + D2(S)] / D3(L)	[D2(S) / D3(W)] / D3(L)
[D1(S) + D2(G)] / D3(L)	[D2(G) + D3(S)] / D3(L)	[D2(S) + D2(S)] / D3(L)
[D1(S) + D2(O)] / D3(L)	[D2(G) s D2(S)] / D3(L)	[D2(S) + D2(W)] / D3(L)
[D1(S) + D2(S)] / D3(L)	[D2(G) s D3(S)] / D3(L)	[D2(S) + D3(G)] / D3(L)
[D1(S) + D2(W)] / D3(L)	[D2(O) @ D0(S)] / D3(L)	[D2(S) + D3(O)] / D3(L)
[D1(S) + D3(G)] / D3(L)	[D2(O) @ D1(S)] / D3(L)	[D2(S) + D3(S)] / D3(L)
[D1(S) + D3(O)] / D3(L)	[D2(O) @ D2(S)] / D3(L)	[D2(S) + D3(W)] / D3(L)
[D1(S) + D3(S)] / D3(L)	[D2(O) @ D3(S)] / D3(L)	[D2(S) s D2(S)] / D3(L)
[D1(S) + D3(W)] / D3(L)		

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[D2(S) s D2(W)] / D3(L) [D3(S) / D2(W)] / D3(L)
[D2(S) s D3(G)] / D3(L) [D3(S) / D3(G)] / D3(L)
[D2(S) s D3(O)] / D3(L) [D3(S) / D3(O)] / D3(L)
[D2(S) s D3(S)] / D3(L) [D3(S) / D3(S)] / D3(L)
[D2(S) s D3(W)] / D3(L) [D3(S) / D3(W)] / D3(L)
[D2(S) X D1(O)] / D3(L) [D3(S) + D3(S)] / D3(L)
[D2(S) X D1(W)] / D3(L) [D3(S) + D3(W)] / D3(L)
[D2(S) X D2(G)] / D3(L) [D3(S) s D3(S)] / D3(L)
[D2(S) X D2(S)] / D3(L) [D3(S) s D3(W)] / D3(L)
[D2(S) X D2(W)] / D3(L) [D3(S) X D1(O)] / D3(L)
[D2(S) X D3(G)] / D3(L) [D3(S) X D1(W)] / D3(L)
[D2(S) X D3(O)] / D3(L) [D3(S) X D2(G)] / D3(L)
[D2(S) X D3(S)] / D3(L) [D3(S) X D3(O)] / D3(L)
[D2(S) X D3(W)] / D3(L) [D3(S) X D3(S)] / D3(L)
[D2(W) @ D0(S)] / D3(L) [D3(S) X D3(W)] / D3(L)
[D2(W) @ D1(S)] / D3(L) [D3(W) @ D2(S)] / D3(L)
[D2(W) @ D2(S)] / D3(L) [D3(W) @ D3(S)] / D3(L)
[D2(W) @ D3(S)] / D3(L) [D3(W) / D2(S)] / D3(L)
[D2(W) / D0(S)] / D3(L) [D3(W) / D3(S)] / D3(L)
[D2(W) / D1(S)] / D3(L)
[D2(W) / D2(S)] / D3(L)
[D2(W) / D3(S)] / D3(L)
[D2(W) + D3(S)] / D3(L)
[D2(W) s D3(S)] / D3(L)
[D2(W) X D3(S)] / D3(L)
[D3(G) @ D2(S)] / D3(L)
[D3(G) @ D3(S)] / D3(L)
[D3(G) / D2(S)] / D3(L)
[D3(G) / D3(S)] / D3(L)
[D3(G) + D3(S)] / D3(L)
[D3(G) s D3(S)] / D3(L)
[D3(G) X D3(S)] / D3(L)
[D3(O) @ D2(S)] / D3(L)
[D3(O) @ D3(S)] / D3(L)
[D3(O) / D2(S)] / D3(L)
[D3(O) / D3(S)] / D3(L)
[D3(O) + D3(S)] / D3(L)
[D3(O) s D3(S)] / D3(L)
[D3(S) @ D2(G)] / D3(L)
[D3(S) @ D2(O)] / D3(L)
[D3(S) @ D2(S)] / D3(L)
[D3(S) @ D2(W)] / D3(L)
[D3(S) @ D3(G)] / D3(L)
[D3(S) @ D3(O)] / D3(L)
[D3(S) @ D3(S)] / D3(L)
[D3(S) @ D3(W)] / D3(L)
[D3(S) / D2(G)] / D3(L)
[D3(S) / D2(O)] / D3(L)
[D3(S) / D2(S)] / D3(L)