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Food for tomorrow?

How the scientific discipline of molecular gastronomy could change the way we eat

Hervé This

For years, a new culinary trend called 'molecular cooking' has been touted as the most exciting development in *haute cuisine*. It is now the newest fashion for chefs to offer their customers fake caviar made from sodium alginate and calcium, burning sherbets, spaghetti made from vegetables, and instant ice cream, fast-frozen using liquid nitrogen. In the most recent ranking of the world's top 50 chefs—by the British magazine *Restaurant*—the top three chefs were Ferran Adria from El Bulli in Rosas, Spain; Heston Blumenthal from The Fat Duck in Bray, UK; and Pierre Gagnaire from his restaurant in Paris, France (*Restaurant*, 2006). In 2005, Blumenthal was first and Adria came second. What is remarkable is that all three of these talented and popular chefs have been inspired by molecular gastronomy.

> **…the science of food is not new**

What is molecular gastronomy? Is it only a temporary trend for people who are prepared to spend a small fortune on the latest in fine food, or is it here to stay? Is it a useful technique for both the average chef and anyone preparing dinner for their family? What does it mean for the future of food preparation? What are we going to eat tomorrow?

First, I will define molecular gastronomy, because there is still much confusion in the media about the true meaning of this term, in part because of mistakes Nicholas Kurti and I made when we created the discipline in 1988. But I will start by distinguish between cooking and gastronomy: the first is the preparation of food, whereas the latter is the knowledge of whatever concerns man's nourishment. In essence, this does not concern food fashions or how to prepare luxury food—such as tournedos Rossini, canard à l'orange or lobster orientale—but rather an understanding of food; and for the more restricted 'molecular gastronomy', it is the chemistry and physics behind the preparation of any dish: for example, why a mayonnaise becomes firm or why a soufflé swells.

Of course, the 'molecular' in molecular gastronomy has the same definition as it does in molecular biology. The similarity is intentional, because chemistry and physics are at the core of this discipline, and I will return to this point to explain how physics and chemistry can change cooking. But it is clear that molecular gastronomy is a new science, and that there is already much more to it than what we read in the press. It is quite possible that a European Molecular Gastronomy Organization will one day be created; there are already such organizations in many countries, such as Argentina, Switzerland and Spain. Molecular gastronomy has developed the furthest in France, where the Fondation Science & Culture Alimentaire (Foundation 'Food Science & Culture') has been created this year by the French Academy of Sciences.

Before telling the story of molecular and physical gastronomy—which later became molecular gastronomy—I want to emphasize that the science of food is not new. In the second century BC, the anonymous author of a papyrus kept in London used a balance to determine whether fermented meat was lighter than fresh meat. Since then, many scientists have been interested in food and cooking. In particular, the preparation of meat stock—the aqueous solution obtained by thermal processing of animal tissues in water—has been of great interest. It was first mentioned in the fourth century BC by Apicius (André (ed), 1987), and recipes for stock preparation appear in classic texts (La Varenne, 1651; Menon, 1756; Carême & Plumerey, 1981) and most French culinary books.

> **…there is a difference between the science of ingredients and the science of culinary processes**

Chemists have been interested in meat stock preparation and, more generally, food preparation since the eighteenth century (Lémery, 1705; Geoffroy le Cadet, 1733; Cadet de Vaux, 1818; Darcet, 1830). Antoine-Laurent de Lavoisier is perhaps the most famous among them—in 1783, he studied the processes of stock preparation by measuring density to evaluate quality (Lavoisier, 1783). In reporting the results of his experiments, Lavoisier wrote, "Whenever one considers the most familiar objects, the simplest things, it's impossible not to be surprised to see how our ideas are vague and uncertain, and how, as a consequence, it is important to fix them by experiments and facts" (author's translation). Of course, Justus von Liebig should not be forgotten in the history of culinary science (von Liebig, 1852) and stock was not his only concern. Another important figure was Benjamin Thompson, later knighted Count Rumford, who studied culinary transformations and made many proposals and inventions to improve them, for example by inventing a special coffee pot for better brewing (Kurti, 1995).

There are too many scientists who have contributed to the science of food preparation to list here; however, there is a difference between the science of ingredients and the science of culinary processes. In the 1980s, food science was engaged mainly in analysing the contents and properties of food, and how they relate to the demands of our bodies, and in developing methods to process food on an industrial scale. However, millions of people who prepared food for themselves or their families had no science to help them understand what they were doing.

Despite having a huge impact on other aspects of our lives, scientific advances have done little to change our cooking habits. When it comes to preparing food—the most important aspect of our life from a physiological point of view—citizens in developed countries still cook almost the same way as their ancestors did centuries ago. Of course, some foods and products—notably potatoes, tomatoes and new spices—were introduced into European cuisines only after the discovery of the New World and with increasing trade with Africa and Asia, but the culinary processes themselves did not change. Kitchens are equipped with basically the same pans, whisks and sieves that cooks used in the seventeenth century. Similarly, culinary books from the fourteenth century to the twenty-first century all look the same, despite the introduction of new recipes; for example, the first emulsion described in a French culinary book appears in 1674 (LSR, 1674), and the ancestor of mayonnaise seems to be a *beurre de Provence* (Marin, 1742).

Indeed, cooking was the last of the 'chemical arts' to become the object of scientific scrutiny and it still relies on telltale and anecdotal knowledge rather than solid science. As recently as 2001, an inspector from the French Department of Public Education said, during a public lecture, that her mayonnaise failed when she was menstruating. Such old wives' tales were partly the reason behind the creation of molecular gastronomy: I first started experimental studies of cooking after encountering a recipe for cheese soufflé that advised adding egg yolks "two by two, never by fractions". Another reason was that the late Nicholas Kurti, professor of physics at Oxford University, UK, was upset by the poor and unscientific way that people cook (This, 1999). Initially, a handful of other people conducted separate studies of culinary processes, but in 1988, Kurti and I decided that we should create a new scientific discipline to investigate culinary transformations.

First, we had to find a name and a scientific programme to state the goals of this new discipline. Consequently, we organized the International Workshop on Molecular and Physical Gastronomy in 1992, held at the Ettore Majorana Centre for Scientific Culture in Erice, Italy, and invited chefs and scientists from all over the world. The success of this first meeting led us to repeat it every two years. In 1995, Jean-Marie Lehn, who won the 1987 Nobel Prize in Chemistry with Donald Cram and Charles Pedersen, invited me to create the first Group of Molecular Gastronomy in his laboratory at the Collège de France, and in 1996, I presented the first PhD in 'Molecular and Physical Gastronomy' at the University of Paris (This, 1996). When Kurti died in 1998, I shortened 'molecular and physical gastronomy' to 'molecular gastronomy'—as it should have been from the beginning—and added Kurti's name to the title of our international workshops.

Recipes, the most important written form of culinary knowledge, traditionally consist of two parts. The first is a 'definition': for example, a soufflé is a foamy product that swells during cooking, and crumples once someone pokes a knife or fork into it (otherwise it would be a cake); or a mayonnaise is an emulsion of oil in egg yolk, salt, pepper and vinegar. In general, these definitions are usually mixed with 'materials and methods' in the form of a cooking protocol: how many to use of each ingredient for a given number of guests and how to process, blend and cook these ingredients to turn them into the final product. In addition, a recipe might contain what I call 'culinary precisions', such as hints and advice, old wives' tales, tricks, adages and maxims.

Take, for example, an eighteenth century book that advises us to cover the pan when beef is cooked with water to produce stock (Albert, 1838). If this recommendation is correct, why? And if it is not, why did someone write this sentence more than 150 years ago? To answer this question, we can use tools from physics, chemistry and biology—for example, the microscope, the thermometer and the gas chromatograph—to investigate the processes that take place during cooking. If we can answer the question, we can correct a mistake, use this knowledge to improve the cooking process or even invent new dishes or ways to prepare food.

One example of how chemistry and physics can lead to new ways of cooking is provided by the egg. If we heat an egg, water evaporates, the proteins denature and polymerize to enclose water, and the end result is a cooked egg. Is there another way to do this? Yes, alcohol can do the same trick because it can denature proteins; thus we achieve the same result by adding liquor to a raw egg. Similarly, the scientifically proven way to obtain an airy soufflé is to heat it from below, so the evaporating water pushes the dough upwards. This is simple physics but it can help us to make better food.

Initially, as written in my PhD dissertation, molecular gastronomy had five aims: to collect and investigate old wives' tales about cooking; to model and scrutinize existing recipes; to introduce new tools, products and methods to cooking; to invent new dishes using knowledge from the previous three aims; and to use the appeal of food to promote science (This, 1995). Today, it is easy to see that this scientific programme was misleading and had shortcomings, and it is surprising that no member of the PhD panel—including two Nobel laureates—mentioned it. The first two aims are really scientific goals, the third and the fourth are only technological applications, and the fifth aim is an educational application of the first four.

> **Despite having a huge impact on other aspects of our lives, scientific advances have done little to change our cooking habits**

Nevertheless, the programme attracted a lot of media coverage, not least for the chefs who collaborated with us to develop molecular gastronomy. In France, the field advanced and spread through monthly seminars, national congresses, courses on molecular gastronomy and the creation of the Foundation 'Food Science & Culture' (This, 2006). Among the chefs who make use of molecular gastronomy, many are famous: for example Christian and Philippe Conticini, Bernard Leprince, Michel Roth and Pierre Hermé, all from Paris; Ferran Adria from Rosas; Michel Bras from Laguiole; Pierre Gagnaire, who has restaurants in Paris, London, Tokyo and Hong Kong; Heston Blumenthal in Bray; and Emile Jung in Strasbourg. Between 2002 and 2005, a European technology transfer programme—Inicon—promoted collaboration between European chefs, scientists, companies and culinary schools. One very important event was a 'science and cooking' menu served by Pierre Gagnaire at the Academy of Sciences, during a lecture on molecular gastronomy at the beginning of 2000. The creation of an online presence (www.pierre-gagnaire.com), which lists a new application of molecular gastronomy every month, has also contributed to the rapid spread of this discipline among scientists and chefs alike.

NEW DISHES NAMED AFTER FAMOUS CHEMISTS

Since 2005, new dishes, produced on the basis of the results of molecular gastronomy, have been named after famous chemists or scientists, so people are now eating 'chemistry'. This is one way to fight the public's fear of science and to promote the diffusion of knowledge.

Gibbs
When an egg white is whipped with oil, a white emulsion is obtained. If this emulsion is cooked in a microwave oven, water heats and expands. At that time, the temperature is about 100 °C, which is higher than the coagulation temperature of egg-white proteins. The emulsion is then trapped into a gel. Of course, oil does not necessarily taste good, but imagine infusing vanilla pods in egg white, dissolving sugar into the mixture and adding very good olive oil before microwave cooking. The product is called a Gibbs, after the famous physicist Josiah Willard Gibbs (1839–1903).

Vauquelin
When an egg white is whipped, a small quantity of foam is formed: about 300 ml for one egg white. Why not more? As whipped egg white consists primarily of water (around 90%), proteins and air, it is easy to discover that adding water will produce more foam. If the foam is cooked in a microwave oven, a chemically jellified foam is formed. To achieve a better-tasting product, use orange juice or cranberry juice instead of water, and add sugar to increase the viscosity and to stabilize the foam before cooking. This new dish is named after Nicolas Vauquelin (1763–1829), one of Lavoisier's teachers.

Baumé
Have you ever put a whole egg into alcohol? If you are patient enough, ethanol will permeate the shell and promote coagulation. After about one month, the result is a strange coagulated egg called a Baumé, after the French chemist Antoine Baumé (1728–1804).

Educational efforts are equally important. In 2001, the *Ateliers Expérimentaux du Goût* (experimental workshops on flavour) were created in French schools. Since then, Canada and France have introduced new curricula for culinary schools to include knowledge obtained from molecular gastronomy. In 2005, the Institute for Advanced Studies on Flavour, Gastronomy and the Culinary Arts was created in Reims, France, to promote gastronomy knowledge, including molecular gastronomy. Universities in various countries, such as the Netherlands, Denmark and Argentina have set up professorships in this discipline.

Despite this spread of knowledge and interest, mistakes are still made. In 2002, for example, the media described some chefs as 'molecular gastronomists', which is obviously wrong because chefs create food, not knowledge. This confusion was caused in part by our scientific programme, which was not purely scientific but included technological applications and education. From the beginning, Kurti and I agreed that molecular gastronomy was science and not technology, so we excluded the technological and educational elements.

Accordingly, our scientific programme became clearer when we reduced it to two aims: to model definitions, and to collect and scrutinize culinary precisions. However, we rapidly found this new programme insufficient as well, because the main aim in cooking is to produce good food, which is art and not technique. Furthermore, a dish can be cooked perfectly, but if it is not presented in an appealing way, all the art and science will mean little to the customer or guest; we therefore decided that we must include the 'love' component of culinary practice. Of course, science will probably never be able to fully explain art or love, but it can help; for example, evolutionary biology can contribute to the exploration of human behaviours, and, accordingly, culinary practice. Consequently, molecular gastronomy not only uses science to explore the technical aspect of cooking but also the 'art' and 'love' components, both of which are important for the main aim of cooking: to delight guests.

Let me try to explain the art component of cooking scientifically. In 2002, I introduced a formalism to describe, in a non-periodical manner, the organization of food space or different foodstuffs. All foods are complex disperse systems, also called 'soft matter'. The simplest of these systems—formerly called colloidal—are well known: emulsions, foams, gels and so forth. However, when food involves more than two phases, this classical description is no longer sufficient to describe something as simple as custard—which is probably why physicists eventually gave up trying to find a global description of complex systems and instead focused on interfaces between different phases (Israelachvili, 1992). But food needs more than interfaces to describe it; even a simple sauce such as a *béarnaise* consists of three phases: solid matter (microscopic egg-yolk aggregate) and a hydrophobic liquid (oil droplets) dispersed in a hydrophilic liquid (water). In order to describe the microscopic structure of such a system, we proposed the 'complex disperse systems' (CDS) formalism in 2002 at the European Colloid and Interface Society Meeting (This, 2003).

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So what is the scientific usefulness of this formalism? I applied it to all classical sauces in French culinary history, from *sauce africaine* to *sauce zingara*, and showed that their number has increased regularly since the fourteenth century; in 2005, French cuisine had developed 23 different systems (This, 2004): solutions, oil-in-water emulsions, foamed emulsions, and so forth. Now, using the CDS formalism, the number of different sauces is potentially infinite, because new formulas can lead to new sauces and, more generally, to new dishes.

Similar to the study of how sauces have evolved over time, we can also study how these sauces evolved aesthetically—indeed, in 2004, it became obvious that if we want to study the art component of culinary practice, we have to analyse the aesthetics of food. The great German writer and philosopher Johann Wolfgang von Goethe wrote to the German writer Friedrich Schiller: "One essential characteristic of epic poetry is that it goes forth and back constantly, hence the epic character of all delaying motives" (Goethe, 1797). Similarly, food can be explained as a story, with a beginning—the ingredients are organized into a dish—and an end: when the plates are empty and the guests satisfied. But the story would be a short and boring one if food were just a liquid, because our brains are built to detect contrasts and draw pleasure from them. Of course, food is mostly water, but this water is organized—for example, in the cells of plant and animal tissues—and proper preparation brings about the contrasts and the consistency of different foodstuffs: tender meat, firm mayonnaise, crunchy crackers. This is why consistency is an important factor of all food, and why cooks care so much about it.

I therefore proposed an additional formalism, which I first introduced in 2004 to describe the organization of foodstuffs (This, 2005). It includes the 'consistency' of food by describing its firmness: gas is attributed a firmness level of zero; a liquid, one; an emulsion, two; a jellified emulsion, three; and so forth up to infinity, for example to describe chewing gum. Using this scale, what food has level four or five, for example? This is why understanding food needed some formalism to describe food preparations in terms of consistency. On the basis of this formalism, we can perform the same research as for sauces using the CDS formalism and, in this way, study the art component of food. This is interesting not only from a purely scientific point of view: if we are able to understand why a certain food is tasty and pleasurable, we can describe its preparation scientifically so even inexperienced cooks are able to make a good dinner without having to rely on years of experience or old wives' tales.

So what is the future of food once we start to explore it scientifically? The difficult thing about the future is that it is hard to predict. We should avoid making the same mistakes that French chemist Marcellin Berthelot made about a century ago: he predicted that the success of organic chemistry would allow us to abandon traditional food and, by the year 2000, eat nutritive tablets instead (Berthelot, 1894). He was obviously wrong—humans are living organisms, with an extremely sophisticated sensory apparatus that has evolved over millions of years to detect odour, taste, consistency, temperature and more. The pleasure of eating involves all our senses and it is obviously important for our wellbeing—why else did our ancestors start to cook their meat and vegetables even before they invented civilization?

One of the most important and worrying trends is the current pandemic of obesity. Even in Crete, where the so-called 'Cretan diet' originated, up to one-third of 12-year-old children are now overweight or obese (IOTF, 2003). Another clear trend is the increasing concern for our environment and healthy food, and the increasing proportion of humans who live in cities. Finally, there is a growing divide between scientists and laypeople, and an increasing disaffection in society for science and research. All these developments will inevitably have an important impact on what and how we eat and, accordingly, on how we prepare our food.

Cooking has to be explored scientifically if we want to improve educational health programmes

Together, these developments further strengthen the idea that children must get more information about food and food preparation. Decades of research on nutrition now provide us with a large amount of data on what and how much our bodies need to stay healthy, but the current trend towards obesity is in good part caused by a fatal attraction to junk food, soft drinks and sweets. Consequently, health programmes that promote a balanced diet cannot succeed if people are unable to make intelligent choices about food. However, traditional cooking is not a guarantee either for healthy food or for a rational preparation of food.

This is where the scientific programme of molecular gastronomy can be useful. If we are able to use the knowledge gained on food preparation, we might find new ways to make healthy food more attractive, we might persuade more people to cook better food and, last but not least, we might convince society to regard eating as a pleasure rather than a necessity. I have now collected more than 25,000 culinary precisions, but they still need to be scrutinized; without more knowledge, culinary books cannot be regarded as reliable. Moreover, educational programmes cannot rely only on traditional recipes, because products, methods and ingredients have changed over time. Cooking has to be explored scientifically if we want to improve educational health programmes.

And what does molecular gastronomy hold for chefs? For them, the scientific exploration of cooking is even more important. Science is the basis for technology and new innovations, so this field will help them to create exciting new dishes and inventions. All sciences are useful for this enterprise, not only chemistry and physics, but also biology, as well as history and sociology. However, for chefs, and hopefully for non-chefs as well, the main aim is to surprise and delight their guests or their family with exciting, tasty and healthy food.

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