Molecular gastronomy

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For centuries, cooks have been applying recipes without looking for the mechanisms of the culinary transformations. A scientific discipline that explores these changes from raw ingredients to eating the final dish, is developing into its own field, termed molecular gastronomy. Here, one of the founders of the discipline discusses its aims and importance.

Molecular gastronomy, having initially become popular through international workshops at the Ettore Majorana Centre for Scientific Culture (Erice, Sicily), is now spreading, with the creation of professorships in France, Greece and Denmark, seminars all over the world[1], conferences, a European programme[2], PhD studies, and also recognition by cooks of the interest of the technological applications of this scientific discipline.

In September 2004, a commentary in *Nature Materials* stated that "we can take our science into the chef's domain — a developing area called molecular gastronomy"[3]. This idea is not entirely accurate, because this would make molecular gastronomy (MG) only a technology, or an application of chemistry and physics. However, MG is actually a scientific discipline in itself, whose importance is greater than simple technology transfer.

Initially, MG included modelling recipes, testing old wives tales, inventing new dishes and introducing new tools, methods and ingredients in the kitchen[4]. However, as any intellectual enterprise is improved when clearly defined, technological applications were finally excluded from MG itself and a more precise definition was given in 2003: it was recognized that all recipes are made of two parts that should be studied in their own right[5]. First the definition of the dish: for example, mayonnaise is obtained by dispersing oil droplets in water, using surfactants from egg yolk to cover the droplets and increase the stability (as any emulsion, mayonnaise is not stable, only metastable); pear jam is obtained by heating pears with sugar and water. The second part comprises detailed descriptions of the processes involved in preparing the dish, technical indications along with old wives tales, proverbs, sayings and so on. We now call these 'culinary precisions', or, for short, 'precisions'.

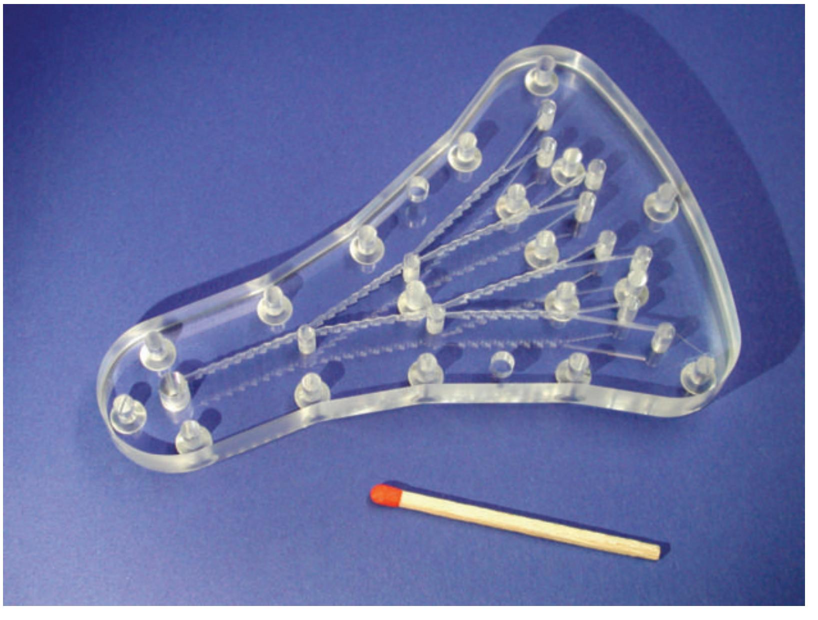

Figure 1 **This system is grouping microreactors in line and in parallel, in order to materialize physical systems described by CDS formalism. Eight inlets can drive gases, liquids and solids into channels where they are dispersed. The prototype has been designed in collaboration with the Institut für Mikromekanik Mainz (IMM), and constructed by Volker Hessel and his team at IMM.**

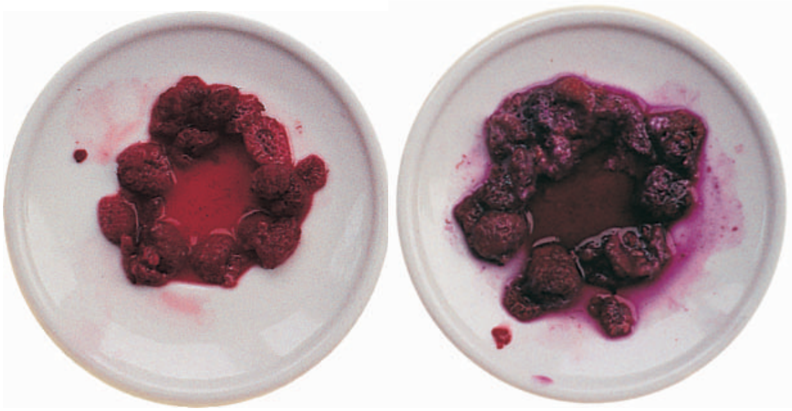

Figure 2 **It has been written by cooks that raspberries turn blue when they are cooked in tin-covered pans. However, the experimental test of this 'culinary precision' refutes it. In fact, tin does not react in the described conditions, but some tin ions added to raspberries do indeed generate a dark blue colour because of the interactions with polyphenols responsible for the colour of red fruits. Left: crushed raspberries with pure water. Right: crushed raspberries with Sn^{2+} ions.**

THE DEFINITION OF THE DISH

Most dishes are composed of disperse systems, formally referred to as colloids. In their most basic form, colloids consist of one phase (gas bubbles, oil or water droplets, or solid particles) dispersed in a different continuous phase. Emulsions, gels, foams and suspensions are all basic colloids, which have many examples in the food world; for example, milk is an oil-in-water emulsion, as is mayonnaise; whipped egg whites are foams and dry into solid foams (meringues); jams are physical gels; and cooked egg whites are chemical gels. Dishes are generally more complex, however. For example, ice cream has gas (air) dispersed (by foaming) in a condensed medium containing ice crystals, protein aggregates, sucrose crystals and fats (either crystals or liquid droplets) — a difficult material to give a technical name to!

Disperse systems can be described by a 'formalism for complex disperse systems' (CDS formalism) based on that invented in 1791 by Antoine-Laurent de Lavoisier[6] for chemistry. By using the following abbreviations: G (for gas); O (oil, that is, any liquid fat, possibly with odorant molecules dissolved in it, such as olive oil, but also melted foie gras, melted cocoa butter…); W (water, that is, any aqueous solution) and S_1, S_2, S_3… (solids of any kind); and with operators such as the following: / (dispersed into), + (mixed with) and so on, formulas can be constructed to describe physical systems.

For example, the process of whipping cream can be written: $O/W + G \rightarrow (G+O)/W$. Equally this formalism can be used to describe new physical systems — for example $((G+O+S_1)/W)/S_2$ refers to a dish made of a gel that contains a water solution where air bubbles, solid particles and oil droplets are dispersed; I called it a Faraday in honour of the great experimentalist and submitted the recipe for a 'Faraday of scallops' (served in 2003 at the Restaurant Pierre Gagnaire, Paris) to the Royal Institution[7,8].

It is interesting to observe that the CDS formalism can describe globally any complex disperse systems, instead on focusing on the interface only. (Note that it would be easy to add new operators as necessary to improve the description of a particular system.) The usefulness of this formalism is obvious: formulas can describe systems that were difficult to imagine, and processes can be generalized. For example, one can keep the $O/W + G \rightarrow (G+O)/W$ process, but change the ingredients: whipping melted chocolate dispersed in water leads to 'Chantilly chocolate', that is, a chocolate mousse with no whipped cream nor whipped egg whites in it; with melted foie gras dispersed in water, one can produce 'foie gras Chantilly' and so on. A piece of apparatus consisting of a series of microreactors has been designed for the practical application of CDS formalism (Fig. 1).

Another formalism has been added to describe dishes and the organization of space[9]. The proposal is to use symbols to describe particular dimensions of objects and to arrange them according to processes described by operators, thus allowing the description of an operating space for the creation of dishes. Such formalism is useful as it can lead to new structures of dishes, with unexplored consistencies.

STUDY OF PRECISIONS

Since 1980, more than 20,000 culinary precisions have been collected, mostly from French cookery books[1]. Consideration of all the collected precisions shows that there is indeed a mixture of all possibilities: some precisions seem true and they are indeed true, some precisions seem true but they are wrong, some precisions seem wrong but they are true, some precisions seem wrong and they are wrong, and even some precisions do not lead to any judgment on their reliability. Intuitions about reliability are not worth considering — experimental tests have to be done (see Fig. 2).

For example, chefs cook green beans in boiling salty water; when the beans are cooked (decided either by smell, texture or flavour), they are strained, then immediately refreshed in icy cold water in order to, chefs say, "fix the chlorophyll"[10]. When asked, chefs admit that "fixing the chlorophyll" means keeping the brilliant green colour of vegetables — but they forget that raw green beans are actually less green than when they are cooked! Is icy cold water useful to keep the green colour? Having observed that cold water has no effect on the visual aspect of green beans, in ordinary culinary conditions (of course, over-cooked beans turn yellow-brown), we investigated the matter further. Chlorophyll pheophytinization (the replacement of the magnesium atom by a proton, at the centre of the chlorophyll molecule) changes the green colour of chlorophyll *a* into an olive–brown colour[11], and it has been shown that the correlation between chlorophyll pheophytinization and the green colour (as measured by colorimetry) of cooked beans is poor. By UV spectroscopy of extracted pigments, it has been found that cooling the green beans in ice has no effect on the colour (C. Gremillet and J. Martin, manuscript in preparation).

The case of mayonnaise helps to understand the reason why culinary precisions arose. Most modern recipes say to add oil to a mixture of egg yolk and vinegar (definition), but many authors add precisions. Some state that the temperature of the room where the mayonnaise is made should not be too hot or that the sauce should be made in a vessel lying on ice cubes; others state, on the contrary, that a cold room temperature is responsible for failure; and others state that oil and eggs should be at the same temperature. Other causes of failure are frequently given: for example, many cooks, in particular in France, think that mayonnaise fails when it is made by women having their periods, or that the cook should always turn the spoon or whisk in the vessel in the same direction.

All these precisions were tested. It was easily checked that women's periods and the direction of whipping do not lead to failure. The question of temperature was also checked, with eggs from the fridge (4 °C) and oil at room temperature (35 °C), or the reverse, and no effect of temperature was observed. This was expected, because mayonnaise is 'only' an emulsion, that is, a dispersion of oil droplets in water; the temperature range of the emulsion stability is quite wide, and so temperature becomes only the main factor for stability under the crystallization temperature of oil, or above protein denaturation points (the first one is at 62 °C, for gamma livetin)[12].

However, some precisions were correct. For example, it was sometimes written that oil should be added 'drop by drop' at the beginning of the sauce preparation. And it is true that mayonnaise fails if too much oil is added first, as water is then dispersed into oil, instead of oil into water. The latter is more stable because of the particular nature of the surfactants from the yolks: proteins and lecithins, which curve the oil/water interface so that oil forms droplets.

Discussion of mayonnaise could fill books, because the sauce is very popular and it has generated many culinary precisions. The question is why do we have this mixture of right and wrong ideas about something as popular as mayonnaise? Consideration of collected precisions led to an assumption: do precisions arise when recipes can fail? To test it scientifically, a mathematical description of how easily recipes fail was needed. This is why we introduced a quantity called 'robustness' of recipes, with which we can now compare the effects of various parameters[7].

For example, when mayonnaise is prepared, oil addition is an important parameter: if one litre of oil were added directly to one egg yolk (which contains about 15 grams of water), whipping would generate the very unstable emulsion of water into oil, and mayonnaise would fail. The maximum volume for oil addition at each step is of the order of the volume of the egg yolk (15 g). If the volume of oil added is lower than this limit, then mayonnaise can succeed (as long as other parameters, such as whipping efficiency, are not limiting factors). This is why 'oil-addition robustness' should depend also on the precision with which oil is added. If this precision is 1 gram, then oil-addition robustness is defined as 15/1 (interval divided by precision), or 15, but if oil were added only at 30 grams at a time, then robustness would be reduced to 15/30, or 0.5. More generally, for any recipe, many particular robustnesses can be calculated (time, mass, temperature) and these quantities can be compared with the number of corresponding precisions.

Box1: NO NUTRITIVE PILLS — EVOLUTION PREVENTS IT

A prediction made in 1894 by the French chemist Marcelin Berthelot was that in the year 2000, humankind would have dropped agriculture and cooking would eat nutritive pills[16]. The year 2000 is over, yet we still stick to our cassoulet, roasted chickens and French fries. Why was Berthelot's prediction so inaccurate?

Berthelot was very enthusiastic about science in general and chemistry in particular, but he forgot that our food behaviour is dictated by both biological needs and our culture. First of all, our many sensory receptors (for odour, taste, consistency, temperature, pain …) have evolved so that, as Brillat-Savarin wrote, "The Creator, by forcing humankind to eat for his living, invited it by appetite and rewarded it by pleasure"[17]. From the point of view of receptor stimulation, pills are much weaker than cassoulets or sauerkraut. Secondly, we eat mostly according to culture: Alsatians like Munster cheese, in spite of its very strong odour but they do not eat durian fruits (a foul smelling but palatable fruit); Asian populations like durian fruits but are repelled by Munster cheese. Finally the maximum energy content of food is in fat, but an easy calculation shows that to get the necessary energy for living, we should eat about 300 g of fat per day, which would require a lot of pills. Clearly, nutritive pills are still a fantasy — it is very unlikely that we shall eat them, even in the year 3000!

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WHAT OF THE FUTURE?

There is a fear that the advancement of science would mean the development of nutrition pills and the abandonment of foodstuffs as we know them (Box 1). On the contrary, MG science proposes a wealth of new dishes and processes[13], and thus has much to contribute to the culinary art. This is why the European project Inicon[2], creating some technology transfer, is centred on MG. This project should contribute to the distribution of new results of MG to professional cooks, first, and later to all the cooks at home. In France, where MG has been very active for years, there are already many projects for presenting MG to the general public: TV shows and radio programmes, courses on MG, French Days of MG, experimental workshops in primary schools[14], various projects in colleges[15]. All these programmes could easily be done in other countries.

The main question of science is to look for mechanisms of natural phenomena. As Louis Pasteur said: "there are no applied sciences, but applications of science". MG is a science, and its applications can be useful for the millions of people that cook daily. We should not fear it, because instead of nutritive pills, which are probably only a bad dream, we can now envision a wealth of interesting new dishes.

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