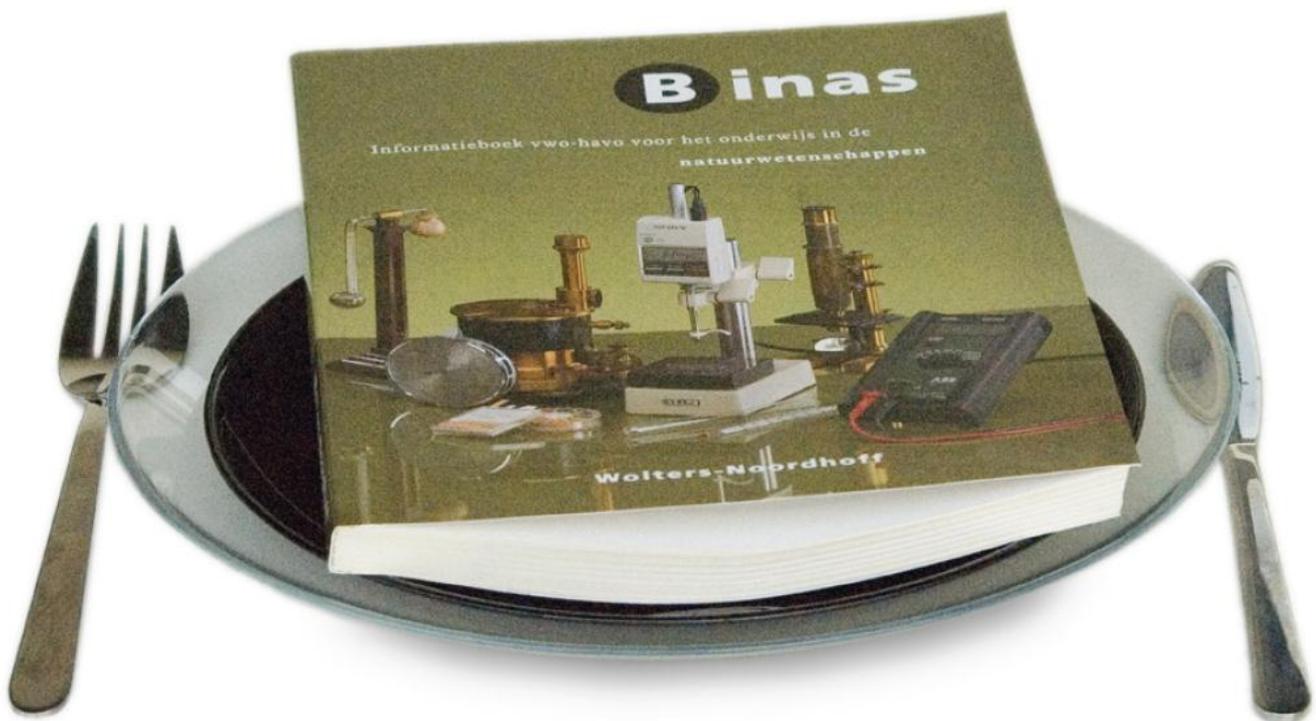


# MOLECULAR GASTRONOMY



Science in the Kitchen



WAGENINGEN UNIVERSITY  
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The 'Molecular Gastronomy – Science in the Kitchen' module is intended for the Nature, Life and Technology (NLT) lessons. The module was certified on 17 June 2010 by the NLT Steering Committee for use on the VWO in domain H (Materials, Process and Production Technology). The certification number of the module is X218-059-VH.

The original certified module is available as a pdf download from <http://www.betavak-nlt.nl>. There is an explanation on this website about the amendments that lecturers are permitted to make to the module, for use in the lesson, without breaching the certification.

This module was developed by

#### Authors

Elma Schenkelaars – lecturer in Chemistry/NLT  
Ids Klompmaker- Wageningen University  
Ties van de Laar- Wageningen University

#### Scientific expert

Erik van der Linden – Wageningen University

#### In collaboration with

Jeroen Sijbers – NLT support team  
Eral Osmanoglou- Wageningen University  
Inge van den Heijkant- Wageningen University  
Brenda Terpstra- lecturer in Chemistry/NLT  
Maarten van Dongen- lecturer in Chemistry/NLT  
Cazimir ten Brink - Wageningen University

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# 1 Introduction

## 1.1 The cook and the scientist

A cook and a scientist sit down for a chat about food. It soon transpires that they are both talking a completely different language. The words *dishes*, *food*, *measuring equipment*, *structures*, *recipes*, *taste*, *cooking*, *molecules* and *ingredients* are thrown about. They are both passionate about their trade, but if they can't understand each other, they will never be able to work together. How can they interconnect this muddle of words so that they can understand each other? The following diagram may help.

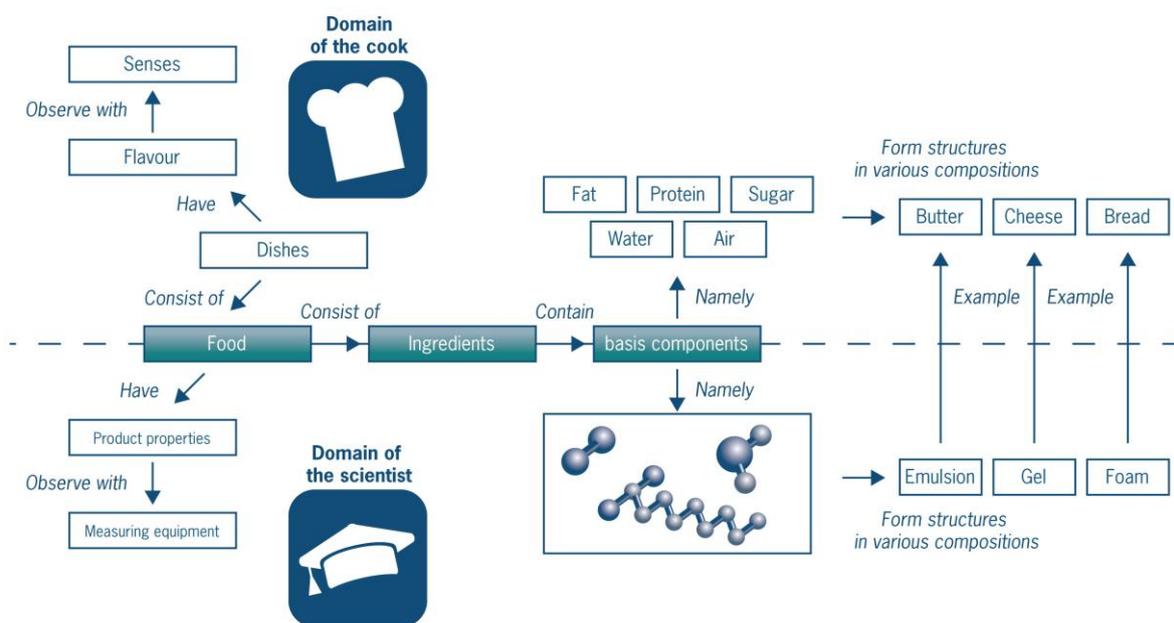


Figure 1 How the cook and the scientist look at food.

Figure 1 is the 'framework' for this module. It shows that the food scientist and the cook take a different view on the same food. This diagram will be deconstructed during the module.

Ask an Italian to name a recipe and he will probably say pasta. For example, pasta with sun-dried tomato and a pesto and crème fraiche sauce. This dish contains pasta, pesto, crème fraiche, sun-dried tomatoes, leeks, mushrooms and onion. A cheese sandwich is also a dish. It consists of bread spread with butter and filled with cheese. Butter, bread and cheese are called foods. The ingredients of a dish are foods. Foods are in turn made up of ingredients.

### Assignment 1

1. Think of your favourite dish, or a dish that you have recently eaten and liked.
2. Try and describe the taste of this dish.
3. Now try and describe *why* you like it.

You have probably already noticed from Assignment 1 that it is not easy to describe the taste of a dish. On the one hand, the term '**taste**' refers to the five basic tastes of sweet, sour, salty, bitter and umami (we will come back to the meaning of umami later). This definition of 'taste' is directly related to *one* sense: that of taste.

However, the word 'taste' is also used more broadly, as in the sentence: 'That is a tasty snack'. Here the word '**flavour**' is more applicable because it infers both taste and the smell and texture of a dish. The appearance of the dish is also important. This module deals with 'taste' as defined in the second, broader meaning.

### Assignment 2

Which senses can you use to determine the *flavour* of a dish?  
Give an example for each sense.

What is the secret of a good cook? The cook makes a dish using food, the ingredients. For this purpose he performs the following **basic actions**:

- **Cutting**
- **Mixing**
- **Heating (or cooling)**
- **Separating**
- **Concentrating**

A good cook knows precisely how much of each ingredient and each action to use. Too much salt will spoil the taste of potatoes. When you puree green paprika, the result is a greyish mush with the taste of paprika: the '*taste*' may be the same, but the '*flavour*' certainly isn't.

### Ingredients

The ingredients for a cheese sandwich are bread, butter and cheese. Bread itself is composed of five ingredients: flour, water, butter, salt and air. The baker knows how much of each ingredient and action is required.

And what about the butter? Does this contain yet more ingredients? Yes it does. Butter is made by "churning" (milk) fat, water, air and salt together.

If you go right down to the molecular level, you arrive at the **five basic components of all foods**:

- **Fats**
- **Proteins**
- **Carbohydrates**
- **Water**
- **Air**

Added to this there are various **flavourings**: substances that play a major role in small quantities: salts, acids, alcohol, etc.

Like the cook, the scientist thinks about which combinations of which ingredients under which actions lead to a certain result: the product. Both cook and scientist are puzzle solvers. They just use a different vocabulary.

The scientist calls bread a foam, butter an emulsion and cheese a gel: see figure 1.

In this module you will become familiar with the terms used by the scientist. You will discover that butter, cheese and bread are molecular puzzles that have things in common.

Studying this module won't instantly turn you into a good cook. But it will teach you why knowledge about the ingredients and the processing of food can help someone become a good cook.

Good luck with the puzzle.

## 1.2 Molecular gastronomy

*“Molecular gastronomy is a branch of science concerned with the study of physical and chemical transformations of edible materials during cooking, and the sensory phenomena associated with their consumption”.*

The kitchen and science are thus united in molecular gastronomy. This module will deal not with the biological function of food, but the background to the production of a dish or food. This will involve taking a look at chemistry and physics.

Hervé This (see box below) further refined the definition of molecular gastronomy. In his definition he distinguishes between *molecular gastronomy*, the study of the processes during cooking, and *molecular cuisine*, the application of this in recipes and food preparation. The first is science, the second technology. Molecular gastronomy is therefore situated on the interface between science and application.

The **scientific aim** is:

- to study recipes, cooking habits and cooking wisdom;
- to explain the chemical and physical processes that take place during cooking.

The **application-oriented aim** is:

- to use the knowledge about the physical and chemical processes of cooking in order to develop new cooking instruments and ingredients,
- to design and invent new dishes with the help of the acquired knowledge about food and cooking processes. In this way, the cook no longer innovates by trial and error but on the basis of scientific knowledge.

The last point concerns **molecular gastronomical dishes**. These are dishes that are innovated by applying knowledge about molecular gastronomy, thus providing us with a fresh outlook on eating and gastronomy.

### ***The emergence of molecular gastronomy as a science***

*Brillat Savarin (1755-1826) was a French politician and judge. He became most famous as a philosopher and gastronome. A gastronome is a connoisseur, someone who has made a study of anything to do with food and culture. In 1825 Savarin wrote a book entitled “[La Physiologie du goût](#)” (the physiology of taste). This almost encyclopaedic work describes all manner of subjects related to food. For instance, he writes about the causes of obesity, the five senses, the history of food and how to make coffee. His book is full of adventures that he experienced during his countless journeys. The following quote from Savarin illustrates why he so enjoyed conducting gastronomical research:*

*“The discovery of a new dish does more for the happiness of mankind than the discovery of a new star.”*



*Figure 2 Brillat Savarin and the title page of his book “La Physiologie du goût”*

In 1984 Harold McGee wrote the seminal book 'On Food and Cooking'. You could say that McGee continued and updated the work of Savarin. His book provides a complete overview of hundreds of products and their physical, chemical and biological background. In 1969, Nicholas Kurti, a physicist from the University of Oxford and a passionate amateur cook, gave a presentation for the BBC entitled 'The Physicist in the Kitchen'. Here is a famous quote from this presentation:

"I think it is a sad reflection on our civilization that while we can and do measure the temperature in the atmosphere of Venus we do not know what goes on inside our soufflés"

Hervé This and Nicholas Kurti met each other at a congress. At that time Hervé This was writing his thesis "La gastronomie moléculaire et physique" (Physical and molecular gastronomy). They got talking and decided to team together to give workshops. In 1998 they jointly defined the term molecular gastronomy as "the chemistry and physics behind the preparation of every dish". And so Molecular Gastronomy was born. From 1992 This and Kurti gave presentations to chefs and scientists, so bringing these two professions together.

Hervé This has written a great many books, the most famous of which is "Molecular Gastronomy, exploring the science of flavour". In this book he investigates the truths and untruths in the culinary world. Did you know, for example, that you can make several cubic metres of foam with one egg? He also describes a method for making meat much more tender. In addition, there are several chapters on learning how to taste and the author gives a few suggestions for new equipment in the kitchen.



Figure 3 Hervé This

The following example is ideal for giving you an idea of the sort of things you can investigate. The English physicist Charles Williams attached such importance to a well-cooked soft-boiled egg that he decided to find out whether he could work out the perfect cooking time with a formula. The result of this research is the following formula.

$$t_{\text{cooked}} = \frac{M^{2/3} c \rho^{1/3}}{K \pi^2 (4\pi/3)^{2/3}} \log_e \left[ 0.76 \times \frac{(T_{\text{egg}} - T_{\text{water}})}{(T_{\text{yolk}} - T_{\text{water}})} \right]$$

where  $\rho$  is density,  $c$  the specific heat capacity, and  $K$  thermal conductivity of 'egg'. According to this formula, a medium egg ( $M=57$  g) straight from the fridge ( $T_{\text{egg}}=4^\circ\text{C}$ ) takes four and a half minutes to cook, but the same egg would take three and a half minutes if it had been stored at room temperature ( $T_{\text{egg}}=21^\circ\text{C}$ ). If all the eggs are stored in the fridge, then a small (size 6, 47 g) egg will require four minutes to cook, and a large egg (size 2, 67 g) will take five minutes

As you can see, science can surface in the most unexpected places in the kitchen.

Finally, another quote which represents the essence of molecular gastronomy:

**"Molecular gastronomy is the science of deliciousness"**

### 1.3 Structure of the module

In this module it's your turn to be the molecular gastronomist! You will work on the two main aims of molecular gastronomy: the study of the processes that take place during cooking and the application of these in recipes and food preparation.

When you have completed this module, you will be able to translate information from cookbooks into molecular interactions. You will be able to make a model of dishes and, using this knowledge, invent your own molecular gastronomical dishes!

During the theoretical part, you will be attempting to convert recipes from cookbooks into models. For this you will use the Figure 1: the basic components of water, fats, proteins, carbohydrates and air are the pieces of the puzzle that form the structures of emulsions and foams. Gels are also mentioned in Figure 1, but will not be discussed again in the module.

Using these puzzle pieces you will build a model of these structures. When you understand this model, you will be able to apply it to an existing example of foams or emulsions, and ultimately you will also be able to use it to design new dishes and recipes.

The module consists of three chapters and a practical course. In the practical course you will use the knowledge from the chapters on emulsions and foams and even make molecular gastronomical dishes yourself. The chapters contain assignments and tasks; assignments are theoretical and tasks are practical in nature. Each chapter will contain a number of different learning goals. The boxed and italic texts are optional reading and offer more in-depth or comprehensive information. You will also come across a number of profession boxes in this module. These blocks are designed to give you an idea of the various people that are involved on a daily basis with food and technology. The first block is situated below.

#### Profession box 1

Hi everyone,

My name is Ties and I am a 3<sup>rd</sup> year student of food technology at Wageningen University. Molecular gastronomy is one of the modules within this degree course. At this point in my studies I would really like to know what I am going to do after I graduate. One of the nice things about the food technology course is the freedom of choice. The course begins in a very broad way and only specialises later. I've been told that I could get a job in any number of places with my degree. But where? In order to find out, I went looking for various people who work with food on a daily basis. I interviewed these people. You will find my interviews throughout this module. Hopefully, they will give you, as they did me, an idea of what life could be like after graduation.

Best wishes,

The content of the chapters is summarised below:

### **Chapter 2**

This chapter forms the basis of the module. It will teach you to look at food from a scientific perspective. You will learn how the gastronomical value of a dish can be translated into interactions that occur on a molecular level. In this chapter you will go step by step through the diagram in figure 1.

### **Chapter 3**

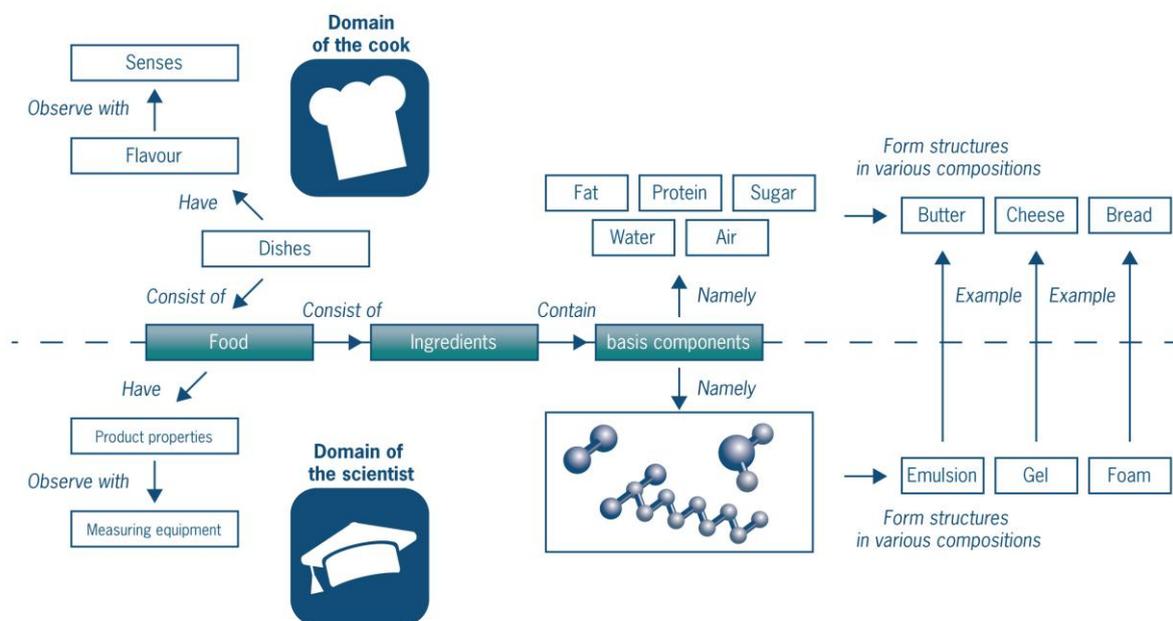
This chapter is about emulsions. What are emulsions? What is the role of the basic components in an emulsion? In addition, you will discover and understand some new emulsions developed on the basis of molecular gastronomy.

### **Chapter 4**

This chapter is about foams. In this chapter you will learn what a foam is, and what role the molecular interactions of proteins and carbohydrates play in the formation of a foam. You will also become acquainted with molecular gastronomical foams.

## 2 The basis

In Chapter 1 you discovered what a molecular gastronomist does. This chapter forms the basis of this module. You will work through the following diagram – identical to figure 1 – so as to become familiar with the terminology used by a molecular gastronomist.



We will begin this chapter with the concept of **flavour**. The various components that go to make up flavour are explained, and a few of the important concepts of flavour are described.

The aspects of flavour are ‘translated’ into **product characteristics**, which in contrast to flavour can be measured objectively. You are going to look at various methods for measuring product characteristics. In addition, you will take a look at **sensory tests**. Both sets of data can be used to improve the flavour of dishes.

Once you have translated the aspects of flavour into objective characteristics, you will look at various dishes and/or foods and see how these can be categorised. This will provide you with a better understanding of dishes. This classification takes place on the basis of **structure**. Structures, which are often visible to the naked eye, are in turn built up of molecules. The five basic components are water, carbohydrates, proteins, air and fats. Four of these will be dealt with in detail. Air also plays a key role in structures, but will not be expanded upon in this chapter because it has very little interaction with the other basic components. In the later chapters, there will be a more in-depth explanation of two of these structures, namely emulsions and foams. In these latter two chapters the knowledge acquired in this chapter will be applied in practice.

Here is an assignment to give you an idea of what a cook can do with molecular gastronomical knowledge.

### Assignment 1

Read Newspaper Article 1 "Dining with a short circuit". Watch the following film clip as well ([URL-1](#) (in the URL list at the end of this module)) to get a better understanding of what molecular gastronomy is about.

1. Name three molecular gastronomic dishes mentioned in this article. Explain why, in your opinion, they relate to molecular gastronomy.
2. Name two physical techniques that Moshik Roth uses in his kitchen, explain why it is a physical technique and name a product to go with every technique.
3. How are the foam biscuits with mustard made? Explain in particular what happens in the distillation stage. On the basis of which physical property are substances separated during distillation?

### Newspaper Article 1

**de Volkskrant**  
12 January 2008

# Dining with a short circuit

text by MAC VAN DINTHER

**In a corner of the kitchen at Brouwerskolkje restaurant there stands an appliance that looks as though it's straight out of a chemistry laboratory. On one side is a water basin in which a flask filled with brown liquid is revolving. The flask is attached at the top with a transparent tube. Under this tube is another flask. A colourless liquid is dripping into this flask. It is all attached to a motor block on which digital figures are flashing.**

That, says Moshik Roth, is a Rotaval, an appliance which can distil substances in a vacuum. The brown slurry that is revolving around inside is composed of soil, leaves and moss from the forest around his restaurant, mixed with a little water. He is distilling his country tea, which he serves with baked foie gras and which can only be described as having the taste of liquid forest earth. 'This is my land,' says Roth, triumphantly holding aloft the glass flask of clear liquid. Literally.

There are only four Rotavals in the world. Three of them are in Spain, the fourth here in the Overveen forest. It is just one of the hypermodern gadgets in the Brouwerskolkje kitchen, where nothing is what it seems. For instance, the large pan in which bacon appears to be cooking is in fact a Gastrovac, a kettle containing bacon in oil under very low pressure. "This helps draw out the flavours of the bacon and then I get delicious bacon oil." Roth uses the same process for his home-made truffle oil from fresh truffle.

In a reservoir there are pieces of fantastic Wagyu meat cooking at 45.6 degrees. Not a half degree higher, says Roth, who with his imposing figure (1 metre 94, 135 kg) is much too big for the small kitchen where five other cooks are standing working. "Above 46 degrees, the enzymes that break down proteins become active." That spoils the taste.

The ice-cream that goes into the egg cup is frozen omelette in powder form. And the yellow foam biscuits that are carefully placed by a cook in a sweet box are not petit fours but foam biscuits made of sauerkraut. Roth smiles and adjusts his horn spectacles. 'I make this by preparing a pan of sauerkraut according to the original Elzasser recipe. I then distil it in the Rotaval, and make the biscuits with the distillate.' The biscuits are spread with mustard cream. A more intense flavour than sauerkraut with mustard is hard to find.

So this is Moshik Roth, the most molecular chef in the Netherlands, our very own version of Heston Blumenthal, the British 3 Michelin star chef who is world renowned for his ham and eggs ice-cream and snail porridge. A chef who brings science into the kitchen with distillation equipment, hot water baths, thermomixers and liquid nitrogen at 196 degrees below zero. Roth is dismissive. "When people talk about molecular cuisine, they always emphasise the technology, but for me it's all about the flavour."

"I can affect flavour in two ways: with the product and with the cooking technique. I take the finest ingredients and try to get the best out of them. You can call it technical, but so is cooking fish. The term molecular cuisine is a load of nonsense, because everything is molecular." His words are all a little stilted, because his Dutch is not yet fluent.

Seven years ago Moshik Roth exploded into the world of Dutch gastronomy. He was born in Haifa, Israel, 35 years ago. His mother was Russian, his father, a professional soldier, had Dutch roots. He had a liberal Jewish upbringing. "I go to the synagogue on feast days, but I drive a car on Saturdays and I eat everything."

After high school Moshik, like every young Israeli, had to do national service. He was three years in the Lebanon, from 1989 to 1992. "During the First Gulf War." He doesn't want to talk about it. Suffice to say, he saw enough blood to put him off his dream career of being a neurosurgeon. Roth decided to become a chef and worked as a trainee in a hotel in Eilat, where he met Els from Bloemendaal. It was love at first sight. "She had to leave the next day, but I knew right away that she was the one." After a brief romance via letter and phone, he joined Els in the Netherlands in 1995.

Initially Roth earned his keep in Amsterdam's pizzerias. But one visit to Jonnie Boer's De Librije changed his life. "That's when I fell in love with haute cuisine. In a year and a half I had been round all the restaurants." He tried out what he saw at home. One day he took the plunge and invited Jonnie Boer to his house.

"I cooked seven courses: foie gras terrine, pigeon breast in cabbage leaves." Jonnie was impressed. "He said: Moshik, you should be a Michelin inspector or a chef." Boer helped him get an internship at a top restaurant in Schipluiden called De Zwetheul. "I worked every spare moment, without earning a cent." After that he cooked for a while in various Amsterdam hotels. In 2001 he arrived in the Brouwerskolkje kitchen, and a year later he and Els bought it.

It is a small white stone establishment set among the trees. Autumn rain splashes on the tar roof and the washed gravel tiled terrace. Inside there are eight tables on a wooden floor beneath a low wooden roof. Unadorned save for a few simple chandeliers, the luxury is to be found only on the plates.

Roth wanders to and fro like a big friendly giant in baggy trousers between the kitchen and the dining room, explaining to the guests what they are eating: a cornet of beetroot with horse radish ice-cream, Wagyu with seaweed, spaghetti of parmesan with bacon foam, 'abstract of the sea', never a dull moment in Brouwerskolkje.

Thanks to Roth the restaurant has undergone a transformation. Before he came along, Brouwerskolkje was an old-fashioned outfit, where hikers and cyclists popped in for coffee and apple pie. Roth immediately got busy with haute cuisine. "Foie gras, turbot. Almost all the regulars left. Only the connoisseurs stayed."

The experimental urge needed no encouragement. He was fascinated by the discoveries of the Spaniard Ferran Adrià and Heston Blumenthal, the pioneers in molecular cuisine and like Roth self-taught in the kitchen, not drilled and kneaded by the rules of classical cuisine.

Molecular cuisine has been called the new nouvelle cuisine, but has also met with resistance. 'Molecular' techniques such as cooking at (extremely) low temperatures, and gimmicks like foams and gels of liquids are used by almost all modern top chefs. But down to the last man, almost all chefs distance themselves from this 'technical' style of cooking.

They don't get it, says Roth fiercely. "My grandfather always said: if a child doesn't understand something, he asks. If a grown-up doesn't understand something, he criticises it. And, by the way, it's not even new: we've been eating ice-cream for hundreds of years and distillation is an age-old process." Yet he does have some sympathy for sceptics.

You might be a good old-fashioned chef with years of experience and suddenly along comes a rookie without a chef's diploma and tells you that you shouldn't let the meat get above 64 degrees because then the protein coagulates and the meat dries out.

"If you don't know why that happens, then you will avoid it. But innovation makes the world go round, modernisation is a form of intelligence. The problem is that it is not properly implemented by many chefs. They're the ones who give molecular cuisine a bad name."

But why in heaven's name would you put a boiled egg in liquid nitrogen to make ice-cream? Roth points to his head: "When you eat this egg, you get a signal at the front of your head to say that the taste is recognisable, but at the back of your head a light goes on indicating that the shape is all wrong. This short circuit creates a smile on your face. That's the surprise element."

The pitfall of innovation is using technology because the gadgets are so great. Roth has fallen into this trap too. "But I've grown up. Now I work with less emphasis on technology. I would no longer drag a good langoustine through the mincer and make a mousse from it." Roth wants to produce flavour. Take, for example, his extract of black rice. "I only want the taste of rice, not the filling. So I make an extract of the rice juice, which has a pure rice taste. I've created something new, but all you taste at the table is rice."

Brouwerskolkje is no different to the rest of molecular cuisine: one person will love it, another won't. Michelin gave Roth one star, Lekker didn't even give him a place in the top 100. Roth sighs: "Sometimes I don't think we speak the same language."

Those who do, however, are scientists at Wageningen. Roth received a 15,000 euro research grant from the Ministry of Agriculture. He will soon be getting a machine that freeze-dries under vacuum. Roth hurries to the kitchen and returns with a piece of chocolate full of air bubbles. Like an Aero, but better. "You can make something like this in a machine with foie gras or *Époisses* cheese. Just think: a cheese aerobar!"

## Learning goals

When you have completed this chapter, you will know/be able to:

1. Simplify a complex dish into the three basic structures and the five basic components using the diagram.
2. Name two examples of molecular gastronomical dishes.
3. The concept of flavour and its three components (taste, smell and texture).
4. Explain that a product characteristic is a characteristic of food that can be determined with a measuring device.
5. Some key physical and chemical properties of four basic components of food.

## Structure of this chapter

Sections:

### 2.1 *Can we do you a flavour?*

The different components of flavour are explained.

### 2.2 *Measuring flavour*

How can flavour be translated into product characteristics?

### 2.3 *From product characteristics to structures*

The three basic structures are named and their differences explained.

### 2.4 *From structures to molecules*

Four basic components (water, carbohydrates, proteins and fat) are explained in detail.

## 2.1 Can we do you a flavour?

When you eat a dish, you make all kinds of observations, using your five senses: smell, taste, touch, sight and hearing.

When you eat a dish with bacon and eggs, you can *see* the white and yellow of the eggs and some nice cooked bacon. You can *smell* the typical smell of bacon. When you take a bite you can *hear* the crunching noise as you chew the bacon. You *taste* the savoury flavour of the bacon and you can *feel* the difference between the crispy bacon and the much softer egg.

The **flavour** of a dish consists of the **taste**, the **smell** and the **texture**. These three components can be measured and described using methods from chemistry and physics.

In this section you will become acquainted with these three components of the flavour of a dish and with the molecular mechanism behind them.

At the end of this section, you will also study the appearance of a dish. This has no direct impact on the flavour, but is nevertheless an extremely important part of the eating experience.



Figure 4 The three components of flavour

### Assignment 2 Describe the flavour

Describe the characteristic flavour and appearance of 5 dishes. For example, in a 'broodje kroket' it is the colour contrast between the 'broodje' and the 'kroket' (white/brown) and the contrasting texture of the 'kroket' itself (crunchy on the outside, soft and greasy with pieces of meat on the inside).

### 2.1.1 Taste

**Taste** is the detection of non-volatile substances using the receptors of the tongue. The tongue is not, as was previously thought, a sort of map divided into different sections where you can exclusively taste a certain flavour. In fact you can detect all tastes anywhere on your tongue. Most people are familiar with four tastes, namely sweet, sour, salty and bitter. However, what many people do not know is that there is another fifth taste, namely umami (umami is Japanese for flavour). Umami is a sort of savoury taste and was first described in 1908, when it appeared that the substance glutamate provided a taste sensation that could not be described by sweet, sour, salty or bitter. Umami was not really accepted as the fifth flavour until Asian cuisine gained in popularity in the Western world (Asian cuisine uses a lot of monosodium glutamate, which also has the umami taste).

Table 1 The five tastes that can be detected with your tongue

Taste	Chemical components	Products in which they can be found
Sweet	Glucose, fructose, aspartame	Sugar, soft drinks, icing
Sour	Lactic acid, acetic acid, phosphoric acid	Lemon, yoghurt, sauerkraut
Salty	Sodium chloride (NaCl), ammonium chloride (NH <sub>4</sub> Cl)	Cooking salt, pickled meat, salty liquorice
Bitter	Quinine, caffeine and phenols	Coffee, wine, beer
Umami (Ve-tsin)	Monosodium glutamate, which is an amino acid (part of a protein)	Old cheese, Chinese food and snacks, e.g. crisps.

The tongue is covered in taste papillae. These are shown in magnified form in Figure 5.

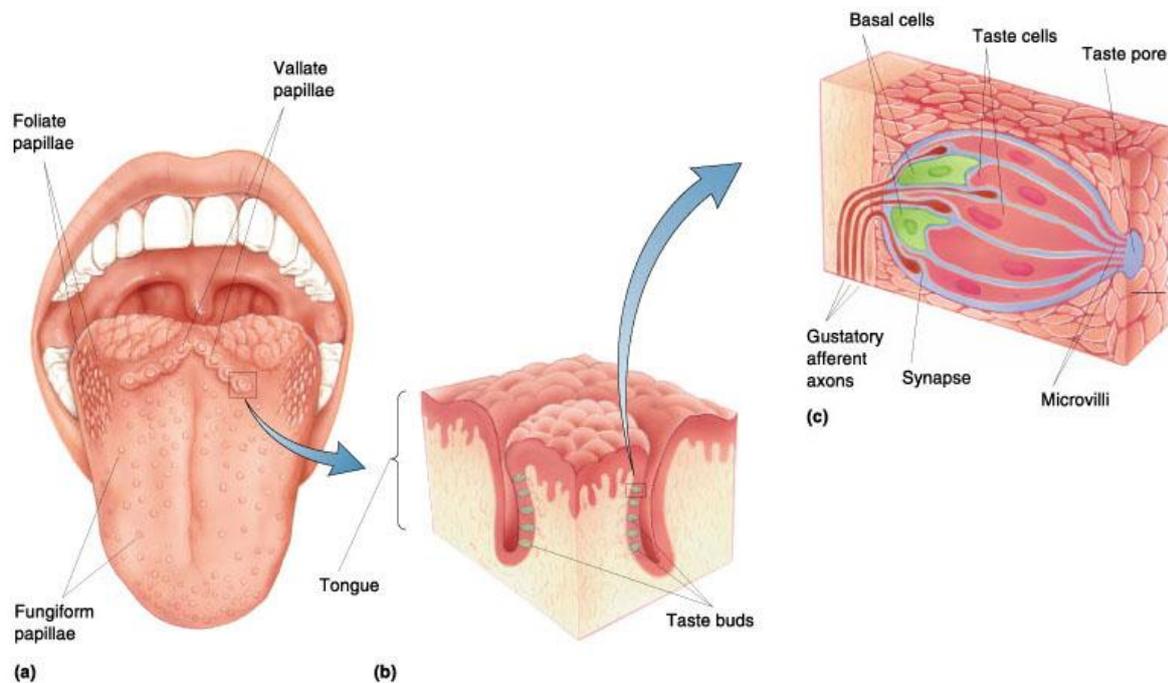


Figure 5 The tongue.

The taste papillae are folds on your tongue. They are necessary for increasing the surface area of your tongue. There are three types of taste papillae on your tongue:

1. Mushroom-shaped papillae (Fungiform papillae)  
These are located on the front two thirds of the tongue; they are embedded with an average of four taste buds.
2. Circumvallate papillae (Vallate papillae)  
These are large dome-shaped papillae which lie in a V-shape on the rear part of the tongue. They are embedded with an average of 250 taste buds.
3. Leaf-shaped papillae (Foliate papillae)  
These papillae lie along the length of the tongue and are embedded with about 1300 taste buds.

Taste buds are therefore found on the taste papillae. In Figure 5c you can see a microscopic image of a taste bud. Taste cells are located in the taste bud.

### ***The action of the taste cells (explanation in Figure 5c)***

*At one end of the taste cells are microvilli (small tentacles), which are in contact with the mouth cavity, and at the other end they are in contact with nerve cells via synapses. On the end of the microvilli there are receptor proteins. There are various types of receptor proteins for detecting sweet, sour, salty, bitter and umami. As a result of a series of chemical reactions arising from the binding of, for example, glucose to the receptor protein, the electrical potential of the taste cell changes. If this action potential is great enough, the cell is activated and information signals are sent to the brain. The minimal concentration of a substance that initiates this reaction is also called the flavour threshold value.*

When can you detect a flavouring? Every flavouring has a **threshold value**, which is the minimum concentration needed to detect the flavouring. In taste research, determining the threshold value of substances is important for various reasons. A number of artificial sweeteners, for example, have an unpleasant after-taste. If the producer can keep the concentration of these substances under the threshold value, the consumer will not taste them and he or she will still like the product. Substances can also migrate into food from food packaging and in excessive concentrations can result in taste anomalies. Obviously, the manufacturer aims to keep the concentration of these substances under the threshold value so that the consumer doesn't notice them.

Not everyone has the same threshold value for flavourings. It is often higher in the elderly than in young people. This is because (taste) cells break down. Most cells in the body can be reproduced, but taste cells fall into the category of those that cannot. As the number of taste cells diminishes, so does their effect. Another reason for deteriorating taste (higher threshold value) is smoking. It is also important how often someone comes into contact with certain flavourings. The more frequently a person experiences a flavouring, the higher that person's threshold value: this is called habituation. One example is spicy Chinese food. This is normal for the Chinese, but often too spicy for us. Because we are not used to eating spicy food, our threshold value for these spicy flavourings is lower.

In task 1 you will practise with these threshold values.

### ***Trouble tasting umami?***

*Perhaps you have difficulties imagining the taste of umami, and how it should taste. If you want to taste umami, simply try some soya sauce. It contains a great deal of monosodium glutamate and has the typical savoury taste of umami (in addition to a slightly salty taste). If you still have difficulty with the umami taste after trying soya sauce, don't worry! Research has shown that Asian people are a lot better than Westerners at tasting umami. The Chinese, for example, are good at distinguishing different types of soya sauce (an Asian sauce which contains a lot of monosodium glutamate) on the basis of the umami strength, while Westerners can only taste major differences in the levels of salt. This is probably because the umami taste has been used in Asia for centuries, while the flavouring is fairly new to the West. This is again due to the threshold value as determined by you in the previous task. Not all substances have the same threshold value. Of sour, sweet, bitter and salty, bitter has the lowest threshold value, followed by sour and salty. Sweet has the highest threshold value.*

### Task 1 The threshold value of quinine

In this task we are going to look at the threshold value of quinine (a bitter-tasting substance). Quinine is one of the substances that makes Tonic taste bitter.

You are going to determine the threshold value of quinine among your fellow students. The task will include some statistics which you don't need to learn, but it serves here to show that taste research is not just about tasting.

On the table before you are 10 plastic beakers numbered 1 to 10. The aim is to sample from each of the beakers in turn. You can sample several times. Answer the questions in the questionnaire.

*Important: Between sampling each pair of solutions, eat a cracker and rinse out your mouth with water to neutralise the taste.*

Take beakers 1 and 2 and try them one after the other.

Which beaker contains quinine?

1	2	both of them		neither of them
0	0	0	0	

Then do the same with beakers 3 and 4.

Which beaker contains quinine?

3	4	both of them		neither of them
0	0	0	0	

Then beakers 5 and 6:

Which beaker contains quinine?

5	6	both of them		neither of them
0	0	0	0	

Then beakers 7 and 8.

Which beaker contains quinine?

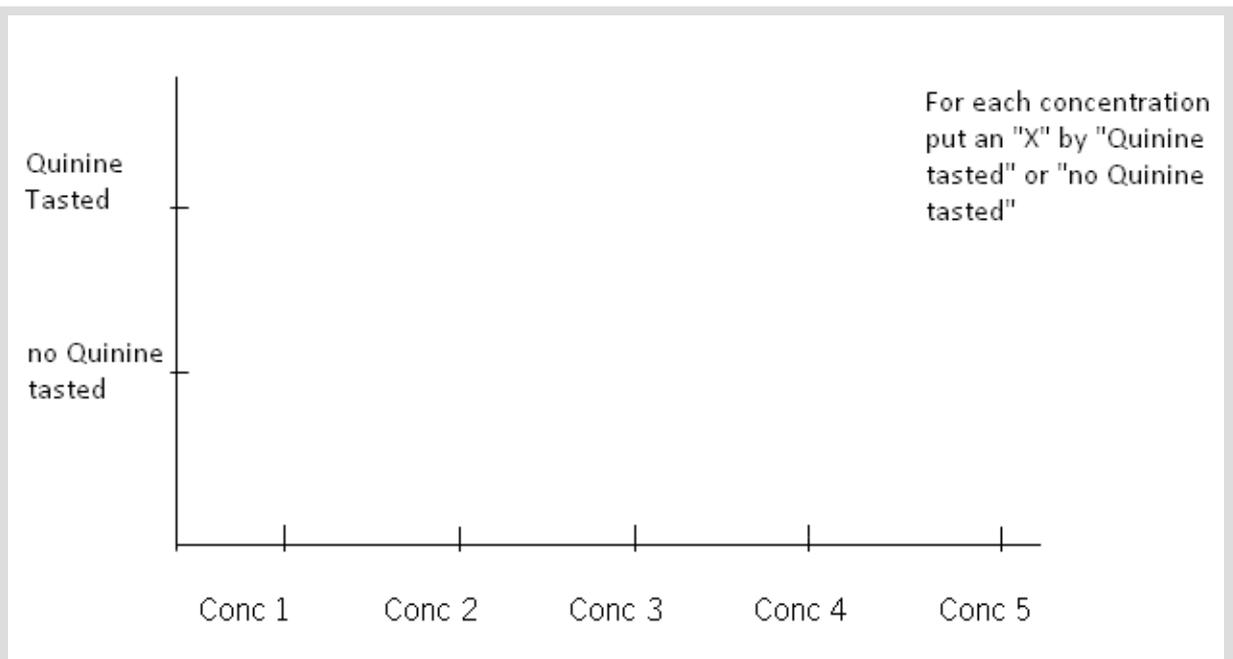
7	8	both of them		neither of them
0	0	0	0	

And finally, beakers 9 and 10.

Which beaker contains quinine?

9	10	both of them		neither of them
0	0	0	0	

Once you have finished sampling the solutions, the lecturer will put the correct answers on the board. Check which questions you got right. The lecturer will also write down the concentrations of quinine. Check which quinine concentration you gave the correct answer for. Enter your answers in the graph on the following page.



Once you have put the concentrations in the graph, you will see in which concentrations you tasted quinine and in which not. You probably gave the correct answer more often for the higher concentrations. All being well, the lecturer has drawn a table on the board. In this table, indicate for which concentrations you gave the correct answer.

Besides the actual tasting, statistics also plays a role in sensory tests. You will see this in the next assignment when you have to calculate the threshold value of the class using a statistical test. In addition, a certain (significant) number of people in the class will have to have tasted this concentration in order to be able to assume that this concentration has really been tasted and that it was not just a good guess.

The following example helps explain this test: *Imagine that you are a producer of a TV quiz show. You want to find questions that are not too easy, but also not too difficult. To this end, you invite 30 volunteers and ask them a number of multiple-choice questions, where they can choose from 'A' or 'B'. If the question is difficult, there are always some people who think they know the answer and a few who simply guess. If at least 20 of the 30 people answer the question correctly, you can say with 95% certainty that they have not just guessed, but that they knew the answer. This question is therefore not too difficult for the participants.*

The same goes for quinine. Sometimes you will have known which answer to choose. But you will also have had doubts about the correct answer on occasion. That's when you ended up guessing. For the concentration that 20 out of the 30 people in your class tasted, you can assume with 95% certainty that the substance really was tasted and not just guessed. This concentration is called the threshold value for your class. 95% is a limit agreed upon by statisticians when something may be assumed.

In the table below you can see the critical value for the number of people in your class (This is therefore the number that can taste the quinine, whereby you can assume that they did not guess; N represents the total number of students in the class).

Number of students in class		Critical value (at 95% certainty)
N	10	9
	11	9
	12	10
	13	10
	14	11
	15	12
	16	12
	17	13
	18	13
	19	14
	20	15
	21	15
	22	16
	23	16
	24	17
	25	18
	26	18
	27	19
	28	19
	29	20
	30	20
	31	21
	32	22
	33	22
	34	23
	35	23
	36	24
	37	24

Questions:

1. a) What is the threshold value of quinine for your class? Does your own threshold value (which can be roughly seen in the graph you drew) deviate much from this? Can you think of an explanation for this?
 

b) The threshold value of quinine given in the literature is 3.4 mg/litre H<sub>2</sub>O. Compare this with that of your class and try and explain the differences.
  
2. Can you now say with certainty that the threshold value of quinine is as high as the results from your class suggest? In other words, can you assume that the results from your class apply to the whole population? Check the set-up of the experiment, and think of a few areas in which this set-up could be improved to obtain a more reliable experiment.

### Task 2 Poor, good and super tasters

With a simple calculation you can determine whether you are a poor, normal or super taster. For this experiment, you will need:

- Blue food dye
- A hole punch
- A cotton bud
- A piece of white paper
- A magnifying glass

Punch a hole in the piece of paper. Dip a cotton bud in the blue dye. With the cotton bud, rub the blue dye over the front part of your tongue. Hold the hole in the paper against your blue tongue. Now let someone with a magnifying glass look at this part of your tongue and count how many taste papillae there are in the hole. If you have fewer than 15 taste papillae in the hole, you are a poor taster. Good tasters have between 15 and 30 taste papillae and super tasters have more than 30 papillae on the surface of the hole.

### 2.1.2 Smell

#### Task 3: What are you eating?

In this task you will notice that smell has a major effect on the flavour of a food, as well as the experience. During this experiment your lecturer will blindfold someone and let them taste various foods. Try and guess what you are eating while holding your nose.

Taste is largely influenced by the smell of a dish; it is even said that 95% of the flavour of a food is determined by the smell. Which is why you can hardly 'taste' food when you have a cold.

#### Assignment 3 Describe the smells

Name five smells that are not related to products (e.g. the smell of bacon). Think of smells like fresh, mouldy, but also nutty.

There are only five tastes, but there are thousands of different smells. In other words: the nose can recognise thousands of different chemical components.

But, as you have seen in assignment 3, it is impossible to name all these smells, in the way tastes can be categorised as sour, salty, bitter, umami and sweet.

The difference between taste and smell is that non-volatile substances are detected by taste, while volatile substances are picked up by **smell**. Volatile substances are simply in the gaseous phase. They are substances that evaporate easily.

Smell is detected with the nose. To be more precise, with the olfactory epithelium, which is indicated by the number 4 in Figure 6. The total surface area of the olfactory epithelium is 5 cm<sup>2</sup>.

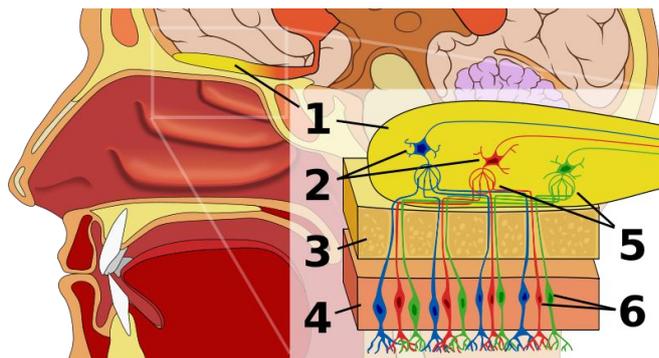


Figure 6 The olfactory organ

#### **How the olfactory organ works.**

Olfactory molecules bind to receptor proteins, which are located on the cilia of the olfactory cells (no. 6). The cilia are situated in a mucous layer of water, proteins and carbohydrates, along which the inhaled air flows. There are about 700 different sorts of receptor proteins on the cilia in your nose. Every olfactory cell contains only one sort of receptor protein. The different kinds of olfactory cells are not grouped together, but are distributed throughout the olfactory epithelium. This is shown in Figure 6 as number 6. The different colours represent the different olfactory cells (each with a different receptor protein).

As with taste detection, chemical reactions also take place when you smell; these eventually lead to a charge difference and activation of neurons. The signals sent by the different kinds of receptor proteins come together per type of receptor protein in the glomeruli, which are shown as number 5 in Figure 6. From there the signals are transmitted to the mitral cells (number 2). These are the neurons that pass the signals to the brain.

Richard Axel and Linda Buck received the Nobel Prize in 2004 for their research on smell and the discovery of the olfactory receptors.

In order to be able to detect a smell, the concentration of this fragrance must exceed a certain **boundary value (similar to the threshold value)**. If the concentration is lower than this boundary value, the smell is not detected. Every substance has a different boundary value. Ethanol is only detected in very high concentrations (more than 100 mg/l); a bucket of 10 l water must contain at least 1 g ethanol for the presence of ethanol to be detected. A substance like 1-p-menthene-8-thiol, which has a grapefruit smell, can be detected at 0.0000002 mg/l; so you can already smell this substance if there is 1 g dissolved in a tank full of water!

Fragrances are also called aromatics. They usually dissolve well in oil. Flavourings such as sugar are best dissolved in water. This difference between flavourings and fragrances is important for the cook. Fragrances are usually also very volatile. This means that they can easily evaporate during the cooking process.

Flavourings dissolve well in water; and thus the saliva in your mouth, allowing them to easily contact the tongue. Conversely, fragrances do not dissolve easily in water; they transfer to the air in the mouth. Fragrances are usually detected by the nose. To highlight this difference, take soup as an example. There are both fragrances and flavourings in soup. The fragrances are in the oil, and this oil floats on the water (you can see this in the form of the small, slightly cloudy circles on the top of the soup). Since fragrances also have a low boiling point (for example, the fragrance of grapefruit, which is already in the gaseous phase at room temperature), they will convert to the gaseous phase and rise from the soup). To prevent the loss of all the fragrances, you cover the pan with a lid.

The relationship in which a substance distributes itself in water and oil is called the **partition coefficient**. This is a fixed number for each flavouring and fragrance.

The partition coefficient can be expressed in a formula as follows:

$$Kp = \frac{[A]_o}{[A]_w}$$

$[A]_w$  is the concentration in mol/l of substance A in water and  $[A]_o$  is the concentration of substance A in mol/l in oil.

If the partition coefficient of the substance lies between 0 and 1, the substance has a great affinity for water. These substances are hydrophilic (water-loving). They are detected by the tongue, and are usually flavourings.

A substance with a high partition coefficient ( $>1$ ) has a great affinity for oil. These substances are hydrophobic (water-repelling). They are detected by the nose and are therefore fragrances. If the number is equal to 1, the substance has an equal affinity for water and oil. The substance zingerone, which is present in ginger, has a partition coefficient of 20.4. This substance dissolves easily in oil and is therefore a fragrance. Citric acid is present in citrus fruit and has a sour taste; it is a flavouring with a partition coefficient of 0.023.

#### Assignment 4 Taste and smell

1. Describe how smell and taste are detected by receptors.
2. Why are taste molecules detected mainly by the receptors of the tongue, and smell molecules by the receptors in the nose?
3. From the molecules in Table 2, indicate:
  - a. Whether the molecule mixes well in water or in oil
  - b. Whether the molecule is detected by receptors on the tongue or in the nose
  - c. Whether the molecule is a smell molecule or a taste molecule

*Table 1 Molecules in products*

Molecule	Product	Partition coefficient
Narangin	Orange peel	0.36
2,6-nonadienal	Fresh salmon	700
Menthol	Mint	2000
Tannic acid	Tea, red wine	0.70
Diacetyl	Butter, cheese	2.8
Capsaicin	Chilli pepper	10000
Acetic acid	citrus acid	0.023
Limonene	Orange peel	67000

4. A chef would like to make a sauce with an orange taste. For the extra orange sensation he grates the peel of an orange. The peel of an orange contains the molecule limonene with a partition coefficient of 67000. The chef is not quite sure whether to make a water-based or oil-based sauce. Advise the chef on the best course of action.
5. Butter kept in the fridge starts to smell foul after a while, not just because of the ageing process but also because...
6. If you add cream (35% fat content) to a strong tasting tomato soup, does the flavour become more intense or less intense? Explain your answer.
7. Would a piece of mint chewing gum taste mintier for longer, if you added a bit of oil to it? Explain.
8. If you have eaten very 'hot' food containing lots of capsaicin, should you drink water or milk to cool down your mouth? Explain.
9. Explain which herb oil is more concentrated: a lemon oil or a chilli oil.
10. Asparagus (and other vegetables) have a stronger taste if they are prepared in oil than if they are prepared in water. Explain this with the partition coefficient of the flavourings in asparagus.
11. Vegetables have many flavourings with a partition coefficient less than 1. Explain how vegetables should be cooked to give them the most taste: boiling or steaming.

### Assignment 5 Fragrances

(from: *Chemie Aktueel* issue 18, no. 53)

Read Source 1

Fragrances are low boiling substances, i.e. they have a low boiling point.

1. Why does a fragrance need a low boiling point?
2. What does this say about the interactions between fragrance molecules?

Carvon is used in the article as an example.

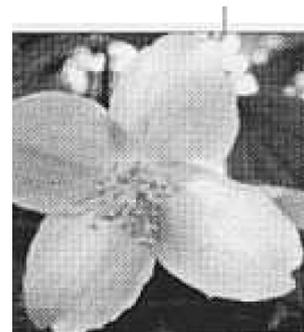
Carvon has the following structure:

3. To which categories named in the article (alcohols, phenols, ketones, aldehydes, ethers or esters) does carvon belong?

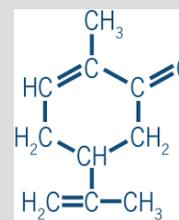
4. Is this substance more miscible in water than oil? Explain your answer.

## Fragrances

Fragrances are low-boiling alcohols, phenols, ketones, aldehydes, ethers or esters. A minor difference in chain length, side chain or another form of enantiomer makes a huge difference to the aromatic experience. For example, the two isomers of carvone smell of caraway seed and spearmint.



Source 1



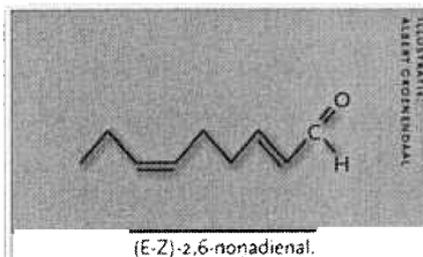
## Cucumber chemistry

Molecular aspects of *Cucumis sativus*

*It's summer and that means the silly season for news. So what better time to take a look at the chemistry of cucumbers. A quick browse of [www.c2w.nl](http://www.c2w.nl) provides a few interesting reactions from the organic, analytical and genetic angle.*

The smell of cucumbers is the result of various bonds, including 2-nonenal, hexanal and (Z)-1,5-octadien-3-on. The most important fragrance, however, is (E-Z)-2,6-nonadienal. Emeritus Professor Lambert Brandsma once synthesised the substance. He prepared a Grignard reagent from 1-bromo-3-hexene and let it react with propyl aldehyde dimethyl acetal in ether at -25°C, with CuBr as a catalyst.

Source 2



The resulting ether was then converted into the desired fragrance using a little sulphuric acid. Brandsma published the recipe in the then KNCV journal *Recueil*, volume 1976, page 66. But he advised caution. "it gives off that intensive smell you get when you slice up cucumber and add vinegar to it. Just one drop makes you feel nauseous, and your whole house will smell of it afterwards"

### Assignment 6 Cucumber chemistry (from: *Chemie Aktueel* issue 18, no. 54)

Look at the structural formula of (E-Z)-2,6-nonadienal in Source 2. Calculate whether cucumber contains a lot or a little of this substance. (Tip: mixes well with water or fat, and therefore...)

### 2.1.3 Texture

Texture is also a component of flavour. The texture of a food is what you feel in your mouth when you chew and swallow it. There is a range of adjectives related to texture: crunchy, soft, melting, rough, smooth, hard, syrupy, crumbly, juicy, fibrous, creamy and fatty. Every food has a number of recognisable textural properties. Once the food no longer possesses these properties, it is no longer regarded as being tasty, even though the taste and flavour may still be alright. An example is the crunchiness of crisps. Crisps may have the right flavour and taste, but once they are no longer crunchy, they are no longer tasty. While chewing food, senses in the palate, cheek and tongue are used. Jaw muscles and joints are also used.

The texture of a food is determined by the structure. The **structure** is defined by the arrangement of the carbohydrates, fats, proteins and water in the food. The four possible structures are dealt with in section 2.3.

The texture affects how you savour a dish, but also the speed with which fragrances in particular are released. Therefore, the texture also dictates the intensity of the smell.

A fragrance is 'locked up' in the structure of a food.

Whether the fragrance is actually detected depends firstly on the characteristics of the fragrance itself. For example, how 'willingly' the fragrance is dissolved in the structure. As explained in the previous section, a hydrophobic fragrance will not remain dissolved in a hydrophilic structure like water for long. The molecule then moves from the liquid to the air, where it can be smelled. If the hydrophobic fragrance is dissolved in oil, it is a lot less easy to smell. The structure of the molecule fits so well with the structure of oil that it stays within the structure.

The second factor of importance for fragrance detection is the speed with which the molecule can move through the structure. Molecules move faster through a gas than through a solid. The structures present in foods fall somewhere between these two extremes. One example of a structure that contains a lot of gas is a foam. A molecule can move rapidly through a foam. An example of a solid structure is cheese. The molecule moves much more slowly through this.

Research has been conducted on the relationship between the intensity of fragrances observed in cheese and its firmness. The results showed that in a firm cheese the fragrances were less intense. The firmer the cheese, the more slowly the molecules move through the structure. The exact relationship between texture and the ability to detect a flavour is the subject of much research at present. What can, in any case, be concluded is that a fragrance has to work its way through the structure of a food. The speed of this movement depends on both the properties of the molecule and the properties of the structure.

### Assignment 7 Texture

1. Which two factors determine whether a smell is released from a food?
2. From the following dishes or parts of dishes, indicate which textural properties are important for the dish. Use adjectives like crispy, rough, etc.

Blancmange, ice-cream, wafers, pasta, whipping cream and crisps

#### 2.1.4 Visual aspects

Appearance has nothing to do with flavour, but it is extremely important in a dish or food. Appearance is what you can see when you look at a dish, i.e. how it is presented on the plate and the various colours that appear in the dish. The colours of a food provide information about the product itself. They can indicate, for example, how ripe a product is: a green banana is not ripe, a yellow one is. You would expect a pink drink to be sweet and not bitter. In addition, colours tell us something about the freshness of a product and the extent to which it has been processed: wilted salad looks very different from fresh salad. The colour can also give an impression of the flavour of a dish. This impression can also be misleading. Take the example of green ketchup, which was on sale in supermarkets not so long ago. Cooks use colour to make dishes look surprising. Pasta can be dyed black with a little help from squid ink (*Figure 7*). This colouring gives the dish a completely different look.



*Figure 7 Black pasta*

## 2.2 Measuring flavour

The previous section contained a description of what flavour is and how it can be detected. The various components that go to make up flavour can be reduced to product characteristics. Table 3 contains a summary of some product characteristics that foods may possess. (Dishes consist of several foods and do not have product characteristics. We therefore refer to the product characteristics of foods.)

Table 3 Product characteristics and measurements.

Flavour characteristic	Product characteristic	Scientific measuring methods
Smell	Rose smell, sulphur smell, grass-like	Gas chromatography Odour analysis
Taste	Salty Sour Bitter Sweet	Measure salt concentration Measure pH Measure quinine concentration Measure sugar content
Texture	Thick, hard, crunchy, creamy, tough, greasy, fibrous, crumbly	Measure thickness Measure foam stability Measure air quantity Measure tensile strength Measure fat levels Measure fat composition Microscopic analysis
Appearance	Dark, light, green, red, colour pattern, sharp, blurred	Colour measurements Microscopic analysis Spectroscopic dimensions

In the table you can detect the three components of flavour and appearance, this time coupled to product characteristics. Product characteristics can be measured and thus the subjective observation of flavour and appearance can be converted into objective measurements.

Scientists carry out these measurements in the lab. The results of these measurements give the cook a better idea of what he/she is doing in the kitchen.

For instance, the cook gains more insight into the product characteristics of the ingredients being used, of the relationship between product characteristic and concentration of the ingredients, and of the effect of the processes he conducts on the food.

Armed with this new understanding and his creativity, the cook can improve his recipes.

A simple example of how this table can be used is as follows. A product characteristic of lemonade is sweetness. Sweetness can be linked to the sugar content in the lemonade: the sugar concentration is a measure of sweetness. The more sugar the lemonade contains, the sweeter the taste. To test this theory, you could perform a sensory test. For example, you could ask a group of children to taste a certain lemonade and give their opinion on how sweet it is.

You can also do this for many other product characteristics, for instance, the crunchiness of a chip or the creaminess of a particular sauce. Using this knowledge you can then innovate and improve existing recipes. Say you want to improve the thickness of a sauce; you could opt to increase the fat percentage of the sauce. You could then measure the thickness (also called viscosity) of the sauce at various fat percentages. You would probably discover that a higher fat content produced a thicker sauce.

In addition to the scientific methods in assignment 8, there is another method of determining product characteristics called a **sensory test**. This concept was previously described in the example of sweet lemonade. A sensory test actually creates a link between a subjective observation and an objective measurement. Sensory tests are often used to see if a new product tastes good, but also to see whether certain changes have a demonstrable effect on the flavour.

There are various kinds of sensory test. The key difference between them is actually the experience of the tasters. You can have the tasting done by a group of people who have no experience in such matters. In this case you would ask questions like “which product did you like best?” or “is the product tasty?” This test is often used to see if a new product tastes good, and is something that a chef often does with a new dish.

Another type of test involves the use of expert tasters. These people are very good at distinguishing between different flavours and are trained to describe smells and tastes (see Task 4). This sort of panel is often used to determine the quality of different products. They don't describe a product as 'tasty' or 'not tasty', but look instead at the differences between products, for example between Heinz ketchup and a generic brand ketchup.

#### **Assignment 8 Product measurements**

Invent a method to measure the amount of air/gas in a product.

#### **Assignment 9 A healthy deep-fried diet**

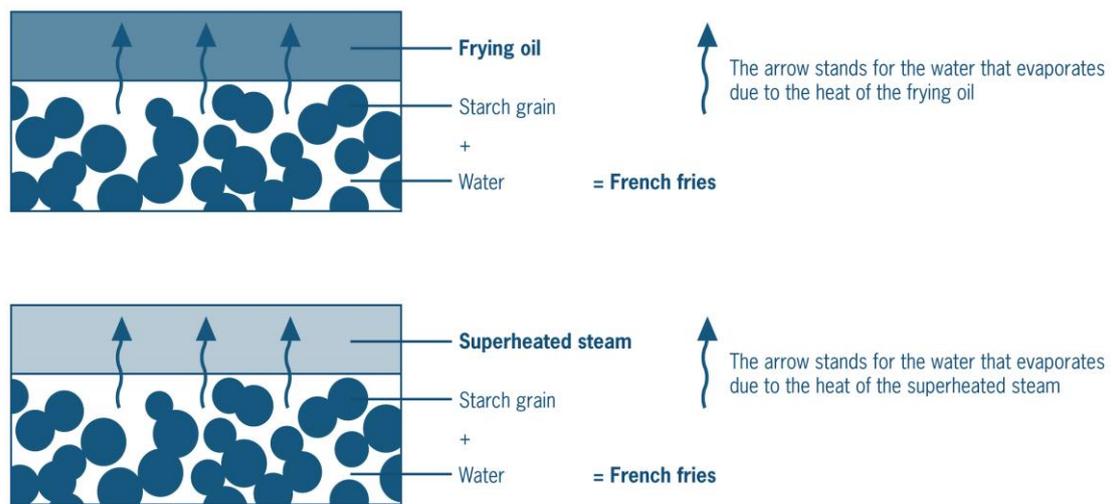
Read the Newspaper Article 2 “Fried food weight loss diet” (on the following page)

1. Name a few key product characteristics of chips.
2. How could you measure the crunchiness of a chip?
3. Explain in your own words the difference between traditional deep-frying and deep-frying using the superheated steam method.
4. What is the relationship between the superheated steam method and molecular gastronomy?

### Fried food weight loss diet!

### Newspaper Article 2

Here is a typical example of the way in which improvements to cooking equipment can improve the eating experience. Because in the near future you may well be able to make healthier chips without having to sacrifice the taste and the greasy mouth-feel. Only recently there was a machine in the news that makes chips using superheated steam. Deep-frying can be compared to a drying process, because the moisture in a chip is partly released in the form of steam. This drying is partly responsible for making chips so crunchy. The superheated steam doesn't contain much water vapour, so the chip also dries, causing the same effect on the chip as with deep-frying, but without the fat. The chips are however made a little greasy to give the right mouth-feel. They still have to be pre-cooked before being made into a crunchy chip. Who wouldn't like to eat chips without feeling guilty and suffering the consequences, e.g. putting on weight? But, apart from the nice greasy taste, isn't that all part of the eating experience?



Bron: NVOX, Isolde van Leeuwen

### Profession Box 2

#### For taste research, let's venture into the world of philosophy

Interview with Bob Cramwinckel, director of the Centrum voor Smaakonderzoek (Centre for Taste Research) (CSO) in Wageningen. Cramwinckel studied food chemistry at Wageningen University.

Cramwinckel gets straight to the point: "natural science and taste research do not run completely in parallel". Natural science is straightforward. There are isolated phenomena, such as magnetism. "Every scientist regards magnetism as an isolated phenomenon, but taste is not isolated, it is an experience". According to Cramwinckel in taste there is a clash between scientific logic and human interaction. It is precisely this interaction that makes it so interesting. "You often hear people say 'there's no accounting for taste'", says Cramwinckel, "this is because people are involved, and consciousness plays a vital role".

Cramwinckel therefore approaches taste as an interactive process, in which human and product jointly determine the outcome. Environment is also important. Cramwinckel cites obesity as an example of this interaction. According to science (and thus logic), the solution is very simple: eat less and do more exercise. Unfortunately this doesn't work in practice, because simple logic doesn't work on illogical people.

His almost philosophical approach to taste and taste research makes Cramwinckel no ordinary taste researcher. No white boxes where people have to stand and taste, as this only gives a superficial scientific feel. No secrecy about the true nature of the research just let people taste and tell them what to look out for. And most important of all: everybody's different, and never assume that your research is representative of the population; these are connoisseurs.

Is taste only subjective, and if so, how can you draw any conclusions from research? “Just because you admit that your research is not representative for the population, doesn’t mean that it isn’t representative for anybody”, says Cramwinckel. His panels are made up only of people who have a real affinity with the product that is being tested, i.e. connoisseurs. According to Cramwinckel these connoisseurs all have the same idea about what is ‘tasty’ about their favourite product. And there’s no dispute about the differences in key features, such as sweetness, firmness and crunchiness. As long as you remember that your research is done *by connoisseurs for connoisseurs* (just a fraction of the population), you can draw some quite powerful conclusions from your results.

Researchers use statistics to try and generalise their results as much as possible, so that they are representative for the entire population. According to Cramwinckel statistics are definitely useful. They enable you to say whether there is a real difference or not. It is a tool, so you have to understand the significance yourself. And in Cramwinckel’s opinion, this significance is currently very important.

“Everybody’s different when it comes to the taste experience”, says Cramwinckel. He uses Albert Heijn as an example: “In this supermarket there are about 20,000 different products, but every family buys the same 200 or so products all the time. This is already a good indication that there are great differences in taste.” That’s why Cramwinckel finds it such fun to do research in this area. According to him, this knowledge about interactions and the illogical behaviour of people and taste also teaches us something about ourselves. You learn something about your own preconceptions and realise that you have your “own reality”. Such knowledge is useful in taste research, but also in the rest of your life: it makes you more tolerant and flexible, says Cramwinckel.

This is evidenced in the way that his business is run. Cramwinckel works in time slots of approx. 2 months, the time it takes to conduct the research. He has no idea what is going to happen after this research, “I have no idea what I will be doing in 4 months from now, my diary is empty”. This may sound reasonable enough, but for a company director it is unique, especially for a business that has been running successfully for the last 20 years!

Is there no research already planned for the future? “Yes”, says Cramwinckel, “the big ‘oliebollen’ study for AD is confirmed, unless they suddenly decide that they have to save money”.

#### **Task 4 Tasting and evaluating biscuits**

In this task you and your fellow students are going to take a sensory test. You are going to look at 2 different biscuits. You will begin by determining which characteristics are the most important to look for, and you will then describe the biscuits. From the descriptions the four most important characteristics will be selected and evaluated on a scale from 1 to 5. Finally, you will decide which of the 2 biscuits is tastiest, as a kind of market research. At the end of the task, the lecturer will explain the differences between the 2 biscuits.

There are 2 kinds of biscuit before you. Try these biscuits and write down 5 taste elements of the biscuits (for example, not just sweet, sour, salty and bitter, but also textural properties like crunchy, juicy, solid, tough, creamy, etc.).

When everyone is ready, read out the elements that you have written down, so that the lecturer can write them on the board.

Enter the 4 most frequently named elements in the questionnaire below. Try the biscuits again and fill in the questionnaire for each biscuit (circle the answers).

*Important: taste carefully and several times. Don’t just taste, look at and smell the biscuits carefully. Between the tastings of biscuit 1 and 2 rinse out your mouth with water and take a bite of cracker to neutralise the taste.*

*Biscuit 1*

Not at all (element 1) Completely (element 1)

1                    2                    3                    4                    5

Not at all (element 2) Completely (element 2)

1                    2                    3                    4                    5

Not at all (element 3) Completely (element 3)

1                    2                    3                    4                    5

Not at all (element 4) Completely (element 4)

1                    2                    3                    4                    5

*Biscuit 2*

Not at all (element 1) Completely (element 1)

1                    2                    3                    4                    5

Not at all (element 2) Completely (element 2)

1                    2                    3                    4                    5

Not at all (element 3) Completely (element 3)

1                    2                    3                    4                    5

Not at all (element 4) Completely (element 4)

1                    2                    3                    4                    5

Enter your results in the table below on the board by putting a stroke near the score that you gave each element.

Once the table on the board is filled in, enter the results of the whole class into the table on the following page.

Try the biscuits one more time and indicate which of the 2 biscuits you find tastiest.

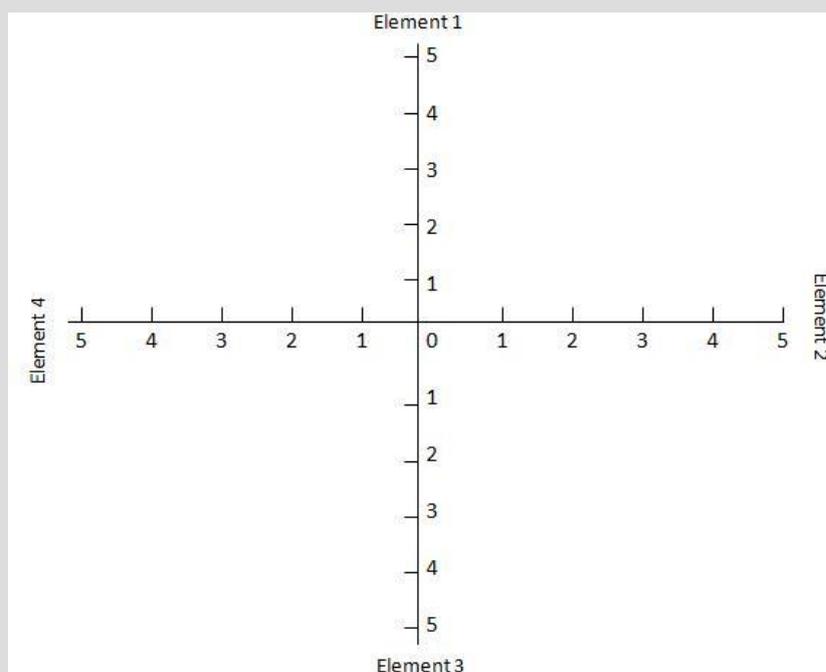
Which biscuit did you find most tasty? Strike this up on the board as well.

Biscuit 1

Biscuit 2

		<i>Number of times 1</i>	<i>Number of times 2</i>	<i>Number of times 3</i>	<i>Number of times 4</i>	<i>Numb er of times 5</i>	<i>Studen ts in class</i>	<i>Total number of points</i>	<i>Avera ge</i>
Biscu it 1	Element 1 .....	1	2	3	4	5			
	Element 2 .....	1	2	3	4	5			
	Element 3 .....	1	2	3	4	5			
	Element 4 .....	1	2	3	4	5			
Biscu it 2	Element 1 .....	1	2	3	4	5			
	Element 2 .....	1	2	3	4	5			
	Element 3 .....	1	2	3	4	5			
	Element 4 .....	1	2	3	4	5			

Draw the average scores per biscuit that are given for each element on the graph and sum up the scores per biscuit. Use a different colour for each biscuit and make a legend for the graph indicating which colour represents which biscuit. Using another 2 colours enter your own scores and indicate this in your legend as well. Do your scores correspond approximately with those of the whole class? If so, you are a good taster!



Before you begin on the questions, your lecturer will tell you what the difference was between the biscuits.

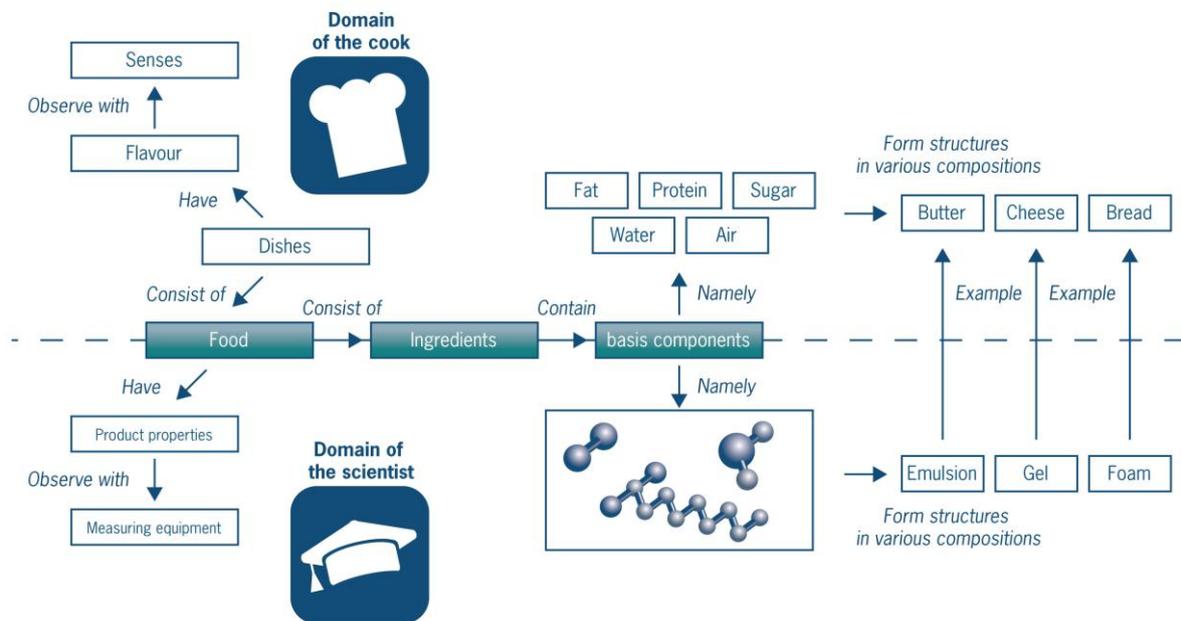
Questions:

1. What strikes you about the differences in evaluation of the taste elements between the 2 kinds of biscuit? Discuss this on the basis of what you know about the characteristics of the biscuits.
2. Why do you think it was necessary to test the biscuits carefully, rather than immediately eating and swallowing them?
3. Do you think you could judge after this test which of the 2 kinds of biscuits the manufacturer should bring to market? Explain why and why not.
4. Indicate which taste elements of sweet, sour, salty and bitter play a role in biscuits and which do not. For all taste elements give at least 3 products in which these elements play a role.

You will have realised from this task how difficult it is to set up a taste study whose results can be applied to a large group of people. Which is why there is still a lot more research being done on how taste works, and how these studies can best be set up.

You may be wondering what use such a study is for cooks. A very good example of this is the Belgian system of Food Pairing. A number of Belgian researchers are investigating which tastes go together, both on the basis of structure, but also on the basis of this sort of research. It can reveal very surprising results, which can be used by cooks to make innovative dishes with strange (but delicious!) combinations.

## 2.3 From basic components to structures



As a rule, all foods consist of five components:

- water
- carbohydrates
- fat
- protein
- air

You might think that an egg consists mainly of protein. But you would be wrong. An egg is 75% water and only 10% protein. Butter seems to contain only fat, but in fact also contains about 10% water as well as protein and carbohydrates.

The five components are arranged in every food in a different way: this is called **the structure**. The arrangement results from the fact that the five components do not mix well. The structures can be found on a microscopic scale between 100 nanometres (1 nanometre is  $10^{-9}$  m) and 1-5 millimetres.

The structure of bread is visible to the naked eye: you can see the holes. However, if you look at a glass of milk, it doesn't appear to have any structure, that is until you look at it under a microscope. Then you will see little globules of fat floating in water. The structure of milk is visible on a microscale (1 micrometre =  $10^{-6}$  m). Foods have microscale structures that ultimately define product characteristics like thickness, taste and colour.

### Assignment 10 The basic components in foods and dishes

For the molecular gastronomical dish below, calculate the quantity of protein, water, fat and carbohydrates in g per 100 g. A few tips:

Start from the quantity on your plate.

Disregard the evaporation effect during the reduction process.

The peel and stubs represent about 20% of the weight of the asparagus.

The data on the ingredients can be found in BINAS table 82A.

### Recipe: Asparagus/white chocolate ice-cream

Normally speaking, ice-cream is made in an ice-cream machine and frozen. This asparagus ice-cream is frozen using liquid nitrogen. Liquid nitrogen has a temperature of  $-196^{\circ}\text{C}$ . When liquid nitrogen is poured over a dish, it freezes very rapidly. In this process the water freezes in all places at the same time, and not first on the outside and then slowly and increasingly to the inside. This simultaneous freezing produces much smaller ice crystals than in 'normal' ice-cream. The result is much creamier ice-cream.

#### Ingredients:

The peel and stubs of 1 kg asparagus  
500 ml whipping cream  
500 ml full-fat milk  
150 g white chocolate.



Wash the asparagus waste thoroughly, let it drain and bring it to the boil in a steel pan with the cream and milk. As soon as the cream mixture comes to the boil, turn down the heat and let the asparagus peel infuse for 30 minutes. Then let the peel cool in the cream and pour the mixture through a sieve. Collect the cooking fluid and use a ladle to push out as much liquid as possible from the peel. Put the asparagus cream in a clean pan and bring to the boil again, and then let the cream reduce until there is 5 dl left. Cut the white chocolate into small pieces. Wait until the asparagus cream is luke warm and then melt the chocolate in it. Leave the mixture to cool to room temperature and then, while stirring, add about half a litre of nitrogen. The nitrogen has now created ice-cream.

As the recipe says, the liquid nitrogen gives the ice-cream a different structure from normal. A molecular gastronomical innovating principle (the use of liquid nitrogen) is, therefore, being applied to an existing dish. This is one of the things that molecular gastronomy is all about: using chemical knowledge (in this case the knowledge that faster freezing produces smaller ice crystals) to improve recipes in the kitchen. In chapters three and four this will be discussed in more detail, because then you will be examining two important structures and how they relate to each other.

Dishes that contain the same quantities of protein, fat, carbohydrate and water can, however, have completely different product characteristics because of their microstructure. A good example of two products that have the same composition but totally different product characteristics is milk and yoghurt. Yoghurt is thick and sour, while milk is sweet and much thinner. Yet (full-fat) milk and (full-fat) yoghurt both contain 87% water and about 3.5% protein, 3.5% fat, 5% lactose and 0.7% minerals.

The reason for this difference is the **microstructure**. Microstructure is a food's structure on a **microscale**, and the microscale covers particles which range in size between 0.001 and 10 micrometres.

In milk, fat takes the form of small globules 'dissolved' in the **plasma**, the liquid part of the milk. The fat globules in milk vary in size from 0.1 to 10 micrometres. Every fat globule is covered with a double layer (membrane), which consists of proteins, phospholipids, vitamin A and cholesterol. This membrane is about 10 nanometres thick (1 nanometre is  $10^{-9}$  m).

The proteins in the milk can be divided into a casein fraction and a whey-protein fraction. The casein is present in the form of micelles (see box). A micelle is an aggregate of casein protein with a diameter of about 0.1 micrometre. The micelle comprises four different types of proteins, as well as other substances, such as calcium.

Before milk can be sold to consumers, it is homogenised. Homogenisation is a process whereby the fat globules in milk are broken up to form a homogeneous mixture. Homogenisation prevents the **(creaming)** of the fat fraction in the milk.

Creaming causes the fat droplets to rise to the top of the milk, resulting in a layer of cream on the milk. Fat droplets actually have a lower density than water. Like oil on water, the fat droplets will form a layer of fat on top of the aqueous (water) phase of the milk.

### **The micelle**

Micelles also appear in soap solutions. Soaps are stearate salts that consist of a  $\text{Na}^+$  or a  $\text{K}^+$  ion with a very long hydrocarbon tail. When soap is dissolved in water, these salts form little bubbles, with the charged part of the soap molecule on the outside (the Na or K ions: the dark blue circles in the figure). This part of the molecule is hydrophilic. The hydrocarbon tails are located on the inside of the little balls. They are hydrophobic, or 'water-repelling'. Figure 8 is an image of an air bubble in soapsuds. The continuous phase in soap suds is the water, containing the dissolved soap. This structure – little balls of molecules in water with the hydrophobic part of the molecule on the inside and the hydrophilic part on the outside – is called a micelle.

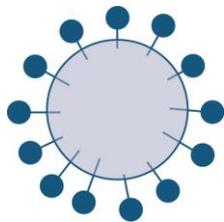


Figure 8 Air bubble in soap suds

Figure 9 shows the microstructure of milk; the big globules are the fat particles, the smaller ones are the casein micelles.

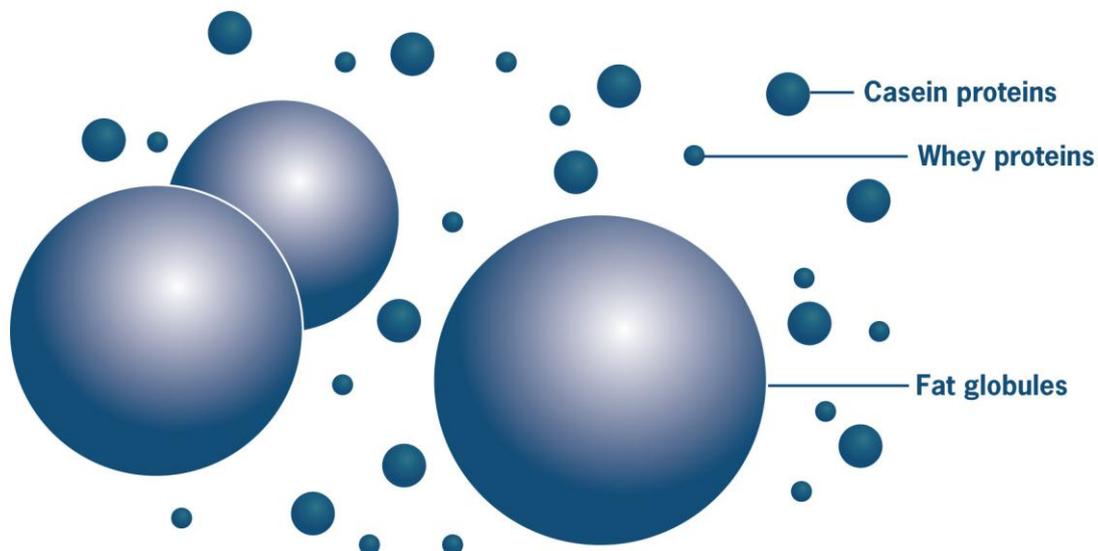


Figure 9 Microstructure of milk

Yoghurt has a lower pH than milk: the pH of yoghurt is about 4.3 and that of milk, 6.8. The low pH of yoghurt is caused by fermentation with lactic acid bacteria. This makes the yoghurt taste much more sour than milk. Another consequence of the low pH is that the casein proteins coagulate into a network. The fat globules are incorporated in this network of proteins. This clustering of proteins and fat globules gives yoghurt a much thicker texture than milk. The microstructure of yoghurt is shown in Figure 10.

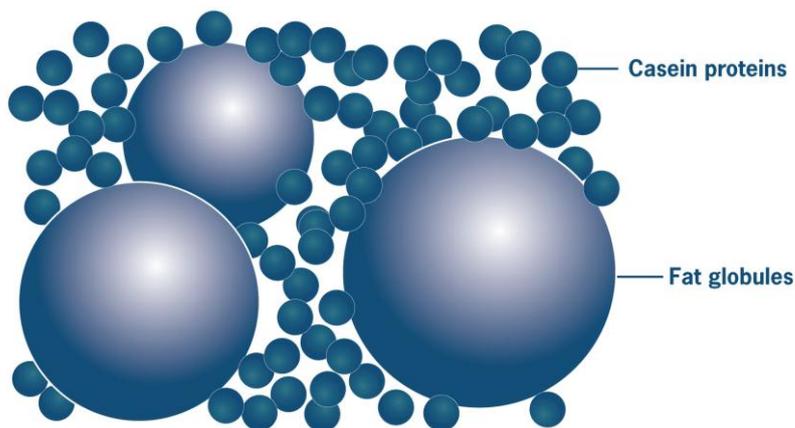


Figure 10 Microstructure of yoghurt

Hervé This, one of the pioneers of molecular gastronomy, noticed that all dishes consist of **dispersions**. Dispersions consist of a dissolved phase (dispersed phase) and a continuous phase (phase which incorporates the dissolved phase). Does that mean that a dispersion is a solution? No. So what is the difference between a dispersion and a solution?

In a dispersion the basic components are mixed together on a microscale, while in a solution the basic components are mixed together on a molecular scale (Figure 11). An example of a solution is a cup of tea with sugar. The sugar mixes with the water on a molecular scale: the sugar molecules are completely miscible (dissolved) in water. Because they are so small, the structure is not visible, even with the help of a microscope. In dispersions such as yoghurt and milk, the structure can be seen at the microscopic level, as you saw earlier in this section. The fat particles are not dissolved on a molecular scale in the water, but instead form structures on a microscale. Previously in this section, you read about the sedimentation of milk. Milk sedimentation is an example of segregation (Figure 11).

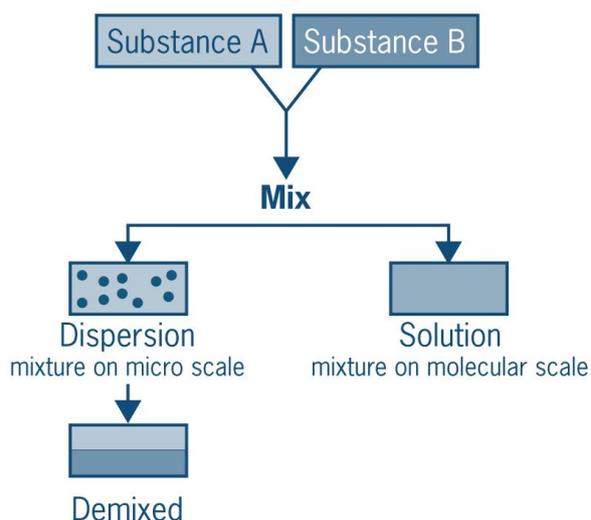


Figure 11 Solution and dispersion

Dispersions are therefore systems that can be mixed on a microscale. They are also called colloidal structures. A **colloid** is a particle that is bigger than a molecule, but too small to be seen with the naked eye. The size of the particles ranges from 0.001 to 10 micrometres. The fat particles in milk, which are 5 micrometres in diameter, are classed as colloids. The casein micelles of 0.1 micrometre are also colloids.

An overview of the different structures on the microscale is shown in Figure 12. There are 9 different dispersions, because both the dispersed phase (the 'dissolved substance') and the continuous phase (the 'solvent') can occur in three different phases: as gas, liquid or solid.

		Dispersion phase (dissolved substance)		
		Gas	Liquid	Solid
Continuous phase (solvent)	Gas	[none] all gasses are soluble within eachother	liquid aerosol <i>fog</i>	solid aerosol <i>smoke</i>
	Liquid	foam <i>beer foam</i>	emulsion <i>mayonnaise, milk</i>	suspension <i>starch solution</i>
	Solid	solid foam <i>bread</i>	solid emulsion (gel) <i>cheese, gelatine</i>	solid substance <i>alloys (bronze)</i>

Figure 12 Types of dispersions

You can use this table to categorise all dispersions. The categories into which most foods fall are framed in red in the diagram: the foams (solid and liquid) and the emulsions (solid and liquid). In chapters 3 and 4, there will be a more in-depth explanation of foams and emulsions.



Figure 13(left) beer foam (a liquid foam) Figure 14 (right) bread (a solid foam)

#### Assignment 11

- We mix a salt solution with soap and oil. What is the dissolved substance or dispersed phase and what is the solvent or the continuous phase? Give your answer in the form of a drawing.
- In beer foam, what is the dispersed phase and what constitutes the continuous phase? And in bread? Do the same for the following products: mayonnaise, milk, ice-cream and butter.

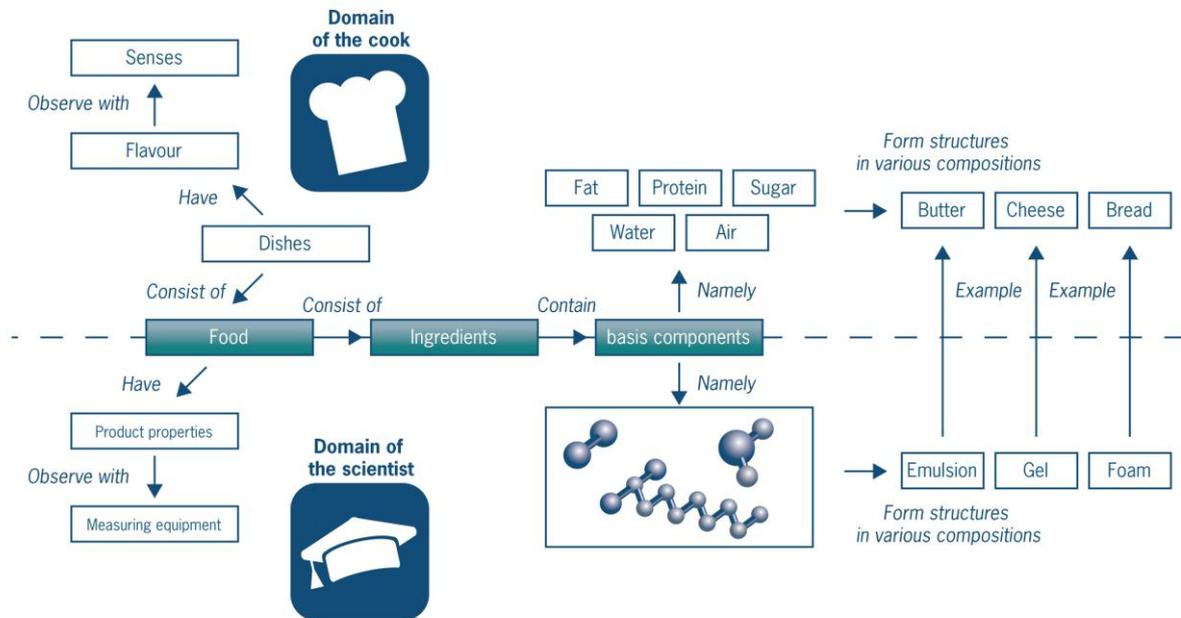
#### Assignment 12

This assignment is about yoghurt and cake. Answer the questions for each of the products separately.

- Which of the 5 basic components does the product contain and in what quantity (g/100 g)? You may use BINAS table 82A to answer this question.
- With a structural drawing indicate where the fat droplets are situated in yoghurt and where the air bubbles appear in cake.
- Is this structural drawing on a microscale or a molecular scale?
- Indicate which components are in which phase. What is the dissolved phase and what is the continuous phase?
- In which category from the diagram in Figure 13 would you place yoghurt? And cake?

## 2.4 From ingredients to basic components

All foods consist of five components: water, carbohydrates, proteins, fats and air. The characteristics of these components and the mutual interactions between them determine the product characteristics of the food.



The interactions between water and fat will be dealt with in more detail in chapter 3 on emulsions.

### Assignment 13 Molecules and structures

Molecules and structures belong to different size categories. A fat globule in milk has a diameter of 5 micrometers. A fat molecule is, however, much smaller.

1. Calculate the volume of this fat globule.
2. Work out how many mols of fatty acid are in this fat globule. For the purposes of this calculation we assume that milk fat consists only of elaidic acid. Elaidic acid has the following properties:
  - a. Molecular weight: 282.45 g/mol
  - b. Density: 850 kg/m<sup>3</sup>
3. Calculate (using Avogadro's constant from Table 7 of BINAS) how many molecules there are in this fat globule.
4. What conclusions can you draw from the difference in size when comparing the fat globule with the molecule of elaidic acid?

The interactions between air, protein and carbohydrates will be dealt with in chapter 4 on foams. In order to give you a better understanding of the basic components, this section will look at some of the key attributes of water, carbohydrates, proteins and fats.

### 2.4.1 Water

Water seems so ordinary, but it is crucial in the preparation of our food. Water consists of small molecules with a strong mutual attraction. Two hydrogen atoms and an oxygen atom ( $\text{H}_2\text{O}$ ) go to make up a molecule of water. The hydrogen atoms are connected by covalent bonds (sharing of pairs of electrons) to the oxygen atom. The oxygen atom pulls more strongly on the electrons in the covalent bond (electron negativity) than the hydrogen atom.

The shape of the molecule is not linear but angular. This is because the centres of + and – charges do not converge, creating a dipole. This means that one side of the molecule has a slightly positive charge, and the other a slightly negative charge. (Figure 15).

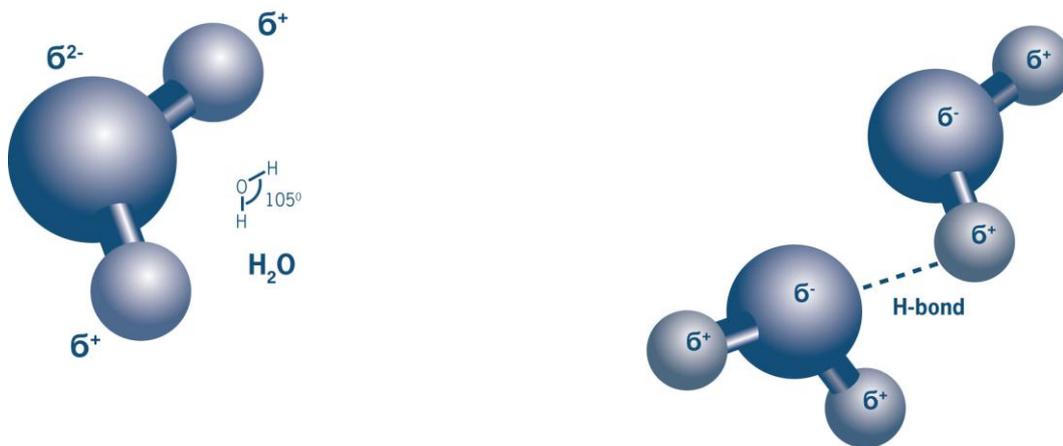


Figure 15 Dipole in water and hydrogen bonds

The difference in electronegativity between O and H is extremely big. As a result the H atom of one water molecule is attracted to the O atom of another water molecule. Hydrogen bonds form between the water molecules, forming a cluster.

These hydrogen bonds create a particularly strong bond between the water molecules.

#### **Hydrogen bonds**

*The water molecules are bound together by hydrogen bonds and are grouped together in clusters (molecular complexes). These hydrogen bonds create a particularly strong bond between the water molecules. Due to this strong bond:*

- *water has a high melting point and a high boiling point. Without hydrogen bonds the melting point would be  $-100^{\circ}\text{C}$  and the boiling point  $-80^{\circ}\text{C}$ .*
- *water has a high latent heat evaporation (= the amount of energy absorbed without a corresponding rise in temperature). This property is used by our body to cool down by sweating. It also ensures that our water-rich country has a moderate climate (in the desert the temperatures at night are  $-10^{\circ}\text{C}$  and during the day  $50^{\circ}\text{C}$ ).*
- *ice is the only solid to float in its own liquid. The optimal hydrogen bonds in the ice crystals create cavities.*

Examples of other groups that can also form hydrogen bonds are the OH group of ethanol (alcohol) and the NH<sub>2</sub> group present in amino acids. In the NH<sub>2</sub> group there is a difference in electron negativity between the H<sup>δ+</sup> atom and the N<sup>δ-</sup> atom. In addition to these two groups, C=O, CO (with three double bonds), and HF groups can also form hydrogen bonds with a hydrogen atom.

Molecules that contain enough of these groups are **hydrophilic**: they dissolve easily in water. Molecules such as fats contain few of these groups and have difficulty dissolving in water; they are therefore **hydrophobic**. Therefore, substances that easily form hydrogen bonds dissolve well in water.

### 2.4.2 Carbohydrates

Carbohydrates are compounds consisting of carbon, hydrogen and oxygen atoms. The carbohydrates group contains a great many different types of molecules. These molecules have one thing in common: they all have several OH groups (hydroxy groups).

They also contain an aldehyde ( $\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{H}$ ) or ketone ( $\text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{R}$ ) group. Carbohydrates are therefore also called polyhydroxyaldehydes or polyhydroxyketones.

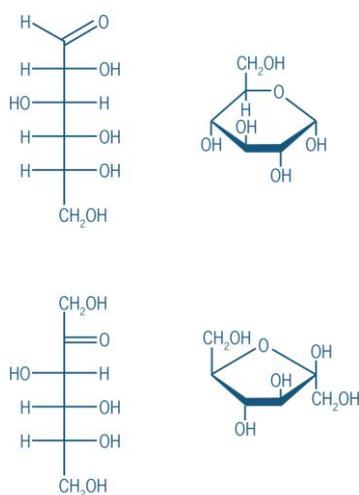
The carbohydrates are subdivided into a number of groups:

1. Monosaccharides
2. Disaccharides
3. Oligosaccharides
4. Polysaccharides

The various groups of sugars are described below in a little more detail.

#### Monosaccharides and disaccharides

Monosaccharides are the smallest and most simple molecules in the carbohydrate group. The monosaccharides that occur most frequently in foods are glucose and fructose (*Figure 16*). Monosaccharides occur in two structures in nature, namely in a linear structure (a straight chain) and in the shape of a ring. When a sugar is dissolved, it can switch back and forth between these two forms (creating an equilibrium).



*Figure 16* Glucose and fructose

When fructose and glucose bind to each other, they form a disaccharide, namely saccharose (*Figure 17*). Saccharose, also called sucrose, is the product we know as sugar. It is made from sugar beet or sugar cane. Saccharose can also be split into two monosaccharides, glucose and fructose.

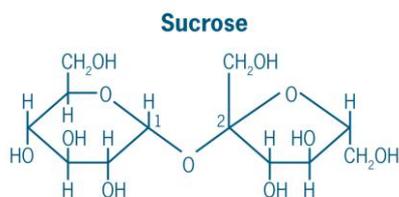


Figure 17 The structure of saccharose

Another well-known disaccharide is lactose. Lactose is present in milk and consists of the monosaccharides glucose and galactose. Lactose is the only existing disaccharide of animal origin. All other disaccharides are made by plants. Table 4 gives an overview of a few of the most commonly occurring disaccharides.

Table 4 Disaccharides

Sugar	Source	Monosaccharides
Saccharose	Cane, beet	Glucose and fructose
Lactose	Milk	Glucose and galactose
Maltose	Grain and honey	Glucose and glucose
Cellobiose	Cotton, jute, paper	Glucose and glucose

**Assignment 14 Saccharose (from: Chemie Aktueel volume 19, no. 57)**

1. Explain why saccharose can be dissolved in water. Can it also be dissolved in fat? Explain why or why not.

Now read Source 3.

2. Why does the manufacturer call “Splenda” a natural product and why do the sugar farmers claim that it is a chemical product?
3. ‘made from sugar, tastes like sugar’. Is this claim correct? Give a brief explanation.
4. Copy down the structural formula of saccharose (from BINAS) and indicate which hydroxyl groups have been replaced.
5. Give an explanation for whether saccharose still tastes sweet if all OH groups are replaced by Cl.

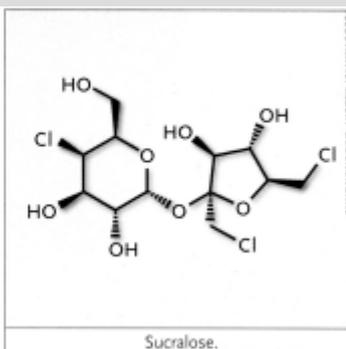
**Source 3**

**C2W, 15 September 2007**

**Sweet can turn sour**

The Sugar Association, an affiliation of American sugar farmers, has accused Johnson & Johnson of deceiving the public. The sweetener sucralose (brand name Splenda, ‘made from sugar, so it tastes like sugar’) is sold as a natural product although it is actually a chemical product.

Sucralose is saccharose in which three hydroxyl groups have been replaced by chlorine. This is achieved in the laboratory in various ways, but only Johnson & Johnson’s supplier Tate & Lyle knows how to do it on an industrial scale. Details about the process and raw materials are carefully guarded. There is, however, a rumour that the infamous toxic gas phosgene is used in the chlorination process.



And ‘made from sugar’ is not necessarily true, because there are sucralose patents that do it without. In order to clear up this matter, the sugar farmers want to film the process in the sucralose plant in Alabama. A judge has rejected their request for the time being. To be continued.

## Oligosaccharides

Chains of 3 -5 monosaccharides are complex saccharides known as oligosaccharides..

Oligosaccharides are to be found primarily in seeds. They are a form of stored energy, which can be used when the seed germinates. These saccharides are of no further interest as far as molecular gastronomy is concerned. We can only absorb simple saccharides (monosaccharides) from the small intestine into the blood. Since our digestive system does not make enzymes to break down oligosaccharides into monosaccharides, oligosaccharides pass through the intestines undigested.

## Polysaccharides

These are macromolecules in which 20 to 5000 monosaccharides are linked together. A few well-known polysaccharides in the molecular kitchen are starch, cellulose, pectin, dextran and xanthane. Polysaccharides also have several OH groups. This enables them to interact with water via hydrogen bonds. However, in some polysaccharides the attraction between the chains is so great (also due to hydrogen bonds) that they do not dissolve in water. Since polysaccharides are big and not completely miscible in water, they belong to the colloids. They play an important role in dispersed systems, described in section 2.3.

The polysaccharides can be categorised in various ways. A distinction can be made between linear and branched polysaccharides. In the linear category all monosaccharides appear in one long chain. The branched polysaccharides also consist of long chains of monosaccharides, but they also have side chains that consist of (chains of) monosaccharides.

The second difference between the polysaccharides can be seen in the number of different types of monosaccharides in the chain. When a polysaccharide consists of only one type of monosaccharide, it is called a homoglycan. When there is more than one type of monosaccharide, for example the combination of glucose and fructose, it is called a heteroglycan. The two categories (linear/branched and homo/heteroglycan) containing polysaccharides, will be further elaborated on the basis of starch and dextran.

### Example 1: Starch

Starch is one of the most well-known polysaccharides. It is present in grains, roots, bulbs and vegetables. It is present in the form of granules in plant cells. The starch granules are a form of energy storage for the plant concerned. Starch consists of not one but two polysaccharides, namely amylose and amylopectin (*Figure 18 and 19*). They are homoglycans, because the chains of both molecules are composed only of glucose molecules. The difference is that amylose is a linear molecule, while amylopectin is branched. It consists of between 200 and 200,000 glucose molecules.

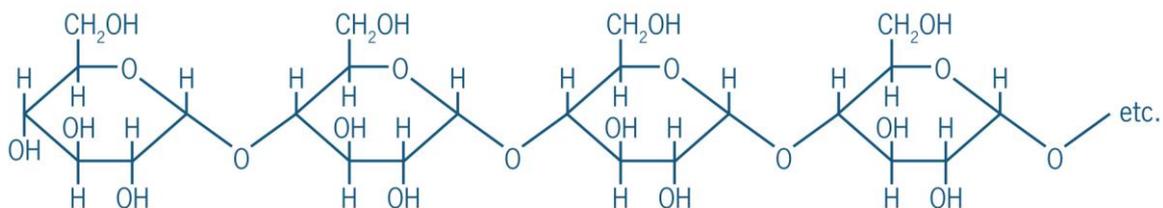


Figure 18 Amylose

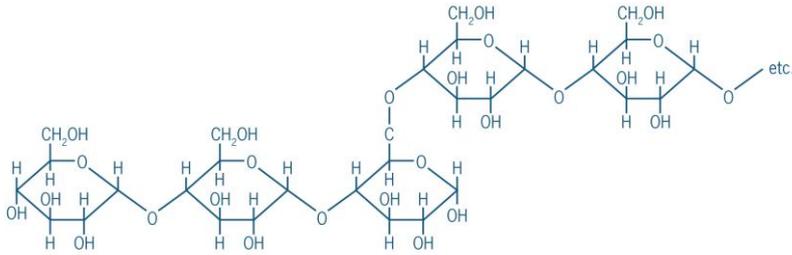
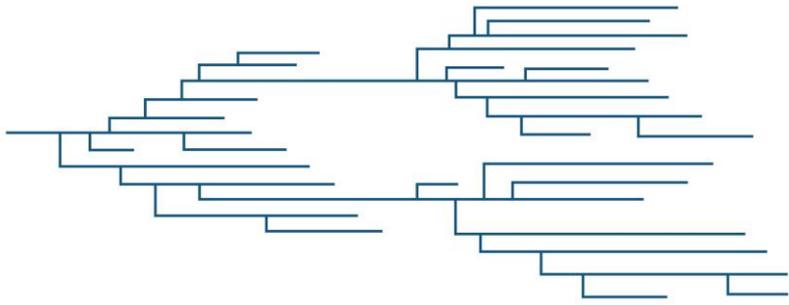


Figure 19 Amylopectin

Products in which starch is used include blancmange, sweets, sauces, dressings and bread. A key characteristic of starch is its ability to thicken products, giving them a better mouth-feel. It is therefore sometimes called a thickening agent. Starch can also form a kind of network, whereby the structure of the product remains stable longer, so that, for instance, a blancmange does not collapse.

**Assignment 15**

Explain whether the thickening properties of starch are the result of water attaching to the starch or the fact that the starch molecules interact with each other.

**Example 2: Dextran**

Dextran is a branched polysaccharide (Figure 20). It is produced on an industrial scale using lactic acid bacteria in bioreactors. Dextran consists of repeating units of glucose with glucose units as branches (in the diagram you can see 2 units of glucose; the dotted lines indicate where another glucose molecule can be attached). It is therefore a homoglycan. Dextran is used mainly as a thickening agent in emulsions.

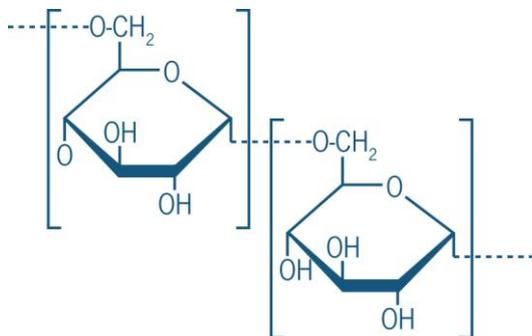


Figure 20 Dextran

### 2.4.3 Proteins

Proteins are present in all cells of all organisms. Some are building blocks, others regulate certain processes.

Based on the size of the molecule, a distinction can be made between:

1. Amino acids
2. Peptides
3. Proteins

Amino acids are the smallest units. These are the building blocks of the proteins. Peptides are short chains of amino acids. The difference between peptides and proteins is not very clear. As a rule of thumb, a peptide is at most 50 amino acids long.

#### Amino acids

Amino acids are the building blocks of proteins. Amino acids have an acid (carboxyl-) and a base (amino-) side and for this reason are called ampholytes. There are more than 200 types of amino acids in nature. Proteins, however, are only composed of 20 different types. (BINAS table 67C)

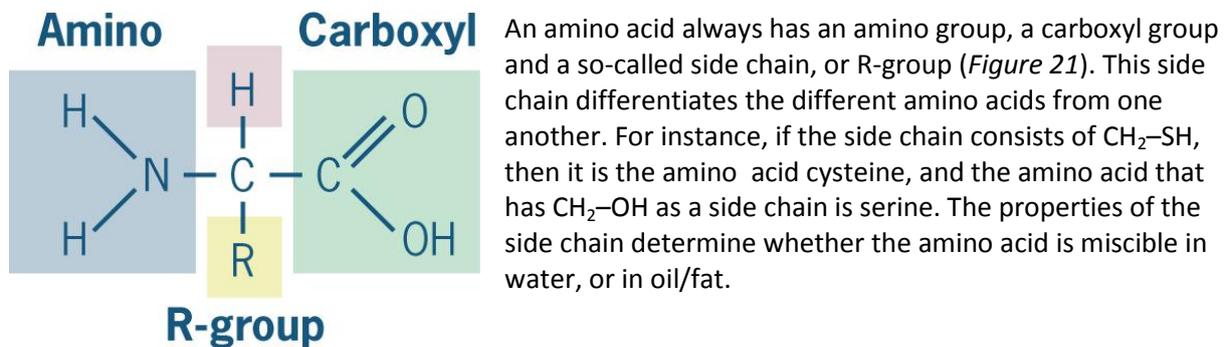


Figure 21 amino acid structure

#### Assignment 16 Amino acids in egg

An egg is composed of 75% water, but it also contains many proteins. The egg white is mainly water and the yolk mainly fat. Think about which amino acids from the table are present in the egg white and which in the egg yolk. Use BINAS to answer this question.

Amino acid	Egg white/Egg yolk
Serine	
Glycine	
Leucine	
Threonine	
Glutamine	
Valine	

## Peptides

A peptide is a chain of several interlinked amino acids. Peptides are similar to disaccharides and oligosaccharides in the carbohydrate group. Two amino acids are linked together by a bond between the COOH group of one amino acid and the NH<sub>2</sub> group of another. This bond is called the peptide bond (Figure 22).

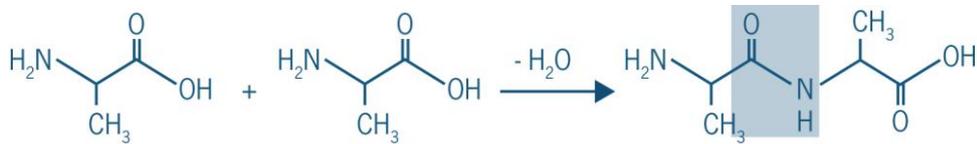


Figure 22 Peptide bond between two amino acids

## Proteins

In a protein the amino acids are linked together in a long chain. The side chains of the amino acids stick out of the chain. The sequence of amino acids in the chain is called the primary structure. This chain can form a spiral structure, or helix, which is called the secondary structure of a protein molecule. This spiral structure comes about because a hydrogen bond is created each time around the four amino acids between the C=O and the N-H of the opposing amino acids. This spatial zigzag structure arises because the peptide bond is not able to turn freely.

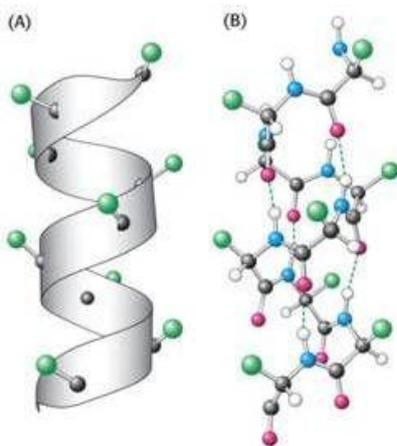


Figure 23 shows the helical shape of a protein. In Figure A the helix can be seen with side chains (green). Figure B shows the spiral with all atom groups.

A perfect spiral is present in proteins that have to ensure firmness. These powerful fibres can be found in skin, hair, fur, nails and hooves. They are also responsible for the firmness of, for example, steaks.

Depending on the side chains of the amino acids, the helix winds itself into a tertiary structure.

Figure 23 Protein: secondary structure

Various kinds of bonds emerge in various places between the amino acids:

- extra hydrogen bonds
- covalent sulphur bonds
- ionic bonds

These sorts of bonds are responsible for the formation of the tertiary structure, which is the final form of the protein (more about this structure later in the chapter on foams).

Proteins also form complexes with each other, whereby they 'stick' to each other by means of hydrogen bonds and/or ionic bonds. This is called the quaternary structure.

### Assignment 17 Amino acids

Which amino acids must a protein contain to be able to form the following bonds?

1. Hydrogen bonds
2. Sulphur bonds
3. Ionic bonds

Use table 67C in BINAS to answer this question.

## ***Cling-on Mussels***

15 August 2006 – Arjen Dijkgraaf

Explanation of chemical bond between mussel and various substrates

Mussels (*Mytilus edulis*) firmly attach themselves to almost any surface. As far as sticking power is concerned, their adhesive resembles most industrial products and is water- and salt-resistant too.

Researchers at Northwestern University (Evanston, Illinois) now think they know why. They have been investigating the amino acid L-3,4-dihydroxyphenylalanine (DOPA), the most important component of the mussel adhesive, with an atomic force microscope (AFM). By attaching one end of the molecule to the tip of the microscope and the other to a substrate, they were able to test the strength of the bond. This amino acid occurs in high concentrations in the proteins in mussels.

The molecule appears to be able to form very strong bonds with the atoms of other surfaces.

The researchers are to publish their findings this week in the online edition of PNAS.

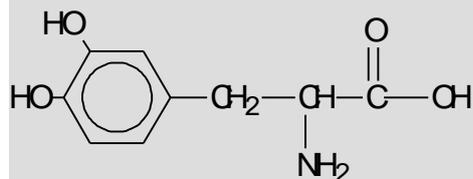
Source: C2W, 15 August 2006

**Source 4**

### Assignment 18 Mussel glue (from: *Chemie Aktueel* volume 18, no. 54)

Read Source 4.

Below is the structural formula for DOPA.



1. On the basis of the structural formula, explain what makes DOPA an amino acid. Depending on the pH the acid group and the amino group may relinquish or take up an H+. The OH groups on the benzene ring can also relinquish H+.

According to the article, DOPA is present in high concentrations in mussel proteins.

1. What is a protein?
2. Explain what happens on the molecular level 'when DOPA is present in high concentrations in protein'.
3. Draw the structural formula of a piece of protein in which two DOPA molecules are adjacent to each other.
4. In the sentence "A group of American scientists have discovered that the molecule can form strong bonds with the atoms of other surfaces", there is a chemical error. Explain why the term 'bond' is incorrect in this sentence.
5. Which word would you use in place of 'bond'?
6. Explain why a DOPA molecule can probably bind well to atoms of other surfaces. If necessary, draw the structure that results from this bond.

### Recipe: Steak marinated in kiwi

One way to make a steak more tender is to marinate it in kiwi puree.

#### Ingredients:

1 peeled kiwi  
1 steak (100 g)  
Oil  
Pepper and salt



Puree the kiwi with a hand-held blender. Place the steak in a bowl and cover it with the kiwi puree. Make sure that all the surfaces are coated with the kiwi puree. Leave the meat to marinate for 20 minutes, then take it out, pat it dry, and season with pepper and salt.

Grill the steaks on both sides until brown (approx. 1 minute). Leave the steak to cook further under aluminium foil. The steak is now ready to serve.

### Assignment 19 Steak marinated in kiwi

Read the above recipe.

The recipe states that the steak is made tender by being marinated in kiwi. This is because there are enzymes in kiwi.

1. What effect do you think these enzymes have on the meat proteins in the steak?
2. What do you think happens if the steak is left to marinate for too long in the kiwi puree?

#### 2.4.4 Fats

All fats have the same chemical structure. However, fats can contain different fatty acids. The fatty acid composition can be responsible for a difference in properties. Fats that are liquid at room temperature are usually called oils. Fats and oils are a useful store of energy in our body. Energy can also be stored in the form of glucose or glycogen, though fat is the most efficient in storing energy. For instance, per gram fat contains 9 kcal of energy, as opposed to the 4 kcal per gram of glucose. In the kitchen fat is a versatile ingredient. It provides a soft structure and helps bring out the taste of a dish.

#### Structure

Fats and oils are triglycerides with long apolar tails: they are composed of glycerol and three fatty acids (see figure 24), which link up when the water is released. The process of this linkage is called transesterification (or rearranging of the esters):

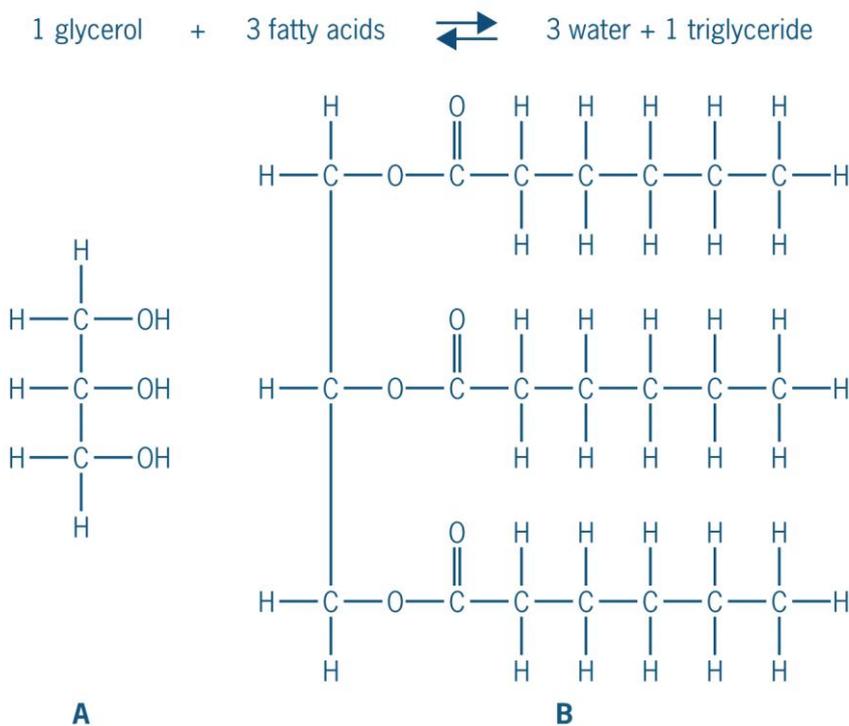


Figure 24 A glycerol and B a triglyceride: glycerol bound to 3 fatty acids

There are 50 different natural fatty acids. Glycerol dissolves in water, while in fatty acids it depends on the structure and fats do not dissolve in water.

#### Assignment 20

Fats contain C=O groups that accept hydrogen and can thus form hydrogen bonds. Why then does a fat not mix in water?

## Fats and saturation

In principle oils are liquid and fats are solid, even though they have the same molecular mass. The difference is in the saturation of the fatty acids that are bound to the glycerol. Unsaturated fat molecules have one or more double bonds between the carbon atoms in the chain (C=C); saturated fatty acids only have single bonds between the atoms in the carbon chain (C-C) (Figure 25). Saturated molecules are flexible and approach each other easily to form a strong Van der Waals bond. A double bond creates a rigid piece in the chain which is difficult to approach and so results in a weak Van der Waals bond. The weaker the Van der Waals bond between the molecules, the lower the melting point.

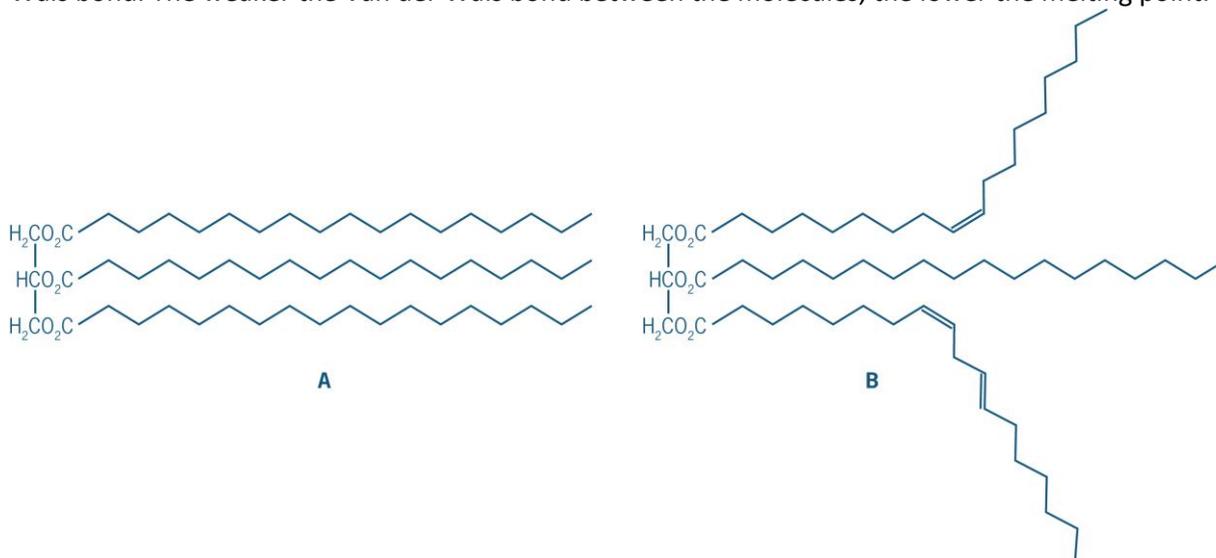


Figure 25 Saturated fat (structure A) and unsaturated fat (structure B)

### Assignment 21

When you look at Figure 25, which of the 2 fats do you think has the lowest melting point?

### Assignment 22

Vegetable fats contain 85% unsaturated fatty acids and 15% saturated fatty acids. Animal fats consist of 50% saturated and 50% unsaturated fats. Is vegetable fat solid or liquid at room temperature? What about animal fats? Explain your answer.

How can you make solid margarine from vegetable oils? By hydrogenating vegetable oil, i.e. letting it react with hydrogen, the double bonds are lifted and more saturation occurs (not 100%). This process is called setting. It is used to obtain the desired structure and shelf life. It is also used for making peanut butter. When you grind peanuts, you get peanut butter, but a layer of oil quickly forms. However, if you hydrogenate the oil, you obtain a blend that no longer separates.

### 3 Emulsions

Making mayonnaise yourself is a difficult process. It often fails. But why? It was once thought that pregnant women could not make mayonnaise. And that the stirring of the mayonnaise should always be done to the right, because if you did it to the left, the mayonnaise would separate. Another myth was that a left-handed man could not make mayonnaise.

Nowadays we know more about the product characteristics of mayonnaise and we know the microstructure. As a result we now know exactly why mayonnaise is so difficult to make.

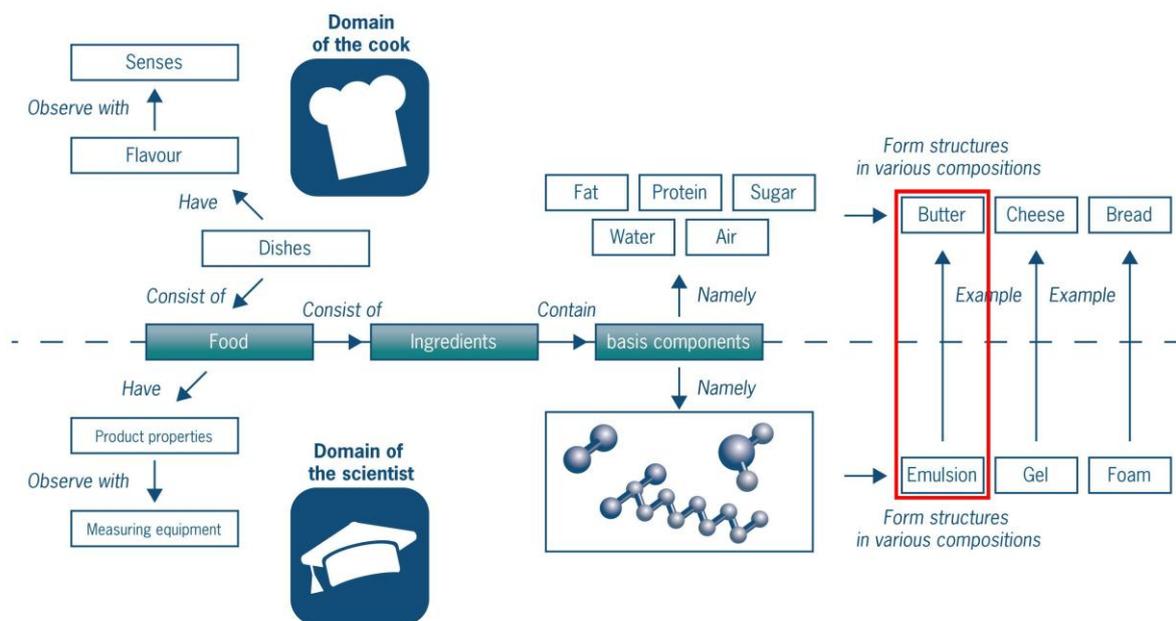


Figure 26 The red line

To give you an idea how mayonnaise is made, here is the recipe. You don't need to try it yet, that will come later in the practical course.

**A recipe for mayonnaise**

**Ingredients**

- 1 egg
- 1 tsp mustard
- ½ tsp salt
- 2 tbsp vinegar or lemon juice
- 3 dl sunflower oil
- pepper

**Instructions**

1. Mix the egg, mustard, salt and vinegar in a bowl.
2. Add the oil slowly to the mixture, stirring all the time.
3. Season with a little pepper.

If you add the oil too quickly to the contents of the bowl, the oil separates from the other ingredients. This process is called **shifting**. The separation occurs because the oil and the other ingredients do not mix. This is probably one of the main reasons why mayonnaise often fails. This mixing problem is one of the features of emulsions.

**'Emulsions'** is a collective noun for products like mayonnaise, yoghurt, milk, butter, margarine and salad dressings. An emulsion consists of two liquids (often oil and water) which are dissolved in one another on a microlevel. As explained in section 2.3 "From product characteristics to structures", the substances are not dissolved together at the molecular level, like sugar in tea, but at the microlevel. Emulsions have a number of common features on the microscale (1 micrometer is  $10^{-6}$  m).

### Learning goals

When you have gone through this section, you will understand why mayonnaise so often fails.

You will also know/be able:

1. explain why mayonnaise shifts and how this can be avoided.
2. the molecular interactions between water, fat and the emulsifier, that form the microstructure of an emulsion.
3. apply this knowledge of molecular interactions to butter and vinaigrette.
4. the key factors that affect the stability of emulsions

You will see that this knowledge can be applied in theory to all emulsions. You are going to use all this acquired knowledge in the last section, where you will be examining molecular gastronomical emulsions!

### Structure of this chapter

Sections:

- 3.1 *What is an emulsion?*  
The features of an emulsion.
- 3.2 *Water and hydrogen bonds*  
The role of water in an emulsion.
- 3.3 *Fats and hydrophobic interactions*  
The basic fat molecule.
- 3.4 *Emulsifiers*  
The role of emulsifiers in emulsions.
- 3.5 *Emulsions in the kitchen*  
Applying the previous sections in the kitchen.
- 3.6 *The stability of emulsions*  
Describes how the stability of an emulsion can be improved.
- 3.7 *Emulsions in the molecular gastronomical kitchen*  
Molecular gastronomical emulsions.

### 3.1 What is an emulsion?

What are the similarities between emulsions such as milk, salad dressing, butter and margarine? If you look at the list of ingredients on the package, you will discover that they all contain fats (in solid or liquid form), water and an emulsifier. Other ingredients are also added to affect product characteristics like colour, flavour or thickness.

In figure 26, the red line, you can see the pieces of the puzzle that go to make up an emulsion:

**An emulsion is composed of water and fat. Normally water and fat (or oil) don't mix. However, with the presence of a third substance, an emulsifier, they do.**

Mayonnaise contains at least 70% fat and more than 10% water. The water comes from lemon juice and the egg (an egg is 75% water). As the recipe states, you first place the water-based ingredients in the bowl. Then you slowly add the oil. The oil is 99% fat. The emulsifier in the mayonnaise is a component of the egg yolk.

What does mayonnaise look like under the microscope? Figure 27 shows mayonnaise that is magnified 500 times under the microscope. You can see the oil droplets in the water. Not all the droplets in the emulsion are the same size.

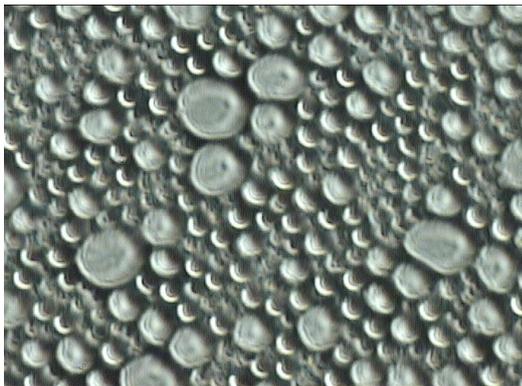


Figure 27 Mayonnaise magnified 500 x

The oil droplets are also called the **dispersed phase**. The water forms the **continuous phase**. The oil droplets are dissolved on a microscale in the aqueous phase. The emulsifier sits at the interface between the oil droplet and the water. Mayonnaise is therefore an oil in water emulsion, abbreviated to O/W emulsion. There are also emulsions in which the water forms the dispersed phase and the oil the continuous phase. These emulsions are called water in oil (W/O) emulsions (Table 5).

Table 5 Different emulsions

Food	Oil in water emulsion	Water in oil emulsion
Full-fat milk	x	
Whipping cream	x	
Vinaigrette		x
Mayonnaise	x	
Butter		x

## Assignment 1 Mayonnaise and chip sauce

### Nutritional value (per 100 ml):

Energy 2800 Kj (690 Kcal)  
Protein 1g  
Carbohydrates 3g (of which sugars) 3g  
Total fat 75g  
    *Saturated 6g*  
    *Mono-unsaturated 48g*  
    *Poly-unsaturated 21g*  
Fibers; less than 0.5g  
Sodium 0.37g

### Ingredients:

Vegetable oil, water, egg yolk (6%), sugar, vinegar, mustard, salt, aroma, antioxidant E385, pigment beta-carotene.

E = by the EU assessed for safe additives



### Nutritional value (per 100 ml):

Energy 1200 Kj (290 Kcal)  
Protein 1g  
Carbohydrates 10g (of which sugars) 6.3g  
Total fat 27g  
    *Saturated 2.1g*  
Fibers 0g  
Sodium 0.57g

### Ingredients:

Water, vegetable oil (25%), vinegar, modified starch, egg yolk, mustard, salt, thickener E415, preservative E200, aroma.

E = by the EU assessed for safe additives



Chips can be eaten with mayonnaise or chip sauce. Chip sauce is a W/O emulsion and mayonnaise an O/W emulsion.

1. Make a note in g/100g of the quantities of the basic components in the chip sauce and the mayonnaise.
2. Which substance acts as the emulsifier in the mayonnaise and in the chip sauce?
3. Which substance ensures that mayonnaise and chip sauce, despite the different concentrations of water and oil, have the same thickness?
4. What is the role of the ingredients sugar, salt and vinegar in the mayonnaise and in the chip sauce?
5. What would be the major advantage of 'reversing' an emulsion, as has occurred in chip sauce?

Why are emulsions usually **white** in colour? The white colour is caused by the particle size of the fat droplets in the mayonnaise. Water is clear (transparent) because the wavelength of light is greater than the diameter of the water molecules. Fat droplets, as present in mayonnaise, are about 1 micrometre in diameter, which is greater than the wavelength of light. Therefore, the light touches the fat particles and disturbs them. This causes the white colour. (The product that is ultimately made in the kitchen from the emulsion may well have a different colour. A cocktail sauce is an emulsion, but the addition of tomato ketchup makes it pink instead of white).

Most emulsions are **liquid**. Mayonnaise, salad dressing and yoghurt are all liquids. But there are exceptions: butter is a solid emulsion and ice-cream also consists of a combination of a foam and a solid emulsion.

#### Assignment 2 Characteristics of an emulsion

1. This section contained a description of various characteristics of an emulsion. Make a list of these characteristics.
2. Look at the structure of mayonnaise under a microscope. Indicate the aqueous phase and the oil phase of the mayonnaise.
3. What colour would an emulsion be, if you made the fat globules smaller than the wavelength of light?

### 3.2 Water and hydrogen bonds

Why do oil and water not mix unless an emulsifier is added? An emulsion consists of hydrophilic molecules (water), hydrophobic molecules (oil) and amphiphilic molecules (emulsifiers).

Water plays an important role in emulsions, particularly because oil and water don't mix. The process by which water forms hydrogen bonds was explained in chapter 2. This formation of hydrogen bonds is important, and will be elaborated upon in the next section when we take a look at fats.

#### Assignment 3 Hydrogen bonds

1. Draw the hydrogen bonds that appear when water is mixed with ethanol.
2. Why does fat not mix with water?
3. Explain why charged particles, such as ions, dissolve well in water.

### 3.3 Fats and hydrophobic interactions

Mayonnaise consists of at least 70% fat. Other emulsions like butter and yoghurt also contain fat. Therefore fat is one of the key components in an emulsion.

**Fats and oils have different melting points:** a fat is hard and an oil is liquid at room temperature (see chapter 2). Fats are mainly from animal sources, such as milk and meat. Oils are usually obtained from vegetable sources, such as olives and sunflowers. The structural formulas of fats are dealt with in section 2.4.4.

#### Assignment 4 Fats and oils

Answer the questions for the foods olive oil and butter (these figures are on the next page)

1. Indicate whether the product contains mainly saturated or unsaturated fatty acids.
2. Linoleic acid (C18:2) is a fatty acid that is present in olive oil (Figure 28).  
Elaidic acid (C18:1) is a fatty acid that is present in butter (Figure 29).  
Elaidic acid has a melting point of 43 °C; the melting point of linoleic acid is -5 °C.
  - a. Explain this difference in melting point using the structural formula of both fatty acids.
  - b. Explain why you expect elaidic acid to be present mainly in butter and linoleic acid mainly in olive oil.

Linoleic acid



Figure 28 Linoleic acid

Elaidic acid



Figure 29 Elaidic acid

Oil cannot form hydrogen bonds. It is a hydrophobic molecule. A hydrophobic molecule contains few charges and cannot make interactions with water. When oil is mixed in water, the network of hydrogen bonds that together form the water molecules is disturbed. This disturbance uses up energy that cannot be retrieved by the formation of new hydrogen bonds. The water molecules just around the surface of an oil droplet cannot make bonds with each other. However, in order to make a maximum number of hydrogen bonds, the water molecules arrange themselves in a cage-like structure around the oil droplets (Figure 30A). The maximum number of hydrogen bonds actually provides the system with an energetic advantage. This reorientation of the molecules can be seen in Figure 30B.



Figure 30A Cage shape



Figure 30B Water molecules around an oil droplet

When two oil droplets approach each other in water, they stick together.

In Figure 31, you can see how the number of hydrogen bonds and the freedom of movement of the molecules increases when two droplets of oil become one droplet. Since the surface of one joined droplet is smaller than that of the two separate droplets, the water molecules can form more hydrogen bonds, thereby obtaining more freedom to move.

The density of oil is lower than that of water. As a result of this difference in density, the fat droplets rise up from the water. The emulsion separates into a layer of water topped by a layer of oil.

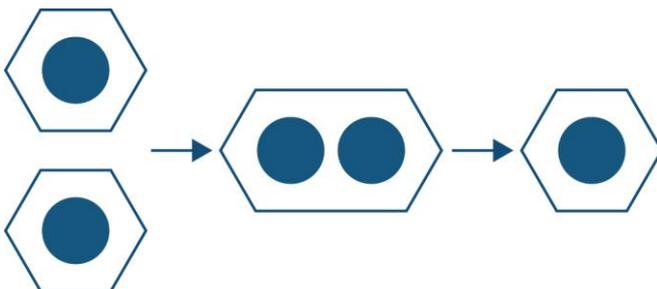


Figure 31 Reorientation of water molecules around oil droplets

### Assignment 5

You have made mayonnaise with oil droplets of 1 micrometer diameter. In this emulsion, the oil droplets comprise 70% of the total volume. Assume that the other 30% is water. You can assume that the oil droplets are round in shape.

1. What is the volume and surface area of 1 oil droplet in this mayonnaise?
2. How many droplets of oil are there in 1 litre of mayonnaise?
3. What is the total surface area of all these droplets together?
4. Imagine that the number of droplets is halved, because two droplets with a diameter of 1 micrometer merge to form 1 new droplet. The diameter of the new droplet is not 2 micrometers. The new droplet is twice the volume of the old droplet. What is the total surface area of the newly formed droplets?

### 3.4 Emulsifiers (surfactants)

Why is egg yolk, aside from oil and water, such an important ingredient of mayonnaise? It is because egg yolk is the emulsifier. An emulsifier is also called a surfactant.

An emulsifier is an amphiphilic molecule. An amphiphilic molecule reacts with both hydrophobic and hydrophilic molecules. In the case of mayonnaise, lecithin, which is present in the egg yolk, is the emulsifier. Lecithin is a collective name for a series of molecules that have an emulsifying effect.

There are about 5 grams of lecithin in one egg yolk. One of the emulsifiers in lecithin is phosphatidylcholine (Figure 32). Phosphatidylcholine has a hydrophobic tail and a hydrophilic head. The hydrophilic head will have interactions, such as hydrogen bonds, with water, and the hydrophobic tail will interact with fat and oil. You can make litres of mayonnaise with the yolk of just one egg.

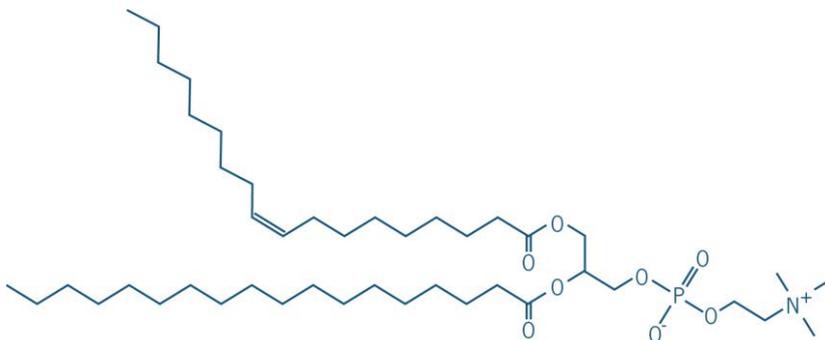


Figure 32 Phosphatidylcholine

A molecule like phosphatidylcholine interacts both with water and oil and in so doing positions itself on the interface of water and oil, see Figure 33. The emulsifier (3) sits with its apolar tail in the fat (2) and with the polar head (the green ball) in the water (1). The function of the emulsifier can be compared with the function of the stearate molecule in soap. This is described in Chapter 2: The Basis.

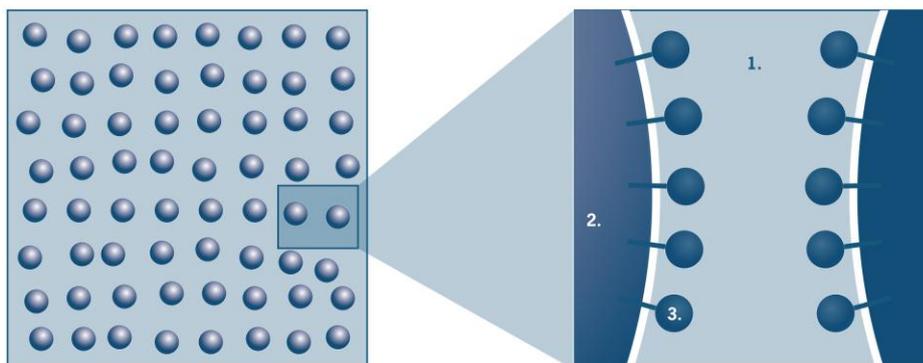
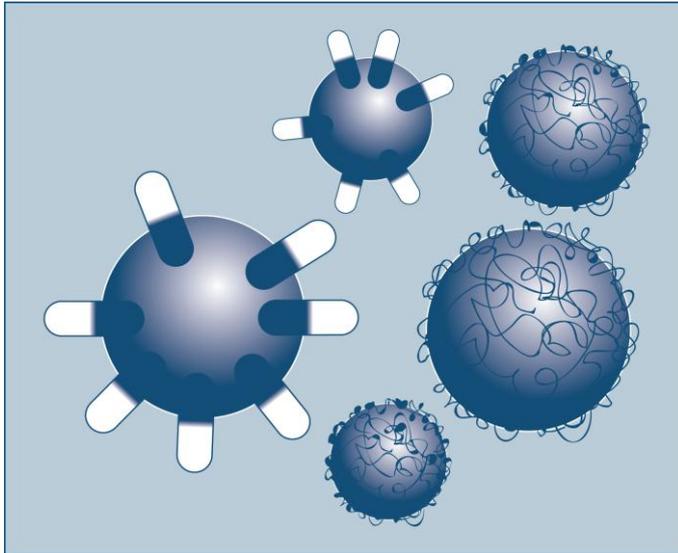


Figure 33 Mayonnaise with the emulsifier (3) on the interface between oil droplet (2) and water (1).

An important group of molecules which also have an emulsifying effect are the proteins. Some examples are soya proteins, gelatin, ovalbumin and milk proteins.

There is an important difference between the proteins and the emulsifiers like phosphatidylcholine mentioned above. As you read in section 2.4.3, proteins consist of a chain of amino acids. One protein is composed of multiple amino acids. Thus, proteins are macromolecules. A protein is therefore much bigger than an emulsifier like phosphatidylcholine. This difference in size means that there are several hydrophilic and hydrophobic parts in proteins instead of one hydrophilic head and one hydrophobic tail per molecule. The hydrophilic parts of the protein stick more in the water and the hydrophobic parts more in the oil (*Figure 34*).



*Figure 34 An O/W emulsion with top left two oil droplets surrounded by molecules of an emulsifier like lecithin; on the right three oil droplets surrounded by proteins like emulsifier.*

There are two types of emulsion: O/W and W/O emulsions. The type of emulsifier largely determines which of these two emulsions is formed, because each emulsifier has, despite being amphiphilic, a slight preference for either the oil phase or the aqueous phase. This preference is expressed in the hydrophilic/lipophilic balance, also called HLB. The HLB scale ranges from 0 to 20. When an emulsifier has a low HLB value (3-6), it means that the emulsifier has a preference for the oil phase. A high HLB value favours the aqueous phase.

The following formula is used to determine the **HLB value** of molecules:

$$\text{HLB} = 20 * (M_w/M_o)$$

$M_w$  is the molecular weight of the hydrophilic part of the emulsifier and  $M_o$  is the molecular weight of the total emulsifier. (It is multiplied by 20 to get to the scale of 0 to 20; this scale is arbitrarily chosen).

### Assignment 6

1. Indicate the hydrophilic and the hydrophobic part of phosphatidylcholine in the structural formula (Figure 32).
2. Indicate the hydrophilic and the hydrophobic part of the following emulsifiers:

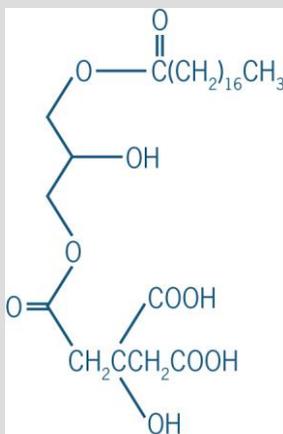


Figure 36 Citric acid ester  
These ester molecules are used as emulsifiers in amongst others margarine

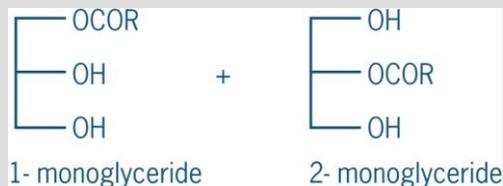


Figure 35 Mono-glycerides

Mono-glycerides are commonly used to stabilise emulsions like ice cream and margarine

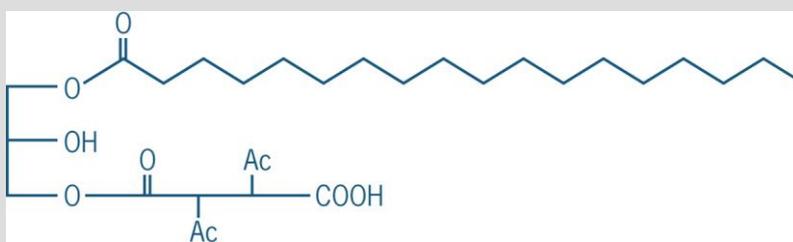


Figure 37 di-acetyl-tartaric-acid ester, commonly used to improve the stability of salad dressings

### Assignment 7

In Chapter 2: The Basis, the action of soap was explained with the help of a diagram.

Draw the structural formula of the soap molecule stearate (stearic acid), see BINAS table 67B1. Indicate on the drawing where the hydrophilic and hydrophobic part of this molecule is situated. Indicate also where the molecule is positioned on the air-water interface.

### Source 5

#### Detergent of peptide basis can be activated and deactivated by pH

by: Arjen Dijkgraaf

Wednesday 22 August 2007

Australian scientists have developed peptide-based surfactants, which can be activated or deactivated by changing the pH of the solution. One of the applications of this would be a washing detergent that will work on a very short rinse cycle, according to Annette Dexter and Anton Middelberg (University of Queensland) during the American Chemical Society Conference in Boston.

The idea is that the detergents in washing powders are already connected such that the pH during the washing cycle is different from that during the rinse cycle. If 'pepfactants' are added to deactivate the soap activity during rinsing, much less water is needed to rinse away the already loosened dirt.

The pepfactants could also be incorporated in eye drops. They are milder than the usual surfactants, and they can also be used in such a way that the emulsion immediately breaks upon contact with the pH of the eye.

Another application is in the separation of petroleum and water. Such emulsions are usually very difficult to break. Thanks to pepfactants it would be possible to 'rinse' much more oil out of an almost exhausted source, whereby the detergents employed could be re-used again and again.

According to Dexter, the problem is that pepfactants cost 500 dollars per kilo. Normal detergents can be bought for 10 dollars..

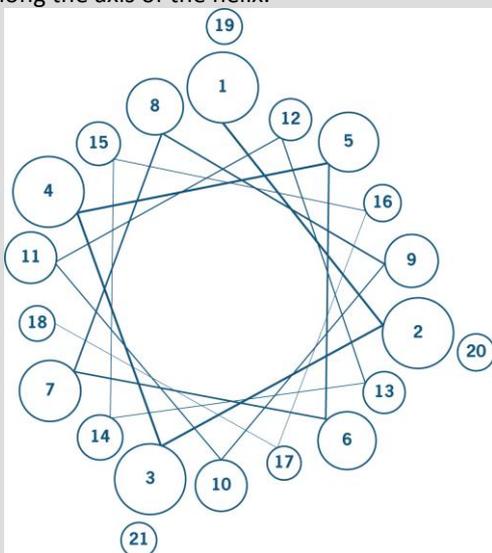
Source: [www.c2w.nl](http://www.c2w.nl)

**Assignment 8 Zap soap (from: Chemie Aktueel volume 19, no. 57)**

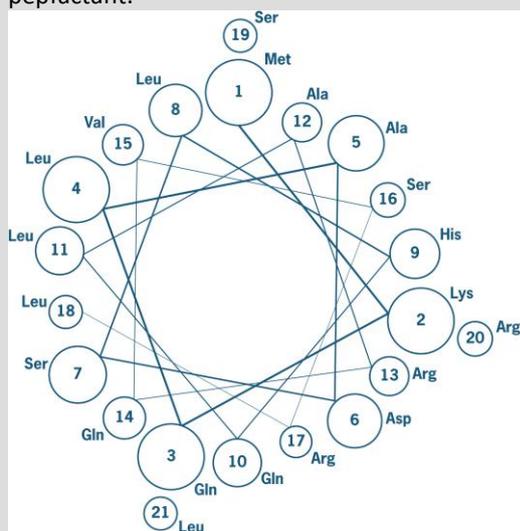
Read Source 5.

Annette Dexter and Anton Middelberg have made a 'pepfactant'. The word pepfactant is a combination of the words peptide and surfactant (substance that lowers the surface tension of a liquid). The peptide consists of 21 amino acids with the abbreviation Ac- M K Q L A D S L H Q L A R Q V S R L E H A -CNH<sub>2</sub>. In this, Ac represents the carboxyl end and CNH<sub>2</sub> the amino end of the peptide. The letters in-between represent the amino acids from which the peptide is composed. See table 67C1 in BINAS for the coding of the amino acids.

1. Draw the "SLHQ" segment of the peptide chain in structural formula.
2. A peptide is a helical structure. Explain why a peptide can form a helix. (See section 2.4.3)  
Below you will see a representation of a helical wheel to help you study the 3D-structure of a peptide. Copy the peptide Ac- M K Q L A D S L H Q L A R Q V S R L E H A -CNH<sub>2</sub> onto a piece of paper and number the amino acids from left to right. Compare this with the helical wheel. The 'wheel' is what you see if you look along the axis of the helix.



In the figure below, the 3-letter abbreviations for the amino acids appear in the helical wheel of the pepfactant.



3. In the helical wheel indicate with an A or a P whether the side group of the amino acid is hydrophobic or hydrophilic. (A=apolar P=polar). See BINAS.
4. Using the answer to question 3, explain how the helix can be used as a soap.
5. Why will the pepfactant not be used on a large scale in the short term?

### Assignment 9 HLB values

1. An emulsion is stable when the emulsifier dissolves well in the continuous phase. Explain what type of emulsion (W/O) or (O/W) is formed with emulsifiers with a low HLB value and which with a high HLB value.
2. Look at the ingredient label of AdeZ, chocolate milk and Becel light (Figure 38-40). Fill in the table below (Table 6):
  - a. Which ingredient is the emulsifier? The names of the ingredients with E numbers can be found in BINAS table 82C.
  - b. Is the product an oil in water emulsion or a water in oil emulsion (use the HLB number that is already entered in the table)?
  - c. In addition to the molecular emulsifiers in the products, there are also proteins present as emulsifiers. For each product write which protein can also act as an emulsifier.

Table 6 Emulsifiers

Product	Emulsifier	HLB	Emulsion type	Proteins
Chocolate milk Frische Vlag		8.0		
AdeZ		8.0		
Becel light		3-6		

3. A chef comes to you with an idea for making a prawn mayonnaise. Some of his clients are allergic to egg protein, so he doesn't want any eggs in his mayonnaise. He is looking for another emulsifier. Give the chef some substantiated advice about which emulsifier would be suitable.

### Ingredients:

Water, fruit juice concentrate (16.5%) (grape, apple, mango (1.8%) peach (1.5%)), sugar, soy-protein (1.1%), citric acid, minerals, vitamins (C, B6, B2, B1), stabilizer (pectin), soy-oil, emulsifier (soy lecithin), artificial sweeteners (sucralose, acesulfame-K), colouring (beta-carotene)

Figure 38 Ingredients AdeZ

### Ingredients:

Skim milk, whey, sugar, cream, cocoa (1.7%), stabilizers: E471, carrageenan, guar gum, aroma

Figure 39 Ingredient Chocolademilk

### Ingredients:

Water, vegetable oil, gelatine, emulsifiers (E322, E471), preservative E202, vitamins (E, B6, A, folic acid, D, B12), aroma's, colouring E160a

Figure 40 Ingrediënten Becel light

## Low-fat mayonnaise can be much tastier

No. 1 March 2010

Source 6

Emulsions, like mayonnaise, are becoming more low-fat, tastier and longer lasting thanks to a very promising new technology. Koen van Dijke has developed a method for the chair group Food Processing Science at Wageningen University, where he graduated with a PhD in November 2009.

Emulsions from immiscible liquids, such as oil and water, are present in everyday food items like milk, low-fat margarine and mayonnaise. "Current methods of mixing use a lot of energy and do not always give the best result", says van Dijke. "With this new microscale system, we allow a very thin film of oil to flow into water. This produces oil droplets, about two thousand per second, that mix with water." These emulsions seem to be more homogeneous than current emulsions and the production process uses far less energy. In addition, double emulsions can be made using this method. So you could make a super low-fat mayonnaise which tastes the same as its full-fat equivalent.

**Source: Wageningen World**

### Assignment 10 Double emulsions

Read the above newspaper article.

Now you have looked at O/W and W/O emulsions, but more and more experiments are being conducted with emulsions. One of the latest developments in the field of emulsions is a so-called double emulsion, as described in the newspaper article.

1. Draw the microstructure of the double emulsion mentioned in the text. Clearly indicate what is water and what is oil.
2. What would you call this double emulsion? An O/W/O emulsion or a W/O/W emulsion?

For the double emulsion in the text, a lot of force is used to make extra small oil droplets. There is an alternative way of making double emulsions, with the HLB values of emulsifiers.

3. How do you think you can make a double emulsion using your knowledge of the HLB values?
4. Will the microstructure of this double emulsion be the same as that of the emulsion you drew in 1.?
5. Which of these 2 methods do you think is the most suitable for making double emulsions?

### Assignment 11 How much egg yolk is required to make mayonnaise?

1. Relatively little egg yolk is needed to make a lot of mayonnaise. You are now going to work out precisely how much mayonnaise you can make with one egg. Start with the following data:
  - a. There is about 5 g emulsifier in one egg (this is 0.025 mol)
  - b. The emulsifier takes up about  $1 \text{ nm}^2$  per molecule
  - c. The oil droplets in the mayonnaise have a radius of 10 micron ( $= 1 \times 10^{-5}$  metre).
  - d. Start from the assumption that the entire surface of the oil droplets is covered with emulsion.
2. In the previous question you started on the assumption that only the quantity of emulsifier in the egg yolk determines how much mayonnaise you can make, but this is not entirely true. What else could you add more of to make an equal amount of mayonnaise with one egg?
3. If you assume that the thickness of the layer of water around the oil droplets is 0.1 micron ( $= 0.1 \times 10^{-6}$  metre) and that there is about 100 ml water in egg yolk, how many litres of mayonnaise can you make without adding water?  
(Remember, the amount of water required for each droplet is the surface area of that droplet multiplied by the thickness of the layer of water)

### 3.5 Emulsions in the kitchen

In the previous section you looked at emulsions at the molecular level. In this section you will be looking at a number of examples of emulsions in the kitchen.

#### 3.5.1 Cream and butter

Milk can be made into cheese, custard, yoghurt, ice-cream, milk foam (for cappuccinos), milk powder, condensed milk, not forgetting butter and cream, the dairy products which we will be examining in this section. Figure 41 shows how some dairy products are made from milk.

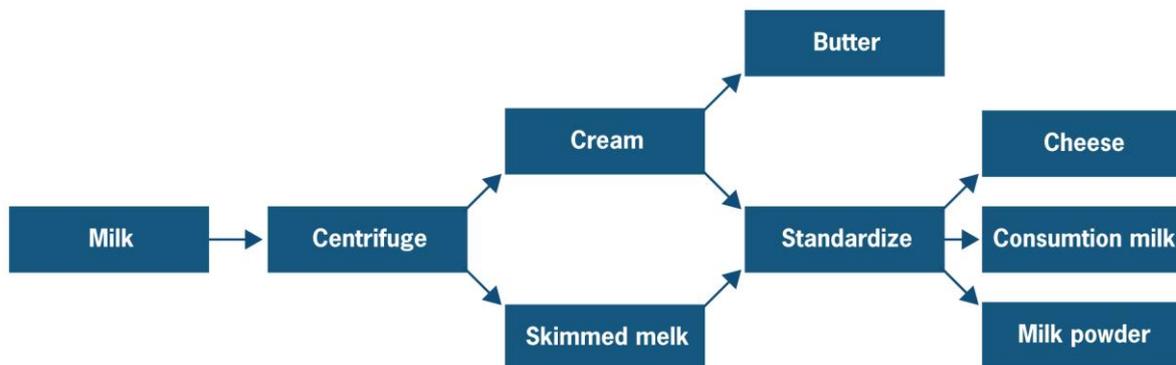


Figure 41 Milk and milk products

First, the milk is centrifuged to separate it into cream and skimmed milk. Butter can be made from the cream. The cream can also be mixed again with the skimmed milk. This mixing process is also called standardisation, because it occurs in a fixed ratio. In this way milk with precise fat percentages can be made: full-fat milk contains more cream than semi-skimmed milk.

Butter is an emulsion, but a special one: it is actually a solid rather than a liquid emulsion.

In this section you will take a closer look at the microstructure of butter and the way in which water, oil and the emulsifier in butter are arranged.

Table 7 shows the composition of cream and butter. Like mayonnaise cream is an oil in water (O/W) emulsion. Butter is a water in oil (W/O) emulsion.

Table 7 Composition of cream and butter

Component	Quantity in cream (%)	Quantity in butter (%)
Water	69.5	17.2
Fat	20.0	82.0
Lactose	5.0	0.2
Protein	3.5	0.6

The microstructure of cream is visible in Figure 42. The key components are the fat droplets (dispersed phase) and the water (continuous phase). Milk proteins and lactose, among other things, are dissolved in the water; this liquid is also called the plasma of the milk. A special membrane made up of several layers of proteins is positioned between the fat droplets and the aqueous phase. This membrane is in fact the emulsifier in the cream, similar to the molecular emulsifiers in the previous section. The proteins sit at the interface of the plasma and the fat droplets.

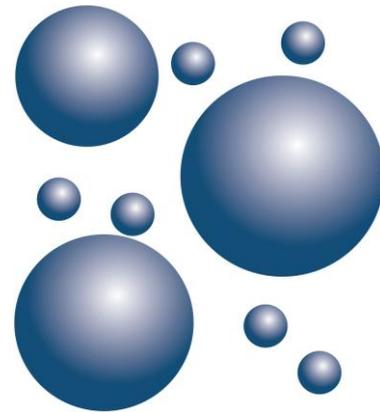


Figure 42 Microstructure of cream

Butter is a solid water in oil (W/O) emulsion and cream is a liquid oil in water (O/W) emulsion.

How do you make butter from cream?

- You have to make a solid emulsion from a liquid emulsion.
- You need to ensure that the O/W emulsion becomes a W/O emulsion.

How can you ensure that these changes take place? By using the characteristics of the components that we have.

Start with the characteristics of the fat molecules. The fats in milk consist mainly of saturated fatty acids, like animal fats in general. Vegetable fats consist for the most part of unsaturated fatty acids. Saturated fats have a high melting point. Table 8 gives a list of the fatty acids present in cream and their melting point. The molecular formulas of the fatty acids can be expressed as Ca:b, where a is the number of carbon atoms in the chain, b is the number of double bonds in the chain. Because of the difference in melting point, part of the fat in milk is always liquid and part solid. The solid part is also called the crystal form. This fraction (the proportion of fat in crystal form) increases as the temperature falls. If you cool cream to about 14 °C, a certain percentage of the fats will become solid (i.e. will assume the crystal form), and the liquid emulsion will become a solid emulsion.

Table 8 The fatty acid composition of cream fat

Fatty acids	Molecular formula of the fatty acids	Percentage of the total fat (%)	Melting point (°C)
Butyric acid	C4:0	9.5	-8
Capronic acid	C6:0	4.1	-4
Caprylic acid	C8:0	0.8	16
Caproic acid	C10:0	3.2	31.5
Lauric acid	C12:0	2.9	44
Myristic acid	C14:0	11.5	54
Palmitic acid	C16:0	26.7	63
Stearic acid	C18:0	7.6	70
Arachidic acid	C20:0	1.8	75
Palmitoleic acid	C16:1	4.3	0
Elaidic acid	C18:1	22.4	43
Linoleic acid	C18:2	3.1	-5

In order to change the O/W emulsion into a W/O emulsion, you use a different property of the fat. The fat in the cream has a greater affinity for an air phase than for an aqueous phase. It is therefore a case of choosing the least bad option, whereby the fat droplets in cream favour the air phase. When you beat air bubbles into the cream, the fat will therefore go to the interface of the air and the cream (Figure 43 step 1; the stripes on the fat globules represent partially hardened fat).

On the water-air interface they spread some of their liquid fat and a part of their membrane over the air bubble (*Figure 43. step 2*). Due to the high concentration of fat, several fat globules stick to one air bubble. The air bubbles move through the liquid and collide. The films of the air bubbles are unstable due to the fat layer, so two air bubbles merge (coalesce). This makes their surface area smaller and the present fat globules are driven towards each other. The liquid fat now works as an adhesive, sticking the fat globules together (*Figure 43. step 3*; a little liquid fat may remain). If you continue to beat the cream, the coagulation will take over: this beating is called **churning**.

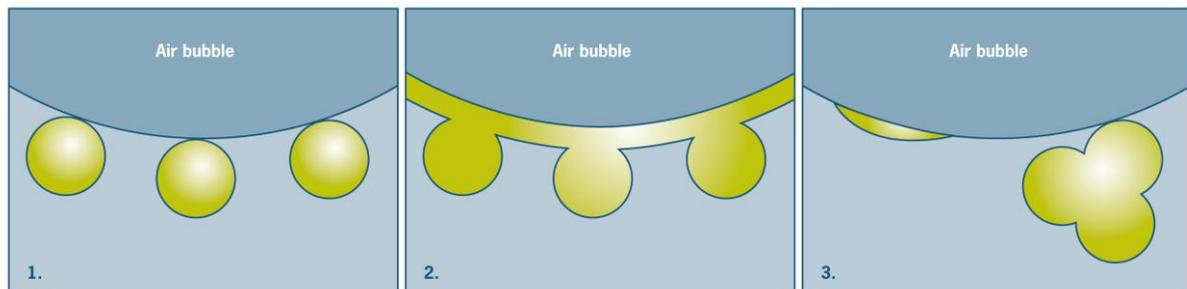


Figure 43 Churning butter

The clots now take part in the churning process, creating bigger clots. The bigger they become, the more direct collisions occur between them and clots grow without the need for air bubbles. More liquid fat is released and at the end of the churning process, there are few air bubbles left, because there are too few fat globules to stabilise the air bubbles. Thus, a network of clotted fat globules is formed that 'envelops' the aqueous phase. At the end of the churning, you have formed a continuous phase of fat, with a few water droplets in-between. The emulsion has been converted from an O/W emulsion to a W/O emulsion; the cream has been transformed into butter. The complete process of butter-making is shown schematically in Figure 44 (Yellow: fat, white: air, blue; water).

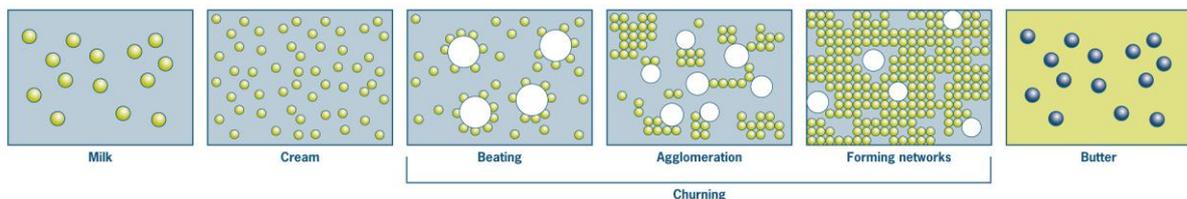


Figure 44 From cream to butter

### Assignment 12 Butter comes in many guises

When you walk through a supermarket, you will notice that there are a great many different types of butter. It is also striking that nowadays there is more and more 'low-fat' butter (e.g. low-fat margarine, Becel light, etc.) on the market.

1. Calculate how many kcal per 100 g there is in butter and in low-fat butter, assuming that butter contains about 80% fat and 20% water, low-fat butter 40% fat and 60% water, and that fat contains 9 kcal per gram and water 0 kcal per gram.
2. These low-fat butters are made by reversing emulsions, thus producing an O/W emulsion. What will play an important role in keeping these types of butter stable? (something that plays hardly any part in normal butter; think about what can go wrong when making mayonnaise).

Apart from its use as a spread for bread, butter is also used a lot in the kitchen for cooking. Either as an ingredient or for cooking ingredients in. Low-fat butter is never used for this purpose.

3. Why do you think it is not possible to use a low-fat butter for cooking?
4. How would you resolve this problem?

In addition to butter and low-fat butter, there is also margarine. Like butter, margarine also contains around 80% fat. The main difference is that margarine is made from vegetable oil and butter is made from milk.

5. What is the advantage of using vegetable oil instead of milk fat as in butter?
6. Could you use margarine for cooking?

### **Make your own butter!**

Heat up 500 ml raw milk to 40 degrees; let it cool and put the milk in the fridge overnight. Next day, separate the cream from the skimmed milk (the milk without fat). Put the cream in a jam jar and get shaking. The fat in the cream will clot and you have made butter. You can buy the raw milk from a farmer.

### **3.5.2 Vinaigrette**

Vinaigrette is a French salad dressing. The basis consists of approximately 1/3 water and 2/3 oil. The aqueous phase consists mainly of vinegar. A vinaigrette is easy to make. The oil, vinegar and other ingredients such as pepper, salt and herbs, are shaken together to create a cloudy emulsion. The vinaigrette is immediately poured over the salad, before the emulsion has time to separate. A vinaigrette can be an O/W or a W/O emulsion.

#### **Assignment 13 Vinaigrette**

1. Salad leaves are also hydrophobic. Give reasons for which type of vinaigrette (W/O or O/W) is most suitable for making salads.
2. Draw the microstructure of this vinaigrette. Indicate the position of the oil, the water and the emulsifier.
3. When salad leaves are cut, the cell fluid which is largely water, is released from the salad cells. Explain which type of vinaigrette (W/O or O/W) is suitable for cut salad.
4. Draw the microstructure of this vinaigrette. Indicate the position of the oil, the water and the emulsifier.

The O/W emulsion and the W/O emulsion are not very alike. The first variant is thick, contains big particles and is white; the latter is transparent and much thinner. The product characteristic thickness is also called **viscosity**. Viscosity is a measure of the amount of energy lost when a liquid flows. The energy is lost because the liquid molecules rub together (friction) when they move alongside each other. The more friction takes place, the higher the viscosity.

You can calculate the viscosity of a liquid in the following way. Imagine you have two plates, with a liquid between them (Figure 45). One plate moves while the other does not.

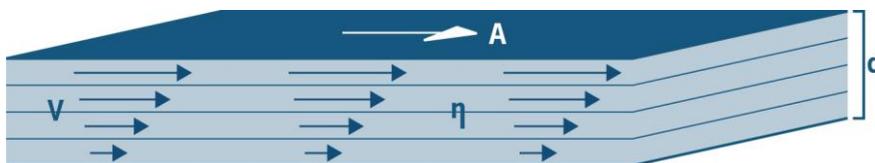


Figure 45 Two plates with a liquid between them. The factors that affect the force are represented.

If there were no friction, you would not need to exert any force on the moving plate. In practice, however, friction does take place. So a force is needed.

This force depends on the following factors:

- The surface area of the plates:  $A$
- The distance between the plates:  $d$
- The speed with which the plates move:  $v$
- A constant, that depends on the extent of friction between the molecules. This constant is also called viscosity –  $\eta$

The above can also be expressed as a formula:

$$F = \frac{A \cdot v \cdot \eta}{d}$$

#### **Assignment 14 Viscosity**

Rank the following products from high to low viscosity:

mayonnaise, water, tomato ketchup, peanut butter, salad dressing, milk

### **3.6 Stability of emulsions**

An emulsion is stable if the two phases mixed with each other do not separate again. The process of separation is also called 'shifting'. In the case of mayonnaise the two phases are oil and water. When the oil and water phase of the mayonnaise separate, you get shifted mayonnaise. This looks unappealing.

If you want to make a molecular gastronomical dish with new ingredients, it is important to know about the factors that affect the stability of your food. You can put a lovely sauce on the table with new ingredients or flavours, but if the sauce starts to shift after five minutes, the effect is lost.

You can calculate the stability factors. Begin by checking which forces are exerted on one single droplet of oil in mayonnaise or in a salad dressing. Which physical forces affect this droplet?

Think of a motionless drop of oil in an aqueous environment. There are two forces constantly being exerted on the droplet. Gravity pulls the droplet downwards and buoyancy pushes the droplet upwards. The latter force equals the weight of the displaced water and so should be greater than gravity because oil is lighter than water. The droplets should therefore move. Or, put more scientifically: there is a resultant that ensures upward acceleration.

The droplet therefore gains speed and this speed increases. But moving objects in a medium always experience resistance. This is because the molecules of the object and of the medium exert forces on each other.

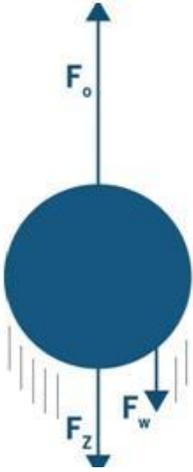


Figure 46 shows the forces exerted on the droplet.

Buoyancy and gravity do not change, and only depend on the size of the droplet and the densities of both liquids. The resistance, however, does change: the greater the speed, the greater the resistance. The resultant and also the acceleration diminish as the resistance increases.

What is remarkable here is that the acceleration itself is responsible for reducing the acceleration. The acceleration digs its own grave! The resistance reacts very quickly to the changes in speed and therefore changes take place relatively quickly. In practice you see droplets of oil in water rising to the top with a constant speed.

Figure 46 The forces that are exerted on a rising emulsion droplet.

What does this constant velocity depend on?

The answer to this question requires further explanation of the above analysis with formulas.

Using Figure 46 and the above analysis, it can be established that where there is a uniform motion of the oil droplet:

$$F_o - F_z = F_w \quad (1)$$

If these forces are described as a function of radius, densities, velocity and viscosity of water, you get a comparison. From this you can deduce how the velocity depends on the radius and the densities of oil and water and on the viscosity of the water.

### Gravity

The following applies to gravity:

$$F_z = m_{oil} \cdot g$$

$$F_z = \rho_{oil} \cdot V \cdot g$$

$$F_z = \rho_{oil} \cdot \left(\frac{4}{3} \pi \cdot r^3\right) \cdot g$$

Therefore

$$F_z = \frac{4}{3} \pi \cdot \rho_{oil} \cdot g \cdot r^3 \quad (2)$$

### Buoyancy

Archimedes' principle applies to buoyancy:

#### **Archimedes' principle**

*"Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object."*

$$F_o = m_{water} \cdot g$$

$$F_o = \rho_{water} \cdot V \cdot g$$

$$F_o = \rho_{water} \cdot \left(\frac{4}{3} \pi \cdot r^3\right) \cdot g$$

Therefore

$$F_o = \frac{4}{3} \pi \cdot \rho_{water} \cdot g \cdot r^3 \quad (3)$$

### Frictional force

How much friction will the oil droplet experience and on which factors does this friction depend?

The following factors play a role:

- The viscosity of the liquid.  
A thick liquid creates more friction than a thin liquid.
- The velocity of the oil droplet.  
The higher the speed, the more friction takes place.
- The size of the oil droplet.  
The bigger the droplet, the greater the frictional force.

These three factors are summarised in **Stokes' law**. Stokes established that the relationship between the frictional force ( $F_w$ ) and the named factors, the viscosity of the liquid ( $\eta$ ), the velocity ( $v$ ) and the size ( $r$ ) of the emulsion droplet – can be expressed as follows:

$$F_w = 6 \cdot \pi \cdot \eta \cdot v \cdot r \quad (4)$$

From comparisons 1 to 4, it now follows that:

$$\frac{4}{3} \cdot \pi \cdot r^3 \cdot \rho_w \cdot g - \frac{4}{3} \cdot \pi \cdot r^3 \cdot \rho_o \cdot g = 6 \cdot \pi \cdot \eta \cdot v \cdot r \quad (5)$$

If you use the diameter ( $d$ ) instead of the radius ( $r$ ), it can be deduced that:

$$v = \frac{(\rho_w - \rho_o) \cdot g \cdot d^2}{18 \cdot \eta} \quad (\text{try and deduce this yourself}) \quad (6)$$

Symbol	Meaning	Unit
$v$	velocity	$\text{ms}^{-1}$
$\rho_w$	density continuous phase	$\text{kgm}^{-3}$
$\rho_o$	density dissolved phase	$\text{kgm}^{-3}$
$g$	gravitational acceleration	$\text{ms}^{-2}$
$d$	diameter of the droplet	m
$\eta$	viscosity	Pa s

#### Assignment 15

Enter the unit for all symbols in the deduced formula and see if you also come up with the unit of velocity.

This formula for calculating the velocity applies to all emulsions with droplets bigger than  $1\ \mu\text{m}$ , i.e. for fat droplets in milk, mayonnaise and vinaigrettes.

### Assignment 16 Making vinaigrettes

Soon after making a vinaigrette a chef will notice that it is not stable. So the time between making the vinaigrette and putting it on the table should not be too long.

1. Describe in your own words what happens to a vinaigrette once it is no longer stable.  
The vinaigrette is made as follows:
  - I. One tablespoon of vinegar, one tablespoon of cold strong stock, half a teaspoon of salt and pepper to taste are mixed together in a bowl.
  - II. Then the olive oil is slowly added.
2. On the basis of this description, explain what type of emulsion is formed (W/O or O/W).
3. The chef would like to know how long the vinaigrette can be left to stand before it separates. For this you need to know the velocity of the oil droplets in the vinaigrette. The oil droplets in the vinaigrette have a diameter of  $50\ \mu\text{m}$  (Figure 47). The viscosity of water is  $1 \cdot 10^{-3}\ \text{Pa s}$ . Calculate the velocity of the oil droplets in the vinaigrette.

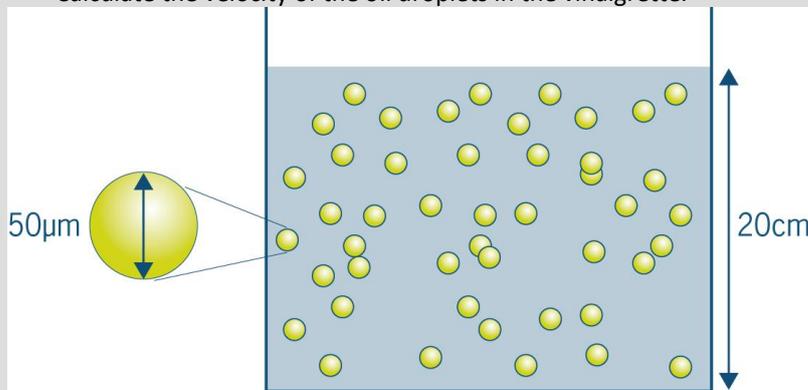


Figure 47 Vinaigrette

4. Calculate how long it will be before the vinaigrette is completely separated. The container in which the vinaigrette is placed is 20 cm high. The oil droplets are uniformly distributed, so the average distance that one droplet covers is 10 cm.
5. Ready-made vinaigrettes from the shops have to stand longer than those in the kitchen. The industry therefore uses thickening agents, such as xanthan, to make the vinaigrette thicker. By adding xanthan, the viscosity of the continuous phase is increased. Calculate how high the viscosity has to be to keep the vinaigrette stable for six months.

## 3.7 Emulsions in the molecular gastronomical kitchen

Armed with your knowledge about the molecular properties of fats, water and emulsifiers, you are going to look at some molecular gastronomical emulsions.

### 3.7.1 Making molecular butter

Butter has the awkward characteristic of being too hard to spread on bread when taken straight from the fridge. How can molecular gastronomy help the cook to adapt this product characteristic of butter to his dish? In his book 'Molecular Gastronomy' Hervé This described how this is possible.

Take a careful look at table 8 in section 3.5.1, which lists the various fats present in butter, along with their melting points. In contrast to water, which melts at 0 °C, butter has not one but several melting points; this is called a melting trajectory. The melting trajectory of butter ranges between -50 °C and +40 °C. At 4 °C, 70% of butter is present in solid form, and at 30 °C, 10%.

Butter can be divided into three fractions on the basis of its melting point:

- The first fraction consists of short fatty acids with double bonds, whose melting point lies between -50 °C and 10 °C.
- The second fraction consists of short fatty acid chains with a few single bonds. These fats have melting points between 10 °C and 20 °C.
- The third fraction consists of saturated fats, which have a melting point between 20 °C and 40 °C.

The French physical chemists Frédéric Lavigne and Michel Ollivon and their colleagues researched not the melting but the hardening of butter. This process is also called crystallisation. First they heated up some butter, then they let it slowly cool down. Because of the different melting points of the fats, they were able to extract the different fat fractions from the butter. Caprylic acid, for example, crystallises at a temperature of 16 degrees, and can then be extracted from the butter, and caproic acid at 31.5°C.

#### **Assignment 17 How do you make perfect butter?**

Imagine you want a soft creamy butter which is easy to spread straight from the fridge. Which fat fractions should you use to make it?

Imagine you want to make a hard butter. Which fractions would you use for this?

#### ***Making molecular butter***

*With a little help from a pack of butter and a pan you can make your own butter at home. In order to separate the different fat fractions, heat up the butter and then let it cool down slowly. This process is also called fractional crystallisation. When you allow the melted butter to slowly cool, you can isolate those crystals (solid particles) that appear at the same temperature and which all consist of the same sort of molecule. Extract the different fat fractions from the butter. When you have a number of fat fractions, you can mix them together again to make perfect butter that will spread straight from the fridge.*

### 3.7.2 Mayonnaise... with a twist!

As you now know mayonnaise is composed of oil, water and an emulsifier. In addition to these components, there are several other ingredients, namely mustard, salt, lemon juice and/or vinegar. These are vital, because they add flavour to the mayonnaise. You also now know what makes a mayonnaise stable and which ingredients it must contain. In the following assignment you will invent new mayonnaises by changing the various ingredients.

#### Assignment 18 Mayonnaise, with a twist

1. First we are going to look at different flavourings that you can add. You know that mayonnaise consists of an oil and a water phase and that flavourings dissolve in one of these two phases (see chapter 2 section 1.2). Think about how you can make a savoury mayonnaise, describe the process at each step (hint: chicken stock gives a wonderful savoury taste).

Your savoury mayonnaise is a big hit, and you are asked to make prawn-flavoured mayonnaise.

2. How would you go about making a prawn-flavoured mayonnaise? (Remember that taste is largely determined by aroma molecules!)

Now that we have looked at a number of different flavours, we can take a look at the egg yolk, the emulsifier.

3. Is it possible to make mayonnaise without this egg yolk? And if so, how?

As you will see, using your knowledge about emulsions and molecular gastronomy, you will be able to make totally different sauces, such as mayonnaise for people who are allergic to chicken protein.

### 3.7.3 Aioli

Aioli is an emulsion sauce from the Provence, a region in France. It is made from olive oil and crushed garlic. But normally speaking oil and water don't mix. So how can this emulsion sauce be stable without the addition of an emulsifier like egg yolk or milk protein?

Hervé This has also done some research on aioli. Garlic appears to contain surfactant molecules. As with the other emulsifiers that you have come across, these molecules sit on the interface of oil and water.

So, if you can make an emulsion from just garlic and oil, does it work with other vegetables?

The answer is right in front of your nose. As we know from biology, all animal and plant cells contain water and proteins. The proteins that occur in nature in vegetables can also be used as emulsifiers, provided that you extract these surfactant molecules from the cells. You must therefore break the cells, just as you crush the garlic to make aioli, so that the emulsifiers are free to do their job.

Meat and fish can also be used to make sauces. The great thing about these is that you don't have to add any extra protein, because the emulsifier is already present! A meat mayonnaise or a fish aioli can be easily prepared in the kitchen.

## 4 Foams

Obvious examples of **foams** in the kitchen are whipping cream, chocolate mousse and cappuccino foam. But did you know that bread, currant loaf and ice-cream are also foams? One thing that these foods all contain is gas.

Ferran Adrià is one of the most famous chefs in the world. Between 2006 and 2009 he was elected the best chef in the world four times in a row. He cooks in the trendsetting Spanish restaurant El Bulli. The unique thing about the philosophy in the El Bulli kitchen is that existing recipes are deconstructed and then put back together again in a new way, using new ingredients and new equipment. Take a look at the following film clip ([URL-2](#)) to get an idea of what goes on at El Bulli.

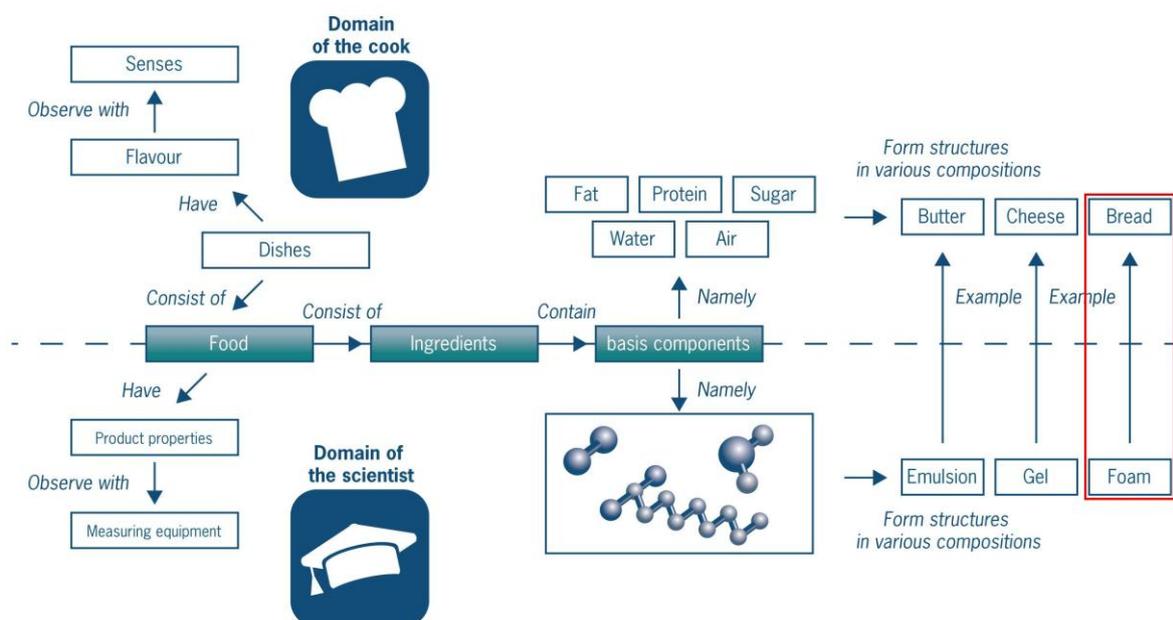


Figure 48 The red line

Following the El Bulli philosophy, the Dutch chef Moshik Roth created a 'new' stew. The various ingredients in the stew (carrot, potato, onion and smoked sausage) were used to make a foam structure. This makes a new experience out of eating stew.

What is the scientific definition of a foam?

**A foam is a dispersion of gas in a continuous phase.** The continuous phase consists of a combination of the basic components water, proteins, carbohydrates and fats. Not all basic components are present in every foam. For example, a beer foam consists only of water, protein and carbohydrates. The gas bubbles in the foam vary in size from a few millimetres (whipping cream), to a few centimetres (bread). The continuous phase in a foam often forms a thin layer, also called an **interfacial film**. Foam can be divided into two categories, depending on the molecules in the continuous phase:

- Foams that are based on proteins and carbohydrates.
- Foams that are based on proteins and fats.

### **The difference between an emulsion and a foam**

The dispersed phase in an emulsion is a liquid and in foam a gas.

A liquid droplet in an emulsion is 1000 times smaller than a gas bubble in a foam.

Major differences between liquids and gases in this context are:

- Gases and liquids differ in density by a factor of 1000.
- A gas can be compressed more easily than a liquid.
- The solubility of gases in water is greater than that of oil in water.

In this chapter the emphasis will be placed on foams based on proteins and carbohydrates. Foams can be liquid (e.g. beer foam), but also solid (e.g. bread foam). There are also a great many intermediate foams: they are not entirely solid, nor entirely liquid (e.g. bread dough, whipping cream and chocolate mousse). The subdivision into solid and liquid foams can be found in Figure 49, a table you will recognise from Chapter 2.

		Dispersion phase (dissolved substance)		
		Gas	Liquid	Solid
Continuous phase (solvent)	Gas	[none] all gasses are soluble within eachother	liquid aerosol <i>fog</i>	solid aerosol <i>smoke</i>
	Liquid	foam <i>beer foam</i>	emulsion <i>mayonnaise, milk</i>	suspension <i>starch solution</i>
	Solid	solid foam <i>bread</i>	solid emulsion (gel) <i>cheese, gelatine</i>	solid substance <i>alloys (bronze)</i>

Figure 49 Types of dispersions

### **Learning goals**

When you have completed this chapter, you will know:

1. the molecular interactions between proteins and carbohydrates that form the basis of a foam.
2. the formation of other foams that have not been dealt with using the knowledge acquired in this chapter.
3. three processes that ensure the stability of foams.
4. the ideas behind molecular gastronomical foams.

### **Structure of this chapter**

Sections:

- 4.1 *The role of proteins in a foam*  
A more in-depth look at the interactions of proteins in foam.
- 4.2 *The role of sugars in a foam*  
A more in-depth look at the interactions of carbohydrates in foam.
- 4.3 *The stability of foams*  
Description of the three mechanisms that ensure the stability of a foam.
- 4.4 *Examples of foams in the molecular gastronomical kitchen*  
Molecular gastronomical foams and a few examples of foams.

## 4.1 The role of proteins in a foam

In this chapter you are going to look at the meringue by way of example. A meringue is a light and crispy foam that is often served as a dessert. The key ingredients are egg white and sugar. There are various stories about the origins of meringue. The traditional view is that meringue was invented in the Swiss town of Meiringen by an Italian chef. The recipe for a meringue had already been recorded in 1692 by the French cook François Massialot.

There are many variations of the recipe. The most well-known of them is the hard and airy version. By way of illustration, you will find one of the recipes below for making meringue. You don't need to make this yourself.



Figure 50 A meringue (Van der Linden, 2008)

### Recipe for Meringue

#### Ingredients

- 2 egg whites (the whites of two eggs)
- 100 g sugar
- 1 tsp vinegar

#### Equipment

- oven
- baking paper

**Preparation** Preheat the oven to 100 °C.

Whisk the egg whites while adding the sugar little by little until stiff peaks are formed. Add the vinegar and mix everything together. With 2 spoons scoop up 12 oval forms and place on the baking tray lined with baking paper or use an icing tube to squeeze out shapes onto the baking tray. Bake the meringues for about 1 hour for small shapes and 1 hour 20 minutes for bigger shapes. The outside should be dry and easy to remove from the baking paper.

### Assignment 1 The microstructure of a meringue

1. In the online nutrient table ([URL-3](#)) table look up which main components the egg white contains (if you do not have access to a computer, you can ask the lecturer for a hard copy). Draw the microstructure of a meringue after it has been beaten to stiff peaks, before it goes in the oven. Indicate on the drawing what is the dispersed phase and what is the continuous phase.
2. Indicate which molecules are in the dispersed and which in the continuous phase.
3. The protein acts as the emulsifier. Draw the protein in the foam. Draw a schematic diagram showing the position of the hydrophilic and hydrophobic parts.

Researchers at Wageningen University together with Jonnie Boer, owner of the 3-star restaurant 'De Librije', have carried out research on the meringue. De Librije wanted to make foams that were similar to meringue, but with a different flavour. Jonnie Boer knew from experience that, for example, you can make a foam with apple, but not with melon. The chefs at De Librije wanted a standard foam recipe, which could be used to make foams with all kinds of ingredients.

The researchers and chefs were inspired by ice-cream. Ice-cream is also a foam and exists in hundreds of different varieties of taste and colour. Would it be possible to make meringues in so many varieties? Can you change the taste and keep the same meringue-like structure? The answer to this question lies behind the science of the meringue.

Figure 51 shows meringues prepared with different concentrations of protein and sugar (sucrose). In this chapter you will find out how the variation in the concentration of the basic components causes these meringues to look so different from one another.

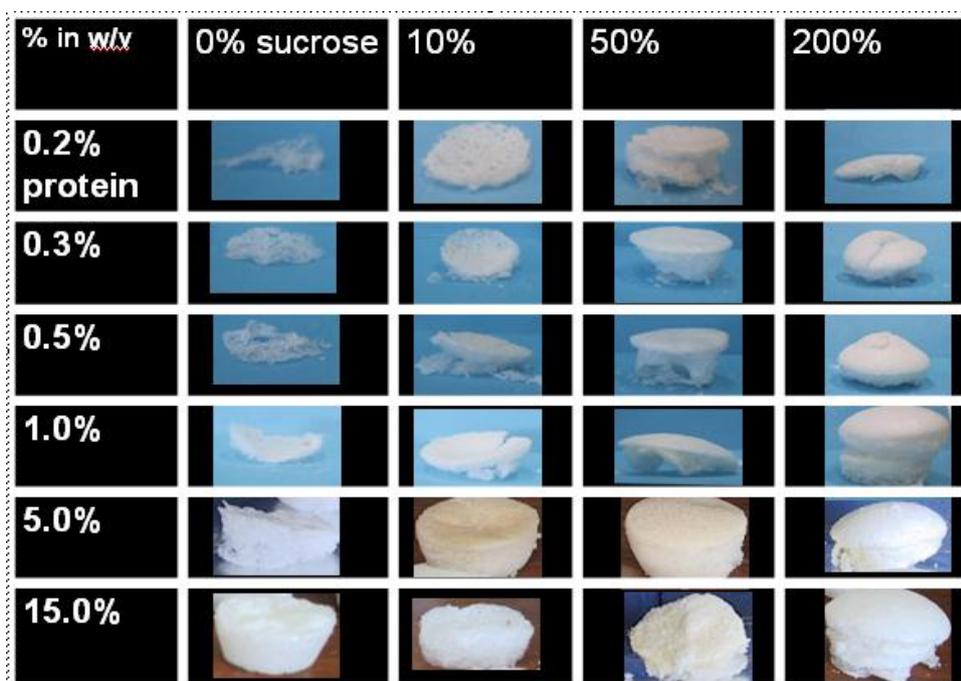


Figure 51 Meringues with different concentrations of sucrose and protein.

In meringue, the basic components of protein, sugar and air are mixed together.

The egg white serves three functions in the meringue:

1. It works as an emulsifier, also called a surfactant.
2. It ensures that the foam remains stable when it is whipped.
3. The denaturation of the protein in the warm oven makes the foam even more stable.

All these three functions will be discussed again later in this chapter.

When making a meringue, you start by beating the protein (the white of an egg). Using a whisk you beat air (the dispersed phase) into the water of the protein. Why don't the air bubbles beaten in this way immediately come out of the aqueous phase again? As we saw in the chapter on emulsions, there are emulsifiers in egg whites (surfactants). The emulsifiers in egg white are proteins.

In the mayonnaise the emulsifiers moved to the interface of water and oil. There is no oil in the meringue. Here the emulsifier positions itself on the interface of water and air, as it does in soapy water.

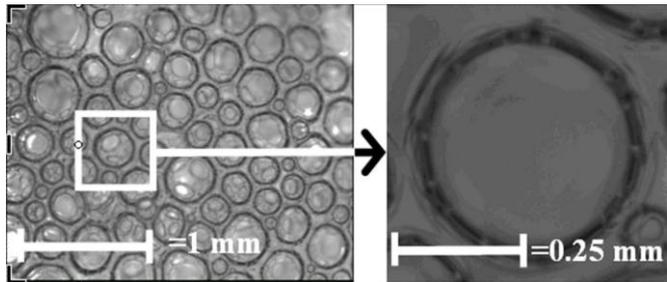


Figure 52 The meringue on a microscale

There is some time between beating the foam and putting it in the oven. In this time the protein and the sugar stop the foam from collapsing. Together they form 'solid walls' between the air bubbles, preventing the joining of several small air bubbles into a bigger one.

## 2 How much protein is needed

1. A chef is going to make a meringue. He only has a few eggs. He would like to make the best use of these to make as much meringue as possible. Calculate how many air bubbles there are in one litre of meringue foam. Do this using the following data:
  - a. The diameter of the air bubbles in the meringue is 0.4 mm.
  - b. 80% of the foam is air.
2. The protein moves to the interface of the air and the liquid. Calculate how much protein is required per  $m^2$  air bubble for the interface. You have the following information:
  - a. With 150 mg protein you can make half a litre of meringue foam (total volume).
  - b. Assume again that 80% of the foam is air.
3. Now determine how many litres of meringue you can make with 1 egg. One egg contains 1000 mg protein.

When the meringue is heated in the oven, the proteins that are present denature. **Protein denaturation** is the change in the structure of proteins under the influence of heat, acid, alcohols, salt or beating. Proteins denature, therefore, if they are exposed to higher temperatures and also if they are beaten.

The denaturation of the proteins and the addition of the sugar turn the liquid foam into a solid foam. In order to understand the concept of protein denaturation, we need to take a much closer look at the secondary and tertiary structure of proteins.

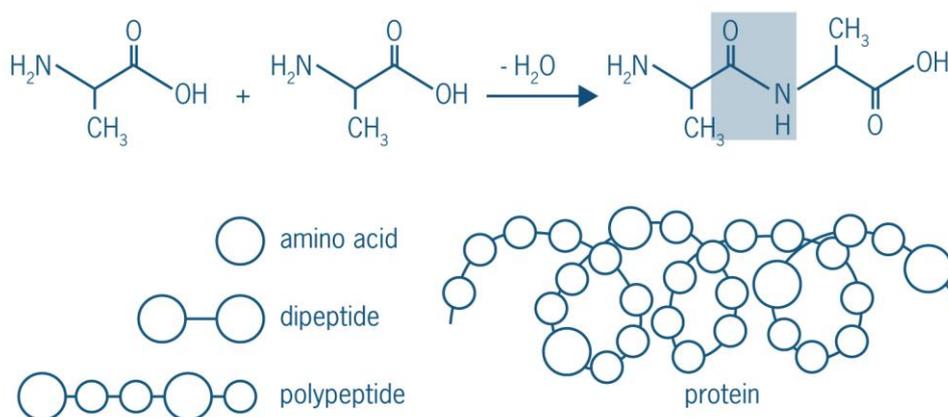
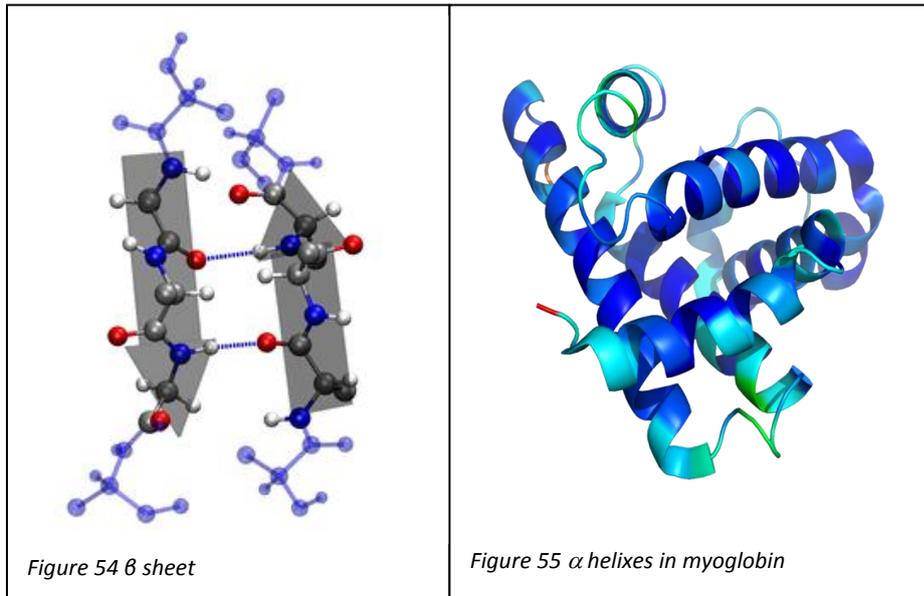


Figure 53 Proteins

Chapter 2 dealt with the composition of proteins and explained the primary, secondary, tertiary and quaternary structure of proteins. The secondary structure of the protein refers to the way in which the amino acid chain that makes up the protein, 'rolls up' or 'curls' in the available space, in short, what spatial form it takes. The form it takes is largely determined by the hydrogen bonds between amino acids.

First, a spiral structure is formed. This form is called the  $\alpha$ -helix (Figure 55). Myoglobin (a protein present in muscle tissue) is an example of a protein that consists mainly of helices. If the protein chain cannot 'curl up' into a perfect spiral by means of hydrogen bonds, a  $\beta$  sheet is formed (Figure 54).



The manner in which these  $\beta$  sheets and  $\alpha$  helices are arranged in 3D (=spatially), is called the tertiary structure of a protein. Figure 56 shows the tertiary structure of the protein alpha lactalbumin which is present in milk. The red spirals are the  $\alpha$  helices and the yellow arrows are the  $\beta$  sheets.



Figure 56 Alpha lactalbumin

### Assignment 3 The tertiary structure of beta-lactoglobulin

The protein beta-lactoglobulin is present in great quantities in milk.

This protein also has  $\beta$  sheets (the yellow arrows) and  $\alpha$  helices (the red spirals).



1. Two pieces of amino acid chains are spliced (cut) from the protein.  
DALFKAL  
ENKVKDT  
Write the names of these amino acids (in three-letter abbreviations) side by side. Use table 67C from BINAS.
2. Draw the structure of these two amino acid chains using the structural formulas from BINAS.
3. On the basis of the type of amino acid, determine whether the two amino acid chains a and b will spatially form a  $\beta$  sheet or an  $\alpha$  helix.

The combination of the secondary and tertiary structure of the protein is also called the protein conformation. Since this conformation is stabilised primarily by hydrogen bonds, it is less strong than the covalent bonds between the amino acids. Two types of protein can be distinguished based on the conformation.

- Globular proteins
- Random coil proteins

Alpha lactalbumin is an example of a globular protein (*Figure 56*). Globular proteins have many secondary and tertiary structures. The hydrophobic groups of the protein – if the protein is situated in an aqueous environment – are on the inside, and the hydrophilic groups on the outside of the protein molecule (*Figure 57*). A globular protein therefore has a hydrophobic nucleus and a hydrophilic exterior. Globular proteins are extremely compact; which is why they don't swell up in water. Examples of globular proteins are gliadin (grain protein),  $\beta$ -lactoglobulin (milk protein) and ovalbumin (egg protein).

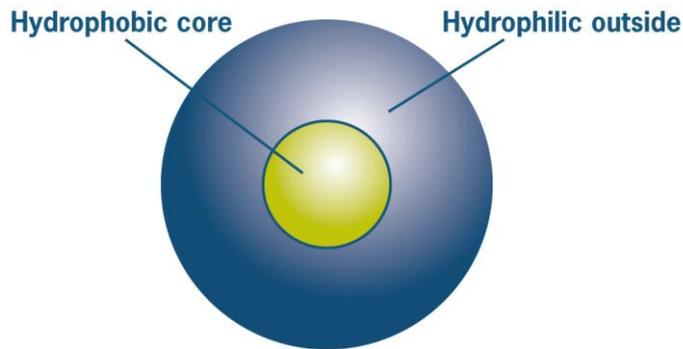


Figure 57 Schematic diagram of globular protein

Random coil proteins are long linear chains, with no secondary and tertiary structures. These random coil proteins are roughly coiled in a round form. The dimensions of these proteins depend on the temperature, flexibility of the chain and the type of solvent (for example, water with or without salt). Some proteins are random coil proteins by nature, for example casein or gelatin. A schematic drawing of a random coil protein can be seen in Figure 58.

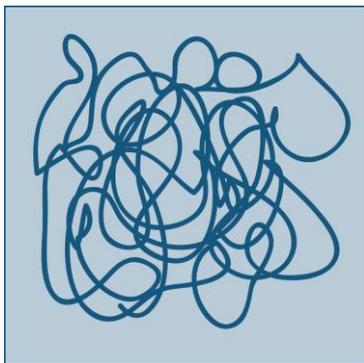


Figure 58 Schematic diagram of random coil protein

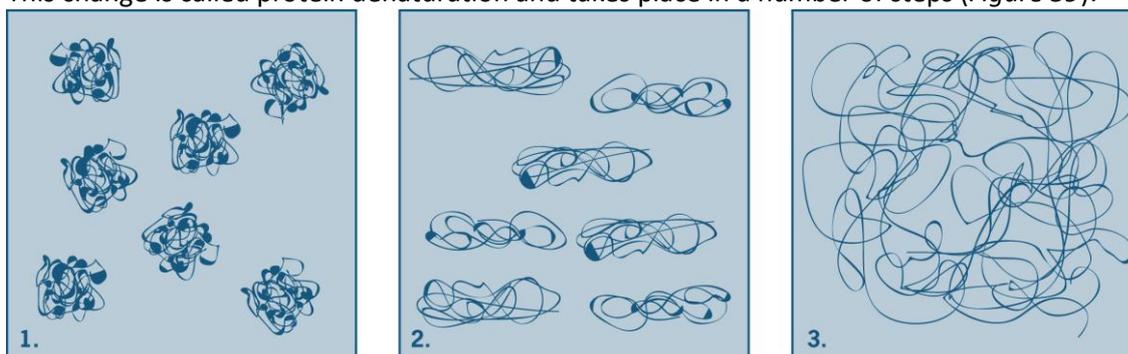
Upon denaturation globular proteins are converted into random coil proteins. The protein in the meringue consists largely of ovalbumin (egg protein), a globular protein. In addition to hydrogen bonds, other bonds also play a role in stabilising the molecule, namely:

- Covalent sulphur bonds
- Hydrophobic interactions
- Van der Waals interactions
- Ionic bonds

The beating of the protein causes denaturation. When the whisk goes through the protein during beating, the forces exerted on the protein molecules cause the protein molecule to open up. When the meringue foam is heated in the oven, further changes occur. The heat causes the breakdown of hydrogen bonds, ionic bonds, Van der Waals interactions and covalent sulphur bonds. As a result the protein is pulled from its globular structure and converted into a random coil protein.

The changes that take place at the molecular level can also be seen with the naked eye. The meringue foam becomes white and firm, when it is heated. But how can this change be explained?

This change is called protein denaturation and takes place in a number of steps (*Figure 59*):



*Figure 59 Protein denaturation in three steps*

In step one the proteins are still globular. In the second step a number of bonds, such as the hydrogen bonds, are broken. The proteins use the sites where bonds are broken to form new bonds with other proteins. This results in a network of proteins. This can be seen in step three. An example of such a network is a boiled egg. This network ensures the firmness of the boiled egg. Protein denaturation can also be represented as follows:

Protein (step 1)  $\rightleftharpoons$  partial denaturation (step 2)  $\rightarrow$  irreversible denaturation (step 3)

To a certain extent, protein denaturation is a reversible process. Initially there is an equilibrium between the protein and the partially denatured protein. But at a certain moment the reaction comes to an end and the process becomes irreversible. This also takes place when an egg is boiled.

How does a boiled egg become white in colour? In chapter 3 you read that emulsions are white because fat droplets are bigger than the wave length of light. The proteins in an egg in contrast are not bigger than the wavelength of light (they are about 5 nm). So the normal protein in an egg is transparent. Yet it turns white when cooked. The cooking process causes the proteins from the egg to denature and stick to each other. The result is a cluster. These clusters consist of a great many molecules, which increase the size of the protein cluster to almost a micrometre. This size is bigger than the wavelength of light, so a boiled egg is white in colour.

#### **Assignment 4 Protein denaturation**

Watch the following film clip ([URL-4](#)) for a more detailed explanation of protein denaturation. In protein denaturation are the covalent bonds between the carbon atoms in the amino acid chain broken? Explain your answer.

## **4.2 The role of sugars in a foam**

The basic molecule of sugar is also present alongside the basic molecule of protein in the meringue. Saccharose, or table sugar, is used to make a meringue. This is a disaccharide, consisting of glucose and fructose. Mono- and disaccharides are used in foams to make them sweeter. They are also responsible for the crispy texture of the foam once it has been baked. Saccharides also play an important role in the thickness of the foam. Before the meringue goes into the oven, the saccharose prevents the foam from sinking due to the liquid running out. The sugar increases the viscosity of the foam (*Figure 60*). Saccharose dissolves on a molecular level, and is present in the continuous phase of the meringue.

### Relative viscosity [cP]

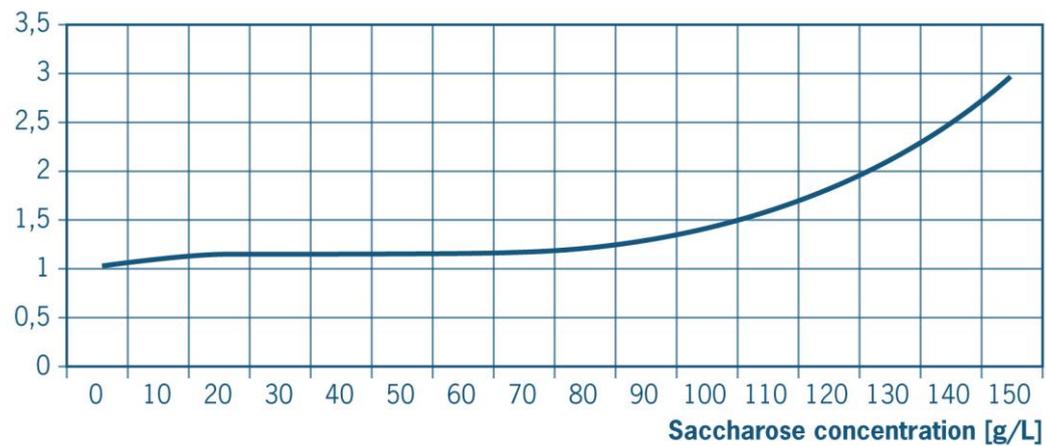


Figure 60 Relationship between saccharose concentration and viscosity

When a meringue is heated in the oven, the water evaporates and the sugar concentration increases. This causes an increase in the viscosity. This together with the protein denaturation turns the liquid foam into a solid foam.

In other solid foams, like bread, biscuits and cake, there is an additional mechanism to protein denaturation that is responsible for preventing the foam from collapsing. These products contain polysaccharides. Since polysaccharides contain macromolecules, they increase the viscosity at much lower concentrations of saccharose. In these foods, polysaccharides form a network similar to that formed by protein denaturation. The water is 'trapped' in this spatial network. See Figure 61.

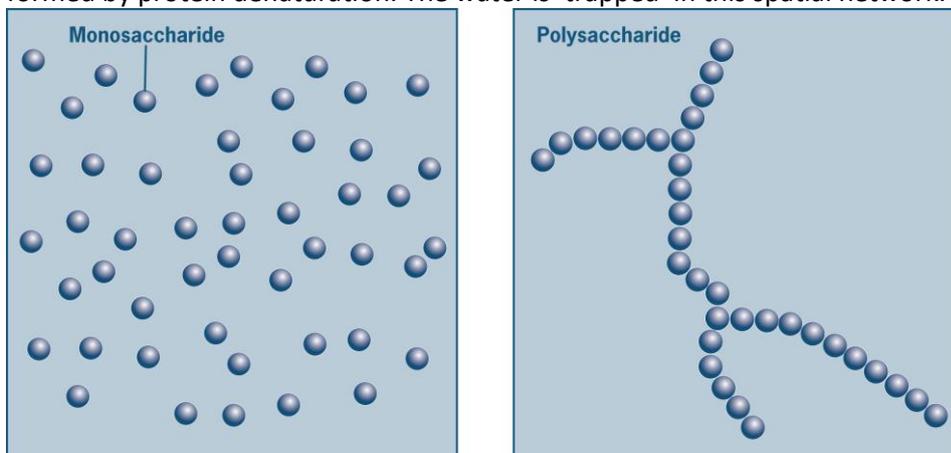


Figure 61 The difference between a monosaccharide and a polysaccharide in solution at the molecular level.

#### Assignment 5 Sugar in foam

1. Draw a schematic diagram in which you indicate the relationship between sugar concentration and viscosity. Indicate the expected relationship for the following types of carbohydrates: saccharose, glucose and starch.
2. In some meringue recipes cornflour is used in addition to sugar. Cornflour consists largely of corn starch. Why is this ingredient used?
3. Can all the sugar in the meringue be replaced by corn starch?

### Profession box 3

#### **A real masterchef has the magic touch**

*Interview with Adrian Bradshaw, born in Australia and working for 11 years at Mars International, two of those years at Mars in the Netherlands (known for Mars®, Snickers®, Twix®, M&M's®) in Veghel as a process manager. Bradshaw studied chemical engineering in Australia and always had an interest in food.*

Bradshaw begins to enthuse about the differences between chefs in the kitchen and those at work in the food industry. "Chefs have got the magic touch", says Bradshaw, "for instance, a real masterchef can mix ingredients and come up with a unique taste combination". He can understand why some people pay a month's salary for this magic. According to Bradshaw, what happens in industry is quite different; here the aim is to ensure that food used on a daily basis is of a good and consistent quality. He gives the example of a Mars bar; this product must have a consistent quality. Whether you eat it the day it was made or 12 months later, the taste must be (almost) the same.

Asked whether 'knowledge from the kitchen' therefore has no place in industry, Bradshaw begins to laugh. He explains that every new project begins in the kitchen. Researchers think up a new product and a chef makes it in the kitchen. If this product complies with certain requirements (stable for long enough, tasty, good price, etc.) the product has to be made on a larger scale (this is called scale-up). This is the point at which Bradshaw gets involved; he forms a sort of link between the technicians who conduct the scale-up and the researchers. In Bradshaw's opinion there are 3 important steps in this scale-up process. First the so-called pilot scale. The new product is still made individually in the kitchen (a so-called batch process); the pilot scale is a little bigger than the kitchen and becomes a continuous process, i.e. like on a conveyor belt. If the product succeeds on the pilot scale, production is scaled up about 10 times. This is called the concept line scale. This concept line scale can already produce enough to provide one country with the new product. At Mars they often use Belgium for this purpose, because 10 million inhabitants can be supplied from North Brabant. If everything goes to plan on the concept line scale and the product sells well, then a decision to increase the process another 5 times is made. This final phase is called the industrial scale, and from this point on the new product can be sold around the world.

According to Bradshaw this scale-up process and the difference with the kitchen can be compared to climbing a mountain. The chef and Bradshaw both want to reach the same summit (a new product), but they both get there in a different way. The chef will walk, while Bradshaw will try and build a cable car. The chef might well be the first to reach the summit, but he may only do it once (i.e. his product will stay on the small scale). Once Bradshaw has finished the cable car, lots of people can reach the summit (i.e. his product is available on a large scale, and more importantly, it is affordable).

You may be wondering why this interview is relevant to a chapter about foams. During his 11 years at Mars, Bradshaw has worked regularly with foams, including meringues and the foam in the Mars Bar. What is the status of the knowledge about foams from the kitchen? Bradshaw explains that the stability of a foam on an industrial scale is crucial, but that at the 'kitchen' scale care already has to be taken to make sure that the stability is very high, otherwise it is almost impossible to let a foam run through a continuous process. Foams are extremely sensitive and are not very resistant to force, yet force is precisely what is needed to move it through the process; in the kitchen, on the other hand, the foam can be handled very carefully. As a result of these difficulties with transportation, foams are added to the product as late in the process as possible, because from that moment the product must be handled with the utmost care. In industry, therefore, you face the same challenges as in the kitchen, but on a greater scale.

However, Bradshaw also sees the benefits of working with foams on an industrial scale. You get a much more even foam structure, which is as a result more stable (remember disproportionation). In addition, nougat (for example, the filling in a Mars bar) is one foam that can actually only be made well on a large scale. It is also easier to use things like high pressure, something that gives an entirely different bubble structure.

Then Bradshaw explains an average working day. "I arrive in the morning and if I see my boss, I run and hide." On a more serious note, he says that his days are all very different. He is usually working on one big project, which usually takes about 4 weeks. Then he works towards a major trial (for example, running tests on a pilot scale), for which enormous preparation is required, given that one day of test runs can quickly run up costs of 20,000 euros. He therefore has to ensure that the test is run as efficient as possible. On the day (or days) of the trial runs, his working day is long and thereafter the new knowledge from these trial runs is processed. One of his key tasks is ensuring that everything runs smoothly.

His job requires a fair bit of travelling, since he is responsible for starting up new offices for Mars all over the world. He says that he spends about 40% of his time travelling, but that for the average employee this figure is nearer to 15%.

The final question is why you would opt for a scientific education, and more specifically, work in the food industry. In Bradshaw's view one important reason is that it is well paid. As a graduate you can do something that not everyone can, you are sought-after. This is certainly the case in the food industry, where starting salaries are on average 10 to 20% higher than in other industries. In addition to salary, Bradshaw believes that a technical job is often more challenging and offers variety (this seems to be true when looking at the variety of Bradshaw's work, always busy with another project, working with different people, in different locations and under different circumstances). "Of course, you have to be passionate about what you do", says Bradshaw. "What you learn at university is important, but you only really start learning when you begin a job. Luckily this is quite different from studying at university."

### 4.3 The stability of foams

The time between making the meringue and the moment it is put in the oven should not be too long. If you wait too long, the foam collapses. A beer foam only remains stable for a few minutes and then slowly collapses: this is called 'killing'. A bread foam on the other hand will never collapse.

A foam is stable if the air in it does not immediately escape. In a bread foam this will not happen, but 'killing' of a beer foam is a very common problem.

Why is one foam stable, and another not? And how can you prevent a foam from collapsing?

There are three processes that largely determine the stability of foams:

- **Drainage**
- **Disproportionation**
- **Coalescence**

#### 4.3.1 Drainage

Drainage is the phenomenon whereby the liquid that forms the continuous phase of the foam runs out from between the gas bubbles (*Figure 62*). As a result the foam collapses more quickly and is therefore stable for less time. This phenomenon is caused by gravity pulling the liquid downwards.

$$F_z = m \cdot g$$

The speed with which drainage occurs depends on the quantity of liquid present in the foam. If there is a lot of liquid, the mass of the liquid in the foam is great. Likewise, the force with which the liquid is pulled downwards is also great. Because this force is great, the speed of drainage will be high. If some of the liquid has already drained from the foam, the speed of drainage will be reduced. Drainage can be prevented by increasing the viscosity of the liquid. The higher viscosity creates a force opposed to gravity.

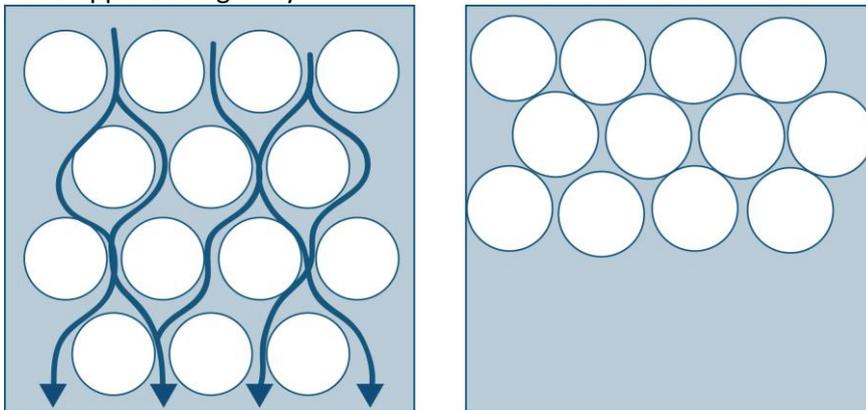


Figure 62 Drainage

Drainage can easily be *measured*, by measuring the volume of liquid under the foam.

Using the following formula you can *calculate* the drainage speed:

$$Q = \frac{2 \cdot \rho \cdot g \cdot 0.4 \cdot d \cdot \delta}{3\eta}$$

Symbol	Meaning	Unit
Q	Drainage flow	m <sup>3</sup> s <sup>-1</sup>
ρ	Density	kgm <sup>-3</sup>
d	Diameter of foam bubble	m
δ	Thickness of continuous phase between the bubbles	m
η	Viscosity of continuous phase	Pa.s
g	Gravitational constant	Ms <sup>-2</sup>

#### Assignment 6 The drainage of meringue foam

Use the formula for drainage in this assignment.

In the study of meringue by three-star restaurant De Librije (§ 1.2), drainage was also investigated. They wanted to know the effect of the protein concentration and sugar concentration on the drainage speed.

1. Explain in your own words what drainage is.
2. Explain which two forces affect the drainage speed of the meringue.
3. Look at Figure 60. Explain the relationship between the sugar concentration in the meringue and the viscosity of the liquid.
4. In figure 63 the amount of drainage from the meringue is plotted against time. Different concentrations of protein and saccharose are used. (In the first column behind the symbol is the protein concentration – from top to bottom from 1.5 to 15% - and in the second column the sugar concentration – from top to bottom from 0 to 200%). Which foam stayed stable for longest? See also Figure 51 for a photo of the 'meringues' that are produced from the various protein and sucrose concentrations.
5. Using Figure 60 explain why the meringue with a low sugar concentration has a lot of drainage, while the meringue with the highest sugar concentration has the least.

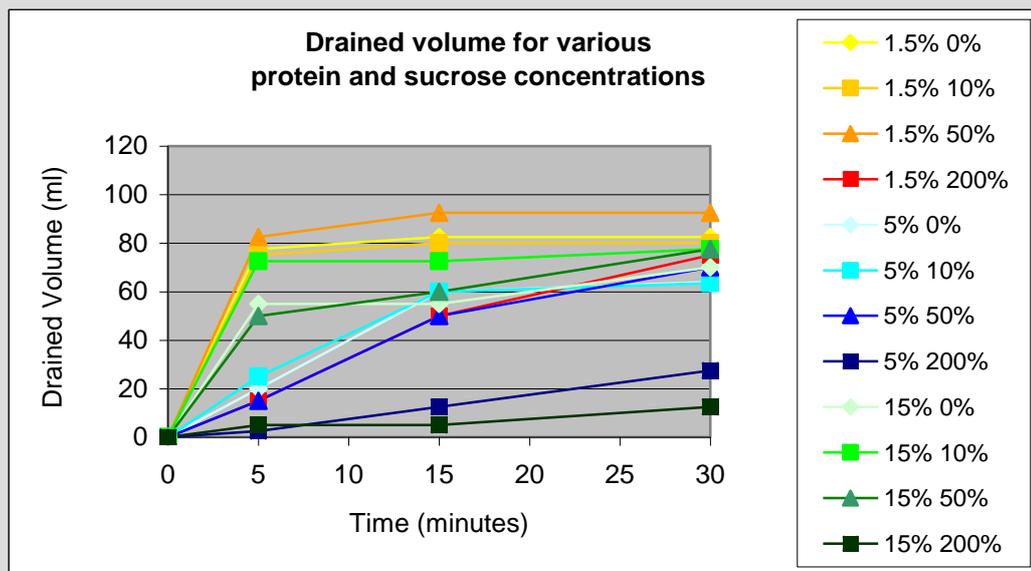


Figure 63 Drainage in the meringue

### Assignment 7 Taking drainage into account

1. Using the formula for drainage, explain how the drainage speed can be reduced.
2. A chef would like to leave the meringue foam to stand longer than usual. So he adds carrageenan to thicken the meringue. Work out how much carrageenan has to be added to allow the foam to stand for half an hour. The relationship between the concentration of carrageenan and the viscosity is shown in the table. Use the following data:

Concentration of carrageenan (%)	Viscosity (mPa*s)
1	57
2	397
3	4411
4	25356
5	51425

- a. The total volume of the foam is 200 ml.
- b. The foam is 85% air and 15% carrageenan/water.
- c. The foam is no longer stable once all the liquid has run out.
- d. The diameter of the gas bubbles is 0.5 millimetres.
- e. The density of the continuous phase is  $1000 \text{ kgm}^{-3}$ .
- f. The thickness of the interfacial film is 100 micrometres.

#### 4.3.2 Disproportionation

When you pour bath foam into a bath full of water, all the gas bubbles are small initially. After a time the gas bubbles become bigger and bigger. This phenomenon is also called disproportionation. It is caused by a difference in pressure between the large and small gas bubbles in a foam. This phenomenon also occurs in beer foam, champagne foam and meringue. Disproportionation is largely responsible for 'killing' beer foam.



Figure 64 Disproportionation

In disproportionation the gas in the air bubbles moves around. This motion can occur in two directions:

- From a small air bubble to a bigger air bubble
- From air bubble to the air outside the foam, which is in fact an infinitely large air bubble.

Disproportionation can be illustrated with a simple experiment. Imagine a tube with two soap bubbles (Figure 65). One soap bubble is blown bigger than the other. There is a tap between the two soap bubbles so that the air from both soap bubbles cannot come into contact with each other. As soon as the tap is opened, air flows from the small to the big bubble. Why does the air move?

There is a **pressure difference** between the big and small soap bubble.

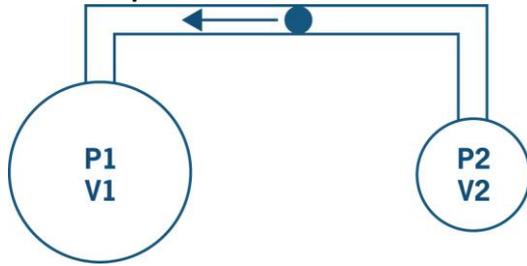


Figure 65 Experiment with two soap bubbles.

The quantity of gas dissolved in the continuous phase is a function of the pressure in the air bubble. The pressure in the air bubble can be calculated using the Laplace equation:

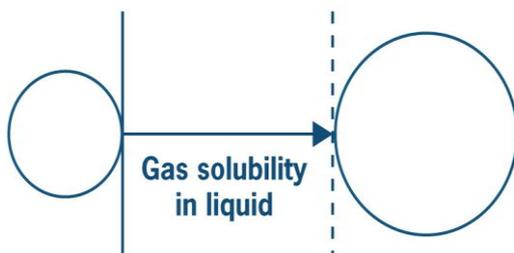
$$\Delta p = p_{in} - p_{buiten} = \frac{2\gamma}{r}$$

Here  $r$  is the radius (m) and  $\gamma$  the surface tension (N/m) of the bubble. The two  $p$ 's represent the pressure inside and outside the air bubble (in Pascal). According to this equation, the pressure in a small bubble is greater than the pressure in a big bubble. If the pressure is more in the small bubble, more gas from this bubble will dissolve in the continuous phase. The concentration of gas is then higher around this small air bubble. As a result of this difference in concentration between the air bubbles, the gas will diffuse from the small to the big air bubble. The result is that the small air bubble shrinks and the big air bubble grows.

#### Assignment 8 Volume of air bubbles

The gas bubbles in a meringue are not all the same size. One air bubble has a radius of 0.5 mm, another is 1 mm.

1. Calculate the volume of these two gas bubbles.
2. How many gas bubbles are there in 1 ml foam?
3. The air bubble with 1 mm radius has a pressure difference of 1 bar. Calculate the pressure in the other air bubble. The air bubbles have a surface tension of 50 N/m.
4. What is the relationship between the size of the air bubble and the pressure in the air bubble?



The experiment above involving the soap bubbles gets a little more complicated when you look at beer foam or meringue. In addition to the pressure difference, the **miscibility** of the gas in the liquid also plays a role. One gas is more miscible in water than another (Table 9). The gas molecules move through the liquid from the small air bubble to the big air bubble (Figure 66). The gas has to overcome the resistance to miscibility in order to be able to move.

Figure 66 Schematic representation of disproportionation [Miscibility of gas in liquid]

Table 9 Miscibility of gases in water

ml /ml water	0°C	15°C	30°C
N <sub>2</sub>	0.0235	0.0177	0.0149
CO	0.0354	0.0268	0.0222
CO <sub>2</sub>	1.713	1.075	0.760
O <sub>2</sub>	0.0492	0.0365	0.0274
N <sub>2</sub> O	0.0235	0.0177	0.0149

### Assignment 9 Whipping cream

Product developers at Friesche Vlag are developing a whipped cream in dispensing canisters.

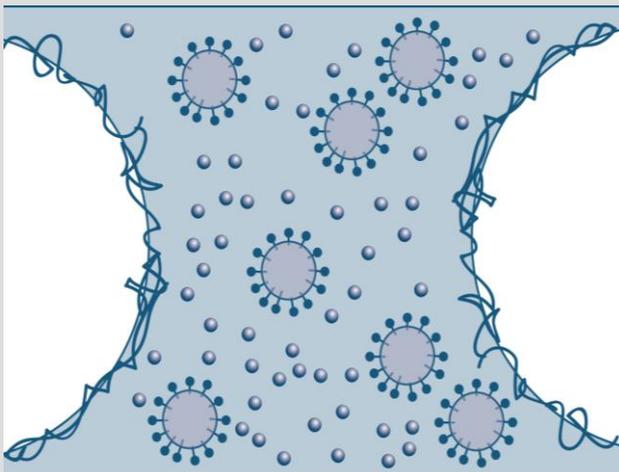
1. Describe the function of the various ingredients in the whipped cream.



**Ingredients:**

Whipped cream, sugar (8.5%), propellant (N<sub>2</sub>O, N<sub>2</sub>), emulsifier (mono- and di-glycerides), stabilizers (E339, carrageenan), aromas

2. Indicate with names the location of the different ingredients in the product in the following drawing.



3. On which two properties of the gas bubbles and the gas does disproportionation depend?
4. Why have the product developers opted to use N<sub>2</sub> rather than CO<sub>2</sub> in the whipped cream?

If you want to make your own whipped cream, you start with milk cream (milk with more fat than usual milk) and you whip it up (beat air into it). In fact, this is the same as when you make butter (see section 3.5.1), except that you do not keep going until the fat in the cream starts to clot and you get a W/O emulsion. In whipped cream there is a network of air bubbles that are stabilised by the fat in the cream. To a large extent the fat fills up the liquid between the air bubbles (as you can see in the image above). Whipped cream is a foam based on carbohydrates and oil, and not carbohydrates and proteins (as with meringue). Therefore, in whipped cream the fat assumes the role of the proteins in stabilising the air bubbles.

1. Why is milk cream used rather than milk for making whipped cream?
2. Why should the cream that you use be unhomogenised?

The whipped cream should be beaten at a low temperature (between 4 and 7 degrees). In addition, whipped cream should not be kept cooler than 0°C.

3. Why is the optimal temperature for making whipped cream so low? (Hint: the fat is important here)
4. Why should whipped cream not be made or kept at a temperature lower than 0°C? (Hint: the water between the air bubbles plays a vital role here)

### 4.3.3 Coalescence

Coalescence is the joining of two air bubbles in the foam, in between which is an extremely thin layer of liquid (distance between the bubbles: 10-100 nm). The thin film between the two air bubbles breaks and the droplets join together to form one new droplet. This phenomenon is shown in Figure 67. Proteins play a role in preventing coalescence. When proteins surround the air bubble, a kind of elastic layer is formed. This layer protects the air bubble from fusing with another air bubble. Like two bouncy balls, the gas bubbles bounce off each other. The fusion can also be prevented by enlarging the layer of liquid between two gas bubbles.

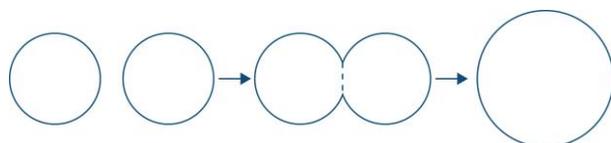


Figure 67 Coalescence

Coalescence and disproportionation cause the increase in size of gas bubbles in a foam. Coalescence and disproportionation occur not only between the gas bubbles in the foam, but also between the gas bubbles in the foam and the air outside the foam. These two processes will eventually cause the gas bubbles to disappear: the foam becomes unstable, and the foam structure disappears.

#### Assignment 10 Comparing the stability of foams and emulsions

Foams and emulsions are actually fairly similar. They are both mixtures of water with something that doesn't actually mix with water. In foams this is air, and in emulsions oil. In this assignment you will look in greater depth at how this difference affects stability. For this assignment, have in mind chocolate mousse for a foam and mayonnaise for the emulsion.

First of all, we are going to look at the solubility of oil in water (emulsion) and air in water (a foam).

1. Which of the two (oil or air) dissolves better in water?
2. What effect does this have on stability, i.e. what will be less stable, an emulsion or a foam? (think of disproportionation as described in section 4.3.2)
3. What do you think would happen if you dropped a few droplets of oil onto the head of a beer?

The bubbles in a foam are usually bigger than those in an emulsion.

4. What effect does this have on stability? Which is more stable?
5. What is your final conclusion, which of the two is most stable?

## 4.4 Examples of foams in the molecular gastronomical kitchen

You now know what a foam is and what role proteins and carbohydrates play in a foam. You also know which processes affect the stability of foams. Now you can apply this knowledge to molecular gastronomical foams in the molecular kitchen.

### 4.4.1 How proteins ensure the formation of a beautiful champagne foam

One of the studies undertaken by Hervé This in his book “Molecular Gastronomy” involves champagne foam. In this study champagne foam was analysed by champagne producer Moët et Chandon. The quality of the ‘head’ had diminished in recent years. It should have been a stable foam with fine gas bubbles. But it had become a foam with big bubbles. It looked less attractive and also disappeared very rapidly. The purpose of the study was to find out what created the beautiful, stable head on the champagne. The study looked at the impact of protein on the foam. For a number of years champagne manufacturers had been using a filtration device to improve the clarity of the champagne. The champagne producers thought that this could be the cause of the problem.

#### Assignment 11 Champagne foam

1. Champagne foam contains the following components: water, proteins, carbohydrates and air. Make a drawing of the foam. Indicate where the components are located.
2. What is the role of the protein in the champagne foam?
3. Upon filtration part of the protein is removed. What effect may this have on the foam?

### 4.4.2 Zabaglione

Zabaglione is a dish of Italian/French origin. It is made by beating together egg yolks and sugar. After beating, the mixture is heated up and a dessert wine is added. The liquid foam emerges with continuous beating. Zabaglione is often served with pieces of fruit, such as strawberry. A deliciously light dessert!



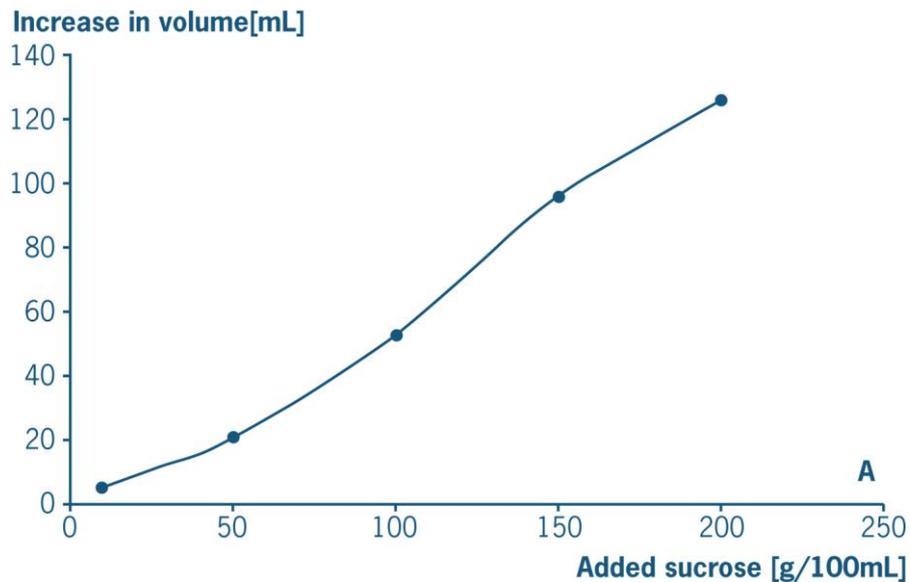
Figure 68 Zabaglione

#### Assignment 12 Zabagliones

1. Explain what happens to the protein on a molecular level when you heat it up.
2. The denaturation temperature of egg yolk is 68 °C. According to chefs, the zabaglione should not be heated up to 100°C. Why not?
3. Explain to which temperature the egg yolk *should* be heated.

#### 4.4.3 The same foam – different proteins

What was the end result of the meringue study by restaurant De Librije and Wageningen University? The study showed that the amount of protein does not limit the amount of foam that can be formed. Approximately 10 g protein per litre liquid is enough to make a stable foam. The amount of liquid is crucial in the meringue. Less liquid means that there is less liquid between the bubbles. In order to be able to produce a foam, there should be a minimum amount of liquid between the gas bubbles. The quantity of liquid can be increased by adding water or extra sugar. The sugar binds the water to hydrogen bonds and causes an increase in the volume of the foam (*Figure 69*). The sugar molecules, like the water, end up between the gas bubbles. Sugar also helps to obtain the right viscosity.



*Figure 69 Impact of sugar on foam volume*

If only protein is used as an ingredient in the meringue, the texture will be rubbery, instead of the desired crunchy structure. The crunchiness depends on the amount of sugar added. The more sugar, the crunchier the meringue!

How can you use this knowledge to innovate the meringue? Would it be possible, for example, to make a meringue with skimmed milk instead of protein, so that you can make as many different flavours as with ice-cream? The answer is yes! Skimmed milk also contains proteins. The amount of protein in skimmed milk is sufficient to cover the entire surface of the air bubbles with protein molecules. It is now possible to make various meringues by adding ingredients to the milk! How about blackberry meringue, orange meringue or caramel meringue? It's all possible thanks to molecular gastronomy!

#### 4.4.4 Making espumas with the gourmet whip

A new kitchen appliance which is used to make many different foams is the gourmet whip (*Figure 70*). A gourmet whip is actually a sort of whipped cream squirter, but a little more flexible. You can use the gourmet whip to make whipped cream, but you can also use it to make all kinds of new and surprising foams. The gourmet whip is mainly used to make the all-popular espumas. Espumas are foams made from, among other things, fruit juice, cucumber juice or coffee. A gourmet whip is a stainless steel can in which you place all the ingredients for the foam. There is a valve on the gourmet whip to which a gas cartridge can be attached. The gas from this cartridge is discharged into the ingredient mix, creating a foam-like structure. Take a look at the following two film clips ([URL-5](#) and [URL-6](#)), in which a beetroot foam and a cappuccino foam are made with a gourmet whip.



Figure 70 Gourmet whip

#### Assignment 13 Making espumas

An example of a recipe for which the gourmet whip is used is strawberry espuma (*figure 71*):

##### Strawberry espuma

##### Ingredients

- 900 g strawberries
- 110 g sugar
- 8.5 g gelatin (5 leaves of 0.85%)

##### Method

Let the gelatin swell in cold water. Cook the strawberries with the sugar. Puree them and push them through a fine sieve. Heat up 200 ml of the strawberry puree to 60 degrees and stir in the gelatin. Add the remaining puree and let the mixture cool down. Beat the cooled mixture with a whisk and put it in the gourmet whip. Use 1 cartridge with nitrogen gas.

1. Why is gelatin suitable for making foam?
2. What is the role of the other ingredients in the foam?
3. Why is the gelatin heated to 60 degrees?
4. Why is nitrogen gas used in the gourmet whip?



Figure 71 Strawberry espuma

## 5 In conclusion

Over the last few weeks you have been looking at two different structures, foams and emulsions. You may remember that the gel structure was mentioned in the red line, but was not discussed further. The following experiment is a particularly good example of how a gel can be used in an innovative way in the kitchen.

### Alginate balls

#### Ingredients

- 250 ml water
- 1.3 g citras
- 1.8 g alginate
- 250 ml mango puree
- Calcium bath with 1 litre water and 5 g calcium

#### Method

- Dissolve the citras in the water
- Add the alginate and mix. Make sure that you add the alginate slowly so that it does not coagulate
- Heat this mixture briefly up to 90 degrees
- Add the mango puree to the cooled solution (put the solution on ice if necessary to speed up the cooling)
- Measure the pH. The pH should be 4. If it is not, add citras until you obtain a pH of 4.
- Make the calcium bath by putting 1 litre of water in a bowl and dissolving 5 g calcium in it

The alginate balls can now be made by carefully dropping little droplets of the alginate solution into the calcium bath using a syringe. Leave the droplets to harden for about 20 to 30 seconds, and take them out carefully with a sieve (tip: It is useful to leave the sieve hanging in the calcium bath and drop the solution carefully into it. Rinse the hardened alginate balls under clean water.



You will see that little gel balls are formed that are hard on the outside and have a strong mango flavour inside. You can of course substitute mango for any number of other flavours, such as juice from the supermarket or even chicken stock to make a savoury ball!

*“Molecular gastronomy is a branch of science concerned with the study of physical and chemical transformations of edible materials during cooking, and the sensory phenomena associated with their consumption”.*

Molecular gastronomy is part of a scientific field that looks beyond the kitchen, namely food technology. Within food technology food is analysed, not just in the kitchen but on a larger scale (as demonstrated in the interview with Adrian Bradshaw). Food technology can also be split into an applied part, where knowledge is used to improve existing processes or invent new processes, and a theoretical part, where the search for new knowledge is central. Food technology combines knowledge about physics, chemistry and biology, with knowledge about a food. As you can see, food technology is more than just molecular gastronomy, and more than just research.

## 6 Glossary

<b>Amino acids</b>	Molecules that have an amino group at one end and a carboxyl group at the other. Amino acids are the building blocks of proteins.
<b>Amphiphile</b>	An amphiphilic molecule reacts with both hydrophilic and lipophilic molecules (water and fat-loving).
<b>Chemical change</b>	New substances emerge from chemical changes.
<b>Coalescence</b>	Two gas bubbles become one, whereby the film between the droplets disappears.
<b>Colloid</b>	A particle that is bigger than a molecule, but too small to be seen with the naked eye. Colloidal particles range in size from 0.001 to 10 micrometres.
<b>Conformation</b>	The spatial structure of a protein, which is mostly determined by the secondary and tertiary structure of the protein.
<b>Continuous phase</b>	The phase that serves as a solvent in a dispersion.
<b>Disaccharide</b>	Two monosaccharides joined together.
<b>Dispersed phase</b>	The phase with the dissolved substance(s) in a dispersion.
<b>Dispersion</b>	A dispersion is a mixture of substances that are mixed on a microlevel (finely distributed). They consist of a continuous phase and a dispersed phase.
<b>Disproportionation</b>	The movement of gas from small air bubbles to big air bubbles, by a difference in pressure.
<b>Drainage</b>	The phenomenon whereby the liquid runs out of a foam.
<b>Threshold value</b>	The lower limit of the concentration of a flavouring whereby it can still be detected.
<b>Protein</b>	A chain of more than 50 amino acids, that often has a spiral secondary structure and usually has a tertiary and quaternary structure.
<b>Protein denaturation</b>	The change in the tertiary structure from a protein, by the breakdown of hydrogen bonds, covalent sulphur bonds, hydrophobic interactions, Van der Waals forces, and ionic bonds.

<b>Emulsifier</b>	An emulsifier is also called a surfactant. It is an amphiphilic molecule that interacts with both hydrophobic molecules, such as fat, and hydrophilic molecules such as water.
<b>Emulsion</b>	A dispersion of two immiscible substances that under normal circumstances do not form a stable or homogeneous mixture. The most commonly occurring emulsion is a dispersion of oil in water or water in oil on the microlevel.
<b>Film</b>	The layer of liquid present between gas bubbles in the foam.
<b>Flavour</b>	The combination of the observation of taste, smell and texture when tasting a dish.
<b>Physical change</b>	When physical changes occur, new substances do not arise, but the phase in which the molecules are situated changes.
<b>Smell</b>	The detection of volatile molecules with the help of receptors in the nose.
<b>Globular protein</b>	A protein that contains many secondary and tertiary structures.
<b>Boundary value</b>	The lower limit of the concentration of a fragrance needed to detect it.
<b>Hardening</b>	A chemical process whereby an unsaturated bond is converted into a saturated bond by adding hydrogen. This process can be used in unsaturated fatty acids.
<b>Heteroglycan</b>	A polysaccharide that consists of 2 or more kinds of monosaccharide.
<b>HLB number</b>	The number indicating whether the emulsifier prefers to be dissolved in oil or water. The HLB number can be used to determine which sort of emulsion will be formed.
<b>Homoglycan</b>	A polysaccharide that consists of one kind of monosaccharide.
<b>Hydrophile</b>	Substances that blend well with water (water-loving). The molecules in this substance can form enough hydrogen bonds with the water molecules.

<b>Hydrophobe</b>	Substances that do not blend well with water (water-repellent). The molecules in this substance form insufficient or no hydrogen bonds with the water molecules.
<b>Hydrophobic interactions</b>	Molecular interactions, caused by a restriction in the movement of water molecules, causing oil droplets to merge
<b>Hydrogenation</b>	The breaking of double bonds in unsaturated fats, creating more saturated fats. This process is also called hardening.
<b>Hydrolysis</b>	The splitting of a chemical bond causing water to be taken up.
<b>Interactions</b>	The balance between repelling and attracting forces between molecules and other particles. On a colloidal scale this determines the stability of emulsions and foams.
<b>Ingredients</b>	The building blocks of a food or dish. Ingredients can be pared back to basic components: proteins, fats, water, carbohydrates and air.
<b>Lipophile</b>	Substances that dissolve in fat/oil (fat-loving). Another word for hydrophobe.
<b>Macromolecules</b>	A molecule that consists of 1-10,000 interlinked molecules.
<b>Microscale</b>	microscale contains particles ranging in size from 0.001 to 10 micrometres.
<b>Microstructure</b>	The way in which carbohydrates, fats, proteins, air and water are arranged in a food or product on the microscale ( $10^{-6}$ m).
<b>Molecular gastronomy</b>	A branch of science concerned with the study of physical and chemical transformations of edible materials during cooking, and the sensory phenomena associated with their consumption.
<b>Molecular gastronomical dish</b>	A dish that has been innovated using knowledge of physics and chemistry. These dishes give us a fresh look on eating and gastronomy.

<b>Monosaccharide</b>	A simple sugar molecule. Contains three to six carbon atoms, and at least 1 hydroxyl group and 1 aldehyde or ketone group.
<b>Neurons</b>	Nerve cells. Cells that process and forward information by means of electrochemical signals.
<b>Oligosaccharide</b>	A chain in which 3 to 10 monosaccharides are linked together.
<b>Unsaturated fats</b>	Fats with a high content of unsaturated fatty acids. These are fatty acids with double bonds in their long carbon chain.
<b>Sedimentation</b>	A form of separation of fat and water in milk, whereby the fat floats on top of the milk.
<b>Buoyancy</b>	An upward force on a body that is submerged in a liquid, caused by this liquid, like an oil droplet in water. The upward force in a liquid is equal to the weight of the displaced liquid.
<b>Partition coefficient</b>	The relationship in which a substance is distributed as a dispersed phase over the continuous phases of water and oil.
<b>Peptide</b>	A chain of 2 to 50 amino acids.
<b>Plasma</b>	In milk: the aqueous liquid in which proteins, milk sugar and other substances are dissolved.
<b>Polysaccharide</b>	A chain consisting of 200 to 5000 interlinked monosaccharides.
<b>Random coil protein</b>	A protein that contains no secondary and tertiary structures.
<b>Reaction</b>	A process that leads to a chemical change.
<b>Relative viscosity</b>	The viscosity of a solution in relation to a reference solution (for example, water).
<b>Foam</b>	A dispersion of air bubbles in a continuous phase that consists of the basic components water and proteins in combination with carbohydrates or fats. The air bubbles are dissolved in the continuous phase on a microscale.
<b>Sensory test/study</b>	A sensory test or study aims to find out more about the various characteristics of the product on the basis of sensory observations.

<b>Taste</b>	The observation of non-volatile substances using the receptors of the tongue.
<b>Texture</b>	All physical and structural characteristics that can be observed by touch and that are related to deformation if a force is exerted on them.
<b>Appearance</b>	What a dish looks like.
<b>Umami</b>	One of the five tastes, alongside salty, bitter, sweet and sour. The taste comes from glutamate.
<b>Transesterification</b>	The coupling of 3 fatty acids and a glycerol molecule to form a fat (triglyceride).
<b>Saturated fats</b>	Fats containing only saturated fatty acids. These are fatty acids with only double bonds in their long carbon chain.
<b>Viscosity</b>	The viscosity is a measure of the resistance when a liquid flows. Energy is lost because the liquid molecules experience friction when they move alongside each other. The greater the friction, the higher the viscosity.
<b>Hydrogen bonds</b>	Molecular interaction between water molecules, which is caused by a difference in the electron negativity between the hydrogen atoms and the oxygen atoms. The hydrogen atoms are a result of interactions caused by the difference in electron negativity between the polar character of the molecules. They can form between molecules that have an OH and NH group.
<b>Frictional force</b>	Friction (sliding friction) is the physical concept that refers to the force of resistance that occurs when two surfaces rub against each other, while being pressed against each other.

## 7 URL list

URL-1:

[http://www.rtl.nl/components/actueel/4inhetland/miMedia/2006/week16/maandag\\_koken.avi\\_plaain.xml](http://www.rtl.nl/components/actueel/4inhetland/miMedia/2006/week16/maandag_koken.avi_plaain.xml)

URL-2:

[http://www.youtube.com/watch?v=UEzDmmfDHU&feature=PlayList&p=D56E3EBD8EF0BC9F&playnext=1&playnext\\_from=PL&index=37](http://www.youtube.com/watch?v=UEzDmmfDHU&feature=PlayList&p=D56E3EBD8EF0BC9F&playnext=1&playnext_from=PL&index=37)

URL-3:

<http://www.voedingswaardetabel.nl/>

URL-4:

[http://www.youtube.com/watch?v=3IL\\_Df5ouUc](http://www.youtube.com/watch?v=3IL_Df5ouUc)

URL-5:

<http://www.youtube.com/watch?v=hhfQlvIVg7A>

URL-6:

<http://www.youtube.com/watch?v=zUyJzQmcKK0>