

OPINION

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# Physics in the kitchen

Peter Barham

## Abstract

The kitchen is a laboratory and cooking is an experimental science. When we cook we generally follow a recipe (either written or from memory); we select, quantify and process the ingredients and then serve the food to our friends, family or guests. A good cook (or scientist) will keep records in a notebook of exactly what they do so that they can repeat the experiment (recipe) as required.

During the meal, as we eat we note how good the food is, where there is room for improvement and what is particularly liked. In effect we analyse the results of the experiment – the good scientific cook will keep notes of these discussions and use them to draw preliminary conclusions about how to improve the recipe. After several more tests of the recipe, we may then begin to derive a model to explain our results and to understand how and why making small changes to the recipe produces different qualities in the final dish – we can then use that understanding and apply it to other recipes, so continually improving our cooking skills.

This is nothing more than the application of the scientific method to cookery – simple but highly effective. If taken seriously and applied properly there is no excuse for any scientifically trained person not to become a superb cook.

But is there more to physics in the kitchen than ensuring physicists are good cooks? Can physics help chefs with no scientific background improve their own cooking? Is this really an area that is worth the attention of serious physicists? Is there new physics to be learned from the study of gastronomy? My unsurprising opinion is that there is good physics to be learned in the kitchen and that investigating the science of cooking is a worthwhile academic pursuit – but of course I would believe that as I have been doing it for more than 25 years now. So perhaps it is time to examine more critically whether it is indeed a worthwhile occupation.

## Heat and thermodynamics

One of the most basic kitchen operations is to heat food to change its texture or chemical make-up (or both). To

ensure some degree of consistency between cooks there is a need to have some assurance that the temperatures used in different kitchens are closely similar (if not the same). Without the use of expensive scientific equipment the only easy way is to use a phase transition that occurs at a fixed temperature – and the simplest and most accessible of these is to use boiling water. Common practice when cooking vegetables, for example, is therefore simply to put them in boiling water for a fixed time. This can provide a system which is sufficiently reproducible that the same recipes can be used by cooks around the world and ensure they get similar results. But is it? We teach our children that water boils at 100°C, but it is only much later when those who progress on to higher levels of education begin to learn that the boiling point of water is not fixed, but actually quite variable – for example, in Denver, Colorado, which is about 1.6 km above sea level and where the atmospheric pressure is around 85 kPa, water boils at around 94°C.

But there is a further problem – water is not itself consistent from place to place. We do not cook with pure distilled water, but rather with the local tap or spring water; the concentration and types of salts present in the water also affect the boiling point. Although the increase in boiling point due to adding even quite large amounts of salts is much smaller than the effect of altitude, salts can have quite different effects on the food that is being cooked – for example, if divalent salts (such as magnesium or calcium) are present they can affect the colour of green vegetables – making them appear a brighter green after cooking [1] – as they interact with chlorophyll molecules to change their shape and hence their vibrational spectra.

A trained scientist will readily understand these issues and be able to adapt their cooking to accommodate the

Correspondence: Peter.Barham@bristol.ac.uk  
H H Wills Physics Laboratory, University of Bristol, Tyndall Avenue, Bristol BS8 1TL, UK

water quality and the altitude. A cook may be baffled that it takes longer to boil an egg in Johannesburg than in Cape Town without hearing the simple explanation – indeed, I have even heard it said that the eggs are different in these two cities (which of course may be true as the hens are kept at quite different altitudes – but that should be the subject of a quite separate investigation).

### Potatoes

Once we can establish a precise control over the water quality and the pressure we can begin to investigate how food immersed in hot water cooks. Perhaps the best example is potatoes. I could write an entire thesis on the structure and cooking of potatoes, but to keep it short and simple here all you need to know is that the starch granules in the potatoes ‘melt’ or ‘gelatinise’ at a reasonably well-defined temperature of approximately 60°C – this change is clearly visible as the texture changes from a wet milky creamy colour to a translucent gel-like sticky texture (this is also an indication that the potato is now edible).

We can use this gel transition to investigate heat transfer through a cooking potato [2]; this approach makes an excellent demonstration experiment for teaching the physics of heat transfer. Basically all that is needed is to place a potato in a temperature-controlled bath for a fixed time and then cut it open and measure the width of the cooked region. The experimental design is challenging; for example, a sufficiently large heat bath is necessary so that the temperature is not significantly reduced by the addition of the potatoes; and the measurement of the width of the cooked region poses some problems as the interface is not necessarily sharp and the cutting may not be exactly perpendicular to the surface; and so forth. However, these difficulties can be overcome (indeed, it is a good test of an experimental physics student to see whether they can meet them).

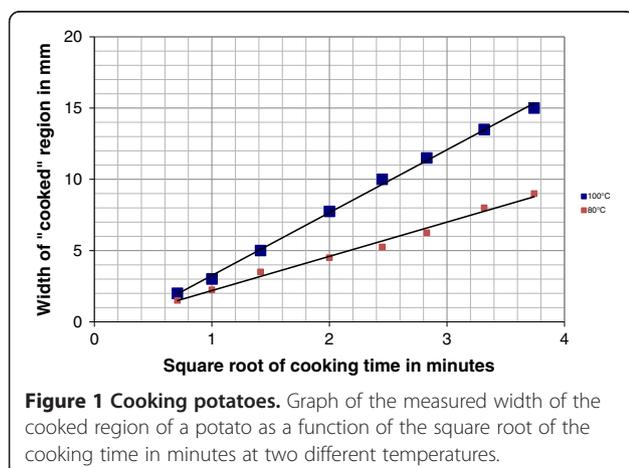


Figure 1 shows the results of one such carefully controlled set of experiments. The data in the figure illustrate that the heat flowing into a potato in a constant temperature bath does indeed follow the expectations of thermal diffusion – the width of the cooked region increases as the square root of the cooking time; and the rate at which this width increases depends on the temperature difference between the potato before immersion and the temperature of the heat bath.

### Meat cookery

Potatoes are roughly spherical and have thermal properties that are more or less constant over the temperature range of interest, and the heat of the gel transition is small enough to be ignored so that these properties can be readily modelled using straightforward thermal diffusivity. Other foods are not so simple. Consider a piece of meat; a steak, for example. The structure of meat is complex; therefore, as well as diffusion of heat, there is mass transport within the meat as it is cooked (we can see and hear water being expelled from the meat as it is being cooked). As the muscle proteins are denatured by the heat and shrink, so the composition of the meat and its thermal properties change; chemical reactions at the surface also affect the permeability of the meat and affect its thermal contact with the pan in which it is being cooked and to make matters more complex all these changes depend on both time and temperature – in short, we are not in a position as yet to be able to model sensibly the heat transfer processes in the cooking of a steak. This is an area where finite element modelling combining heat flow, chemical changes and mass transport might in the future be able to provide new insights – it is, in short, an area ripe for curiosity-driven research that could lead to new developments in modelling complex systems in general.

### Ice cream

Everyone loves ice cream (well almost everyone). But what makes good ice cream? For most people the answer seems to be how smooth and creamy it is. The perceived smoothness seems to increase as the size of any solid particles in the ice cream decreases; this is especially true of the ice crystals. So a good ice cream has the smallest possible ice crystals.

This leads to many questions; for example, how can we avoid ice crystals growing larger during storage and transport in commercial ices? Simple thermodynamics tells us that smaller crystals are less stable and will slowly disappear as larger crystals grow steadily larger – this process (known as Ostwald ripening) is well documented and understood in model systems, but as yet little work has been done on actual ice cream. Commercial ice cream manufacturers have to find ways to slow down the ripening process [3-5] – some of the best solutions

come from the use of additives that coat the surfaces of ice crystals and act to reduce the growth rates as they effectively reduce the liquid solid surface energy stabilising small crystals with a high surface-to-volume ratio [6,7]. Such anti-freeze proteins are found in fish that live in the cold polar waters – so the understanding of how fish evolved and survive in such cold water where they risk death from the formation of ice crystals in their bodies has a direct link to the production of ice cream.

In a restaurant or domestic environment, the storage of ice cream is not a major issue – it gets eaten as soon as it is ready! So all that is required (apart from the flavour and so forth) is to ensure the ice crystals are as small as possible. But how to do that? Traditional machines simply scrape growing crystals from the cold outer surface to stop them growing – the crystal size then depends on how well the scraper fits the surface, how stiff and sharp it is, how fast it rotates, how quickly the mixture is freezing and how long it is held before serving. A newer type of machine, the Pacojet, drives a rapidly rotating scraping blade into a solid block of ice cream mixture at a low temperature (approximately  $-20^{\circ}\text{C}$ ) to so that it advances around 0.001 mm per revolution – this shaves crystal fragments that have a size typically around 0.005 mm. Even smoother ice cream can be made by freezing at very low temperatures using liquid nitrogen as the coolant – by nucleating crystals at very low temperatures, very small crystals can be stable so it is possible to have an ice cream with ice crystals that are smaller than 0.001 mm, although it is very difficult to find experimental methods to measure the sizes of such ice crystals. In fact, the attempt to measure the sizes of such crystals has the potential to develop new methods of investigating the physics of phase transitions in confined spaces.

### **Gastrophysics: what is it and do we need it?**

If the science of the kitchen is worthy of study, it is worthy of a name as well. Many have been suggested: culinary science, molecular gastronomy, kitchen science and now gastrophysics. These names each have connotations that may or may not be helpful and it is not my place to promote any of them – in fact I dislike them all for different reasons, but I shall not elaborate here on any except gastrophysics as that was the topic of the meeting that led to this article.

I first came across the name gastrophysics in the 1980s when it was noted by Nicolas Kurti as one of the possible, but discarded, names for the International Workshop on Physical and Molecular Gastronomy that he and Elizabeth Thomas organised in Erice (these eventually gave rise to the term molecular gastronomy). Later, gastrophysics was rejected as the title of a series of public lectures I gave in Bristol on the science of food and cooking and then was also rejected as the title of my book *The Science of Cooking*

[2], and even as the title of one of the chapters of that book – eventually entitled ‘Heating and Eating – Physical Gastronomy’. In all these cases the reason for rejecting gastrophysics as a name was that it would make people think of gastric problems – the echo of gastroenteritis is unlikely to persuade people to buy a book or attend a lecture!

My own arguments in favour of gastrophysics came from an analogy: gastrophysics should be to gastronomy as astrophysics is to astronomy. Astronomers observe the planets and stars, they note how they move and even predict future movements; but astrophysicists explain why the stars are where they are and how they got there, and they also supply the sound scientific basis for the whole subject.

### **The future**

At the start of this article I asked whether there can be more to physics in the kitchen than ensuring physicists are good cooks? Or whether physics can help chefs with no scientific background improve their own cooking? And if this really is an area that is worth the attention of serious physicists, whether there is new physics to be learned from the study of gastronomy?

I contend that the answer to all these questions is yes. The almost trivial examples I have given above should serve to illustrate that even a rudimentary knowledge of physics can assist the cook in the kitchen. There are numerous areas where researching the physics in the kitchen can lead to new techniques that can be applied to more conventional branches of physics – indeed, I believe we can look forward to seeing this happen in the near future.

To me, however, by far the most important aspect of using the kitchen as an experimental laboratory is that it provides a route to encourage people of all ages to engage with science in a way that is not otherwise possible. We can use examples of what happens when we cook to teach science at all levels. In an ideal world, school students would have at least some of their science lessons in the school kitchens and would learn both basic cooking skills and basic science at the same time. If they can take their experiments home and talk about them while eating them over a family dinner, then the potential benefits to society are incalculable – improving diet to reduce obesity and improve health, bettering social cohesion through combined family activities, and creating a more scientific-literate society are all within the bounds of possibility.

Whatever we call the field, this is something we should strive towards.

### **Competing interests**

The author declares that he has no competing interests.

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