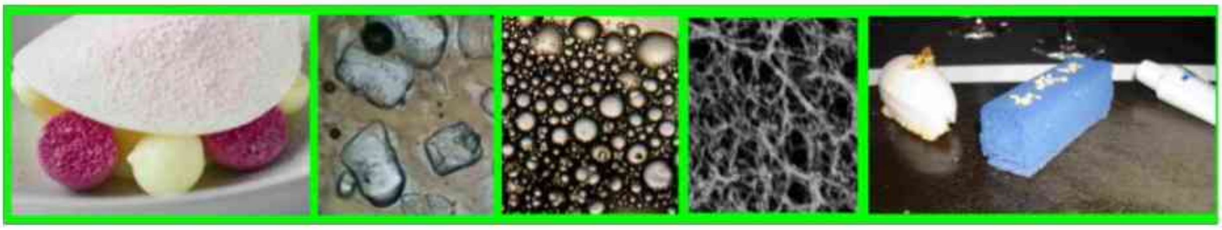

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# Using a descending approach for exploring "culinary definitions", in view of analysis and food innovation

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**Abstract**
The interest of the scientific discipline called molecular and physical gastronomy for education in science and technology is that it focuses on the mechanisms of the phenomena that occur during culinary transformations. To train students to look for such information (that is mechanisms of phenomena, key to good science, technology and engineering, and also to efficient product design and creative innovation), it is useful to show how to move step by step from the macroscopic description of the transformations to molecular descriptions of changes involved, *via* microscopy and analyses of changes at supramolecular level. At each step, quantifying the phenomena helps to select explanations among the many possible ones.

**Keywords**
course, analysis of transformations, descending approach, chemical interpretation

## 1. Introduction

The course whose text is given after this introductory paragraph has been taught at Master level to future food scientists and engineers having a specialization in food innovation and product design.
The aim and objectives of the course are first given, before explaining that looking for mechanisms is key to food innovation and advanced technology. A rational – descending - analysis of phenomena is presented, with a final insistence on the chemical changes, which are the ultimate "explanation" of transformations.
In order to make the matter clearer, many examples are considered. In particular, the approach is leading to the proposal of a categorization of culinary phenomena and "culinary definitions", by decreasing order of material modified during processes.

As a conclusion, it is recalled that food is not limited to a chemical composition : firstly the compounds making up food are organized in physical structures, and secondly the interaction of food with the human body is important for ranking the various compounds that make the food systems.

## 2. The aim of this course: learning a method in order to explore the mechanisms of phenomena that occur during food preparation

▪ This course, intended for future scientists and engineers, aims mainly to give them a method for analysing transformations (in particular food transformations), with a view to producing new systems (in particular food systems). Examples are discussed.
▪ The interest of this method is first presented, before considering an example that shows the implementation of the analysis, first at the macroscopic scale, then at the microscopic scale, before moving to the supramolecular scale and finally to the molecular scale.
▪ In all these analyses, considerations of physics, biology, chemistry are essential, but, better, they must be mobilized in an ordered sequence, in the descending analytical movement indicated above.
▪ The ultimate point of analysis is the molecular (or "chemical") analysis, which is present, even when no chemical reactions are apparent *a priori.*
▪ This observation leads to the possibility of classifying quantitatively the food transformations (by order of quantity of chemically modified tissue).
▪ The importance of chemistry is recalled, in particular by emphasizing the fact that the reactions identified are the analogue of the main equations ("laws") of physics. A particular case that highlights this point is discussed, with a view to inviting students to properly implement the chemical analyses that are the end of their explorations.
▪ However, it should not be forgotten that foods are physico-chemical systems intended to interact with the human body (especially the sensory and digestive systems). This observation leads to new classifications.
▪ References are given for all the points discussed. The students are invited to read these articles, but the text given here should enable independent study.
▪ For the assessment of learning, exercises are proposed in the course of the text (italics in square brackets).
▪ As a whole, the minimum number of hours to be spent on this course (including exercises) was measured to be 3.
▪ After following this course, the students should:
1. know what is a “culinary definition”,
2. know the successive steps of the scientific method (for sciences of nature),
3. know what is the “descending approach for analysing culinary definitions”,
4. be able to rank phenomena by scales, from macroscopic to molecular scale,
5. be able to apply this method in different cases,
6. be able to calculate indexes of transformation,
7. be able to distinguish the “dimensions” that they study.

## 3. Culinary definitions

This course is based on the study of “culinary definitions”, whose study was identified as one of the main projects of "molecular and physical gastronomy". This scientific discipline is the exploration of the mechanisms of phenomena that occur during culinary transformations, not to be confused with molecular cooking, molecular cuisine, synthetic cooking or note by note cuisine (This, 2009a; This vo Kientza, 2021a). It explores in particular the three parts that can be discerned in the protocols called "recipes" (whether oral or written), namely:
- the “definition” of the dishes,
- culinary details added to the definitions (“culinary precisions"),
- third part (This, 2009a; 2010).
Firstly the “culinary definition” of a dish is the

minimum technical information that is necessary for preparing the dish. Sometimes, the name of the dish is enough to indicate the protocol to be used to produce it, but on other occasions, it is necessary to refer to historical sources to know what the definition is.
For example, “grilled meat” is sufficient for knowing what is meant by the expression, even if there are different ways of grilling; or consulting a dictionary is enough to understand that an "apple compote" is obtained by cooking apples with sugar and water (British Standard Dictionary, 2024). On the other hand, historical research is necessary to understand that "civets" are stews that must contain parts of plants of the genus *Allium* (chives, spring onions) (This, 2024a).

*[Exercise 1: Select a culinary recipe from a book or the internet, and identify the “culinary definition”. Calculate the proportion of text relating to this part.]*

Secondly, “culinary precisions” are technical additions that specify the technical protocol. It is worth knowing that 24 years of monthly molecular gastronomy seminars, with public experiments, have shown that 87% of the culinary precisions given by chefs were experimentally shown to be wrong (This vo Kientza, 2021b; This, 2024b).

*[Exercise 2: In the culinary recipe found for Exercise 1, identify the culinary precisions. Calculate the proportion of text relating to these parts.]*

Finally, in recipes, what is neither the definition nor precisions can have an artistic, social or strictly literary interest. This is called the “third part”.

*[Exercise 3: In the culinary recipe found for Exercise 1, identify the third part. Calculate the proportion of text relating to this part.]*

Each of the three aspects of recipes can be explored from a scientific point of view, which means that (This vo Kientza, 2024):

- phenomena have to be first identified,
- they are quantitatively characterized,
- quantitative data are synthesized into equations ("laws"),
- equations, together with new concepts, are grouped into theories,
- testable theoretical consequences of the theories are sought,
- theoretical predictions are experimentally tested.

The objective, in each case, is the exploration of the mechanisms of phenomena (This, 2009).
As an example, a recipe for pear jam can be analysed (Albert, 1838, personal translation):
"*Take about ten medium-sized pears, peel them and gradually put them in cold water. Then melt 125 grams of sugar cubes with a little water over low heat in a pan: as soon as the sugar has melted, place the pears in it, sprinkle them with lemon juice if you want the pears to remain white; if you prefer them red, do not add lemon juice, and it is essential to cook them in a tinned copper pan. Cook gently, and when cooked, place the pears in a fruit bowl, cutting a little on the knot side to keep them upright. Turn on the heat, reduce the syrup and pour it over the pears. You can add a large glass of red wine to cook the pears in*".
In this recipe, the definition is simply "heat pears with sugar and water". The thermal treatment leads to a softening of the pears, and, possibly, to a change in colour (it should be noted that what is written in this regard about the red colour is wrong, see This, 2009a). The recipe includes many "culinary precisions": the proportions (10 pears for 125 grams of sugar), addition of lemon juice, cooking in tinned copper, etc. In this recipe, the third part is almost absent.
This example is a particular case of a large category of processes: during food preparation, plant tissues are frequently used, and often softened by thermal processes, whatever the type of thermal treatment used (in aqueous solution, in hot oil, in hot dry air, etc.). In other words, in the corpus of "classic" food preparation from ingredients that are often plant or animal tissues, the exploration of the phenomena is both:

- the key to understanding, that will allow improvements of classic productions,
- the key to innovations.

For example:

- while classic cookbooks (for example Saint-Ange, 1925) indicate that the quantity of mayonnaise sauce that can be made from one egg yolk is about a third of a litre, understanding the structure of emulsions, the chemical composition of eggs and the chemical composition of vinegar makes it possible to produce more than 60 litres of mayonnaise sauce from one egg (This, 2000);

*[Exercise 4: Look for the chemical composition of eggs and vinegar, and calculate to check the value of 60 L volume given above.]*

- understanding the foaming properties of proteins, gelled foams called "würtz" (Figure 1) can be produced by whipping an aqueous solution (broth, wine, fruit juice, etc.) in which gelatine has been dissolved (This, 2009b);
- understanding the composition of Chantilly creams, egg-free chocolate mousses of the same consistency as whipped cream ("chocolate Chantilly") can be produced (This vo Kientza, 2021c);
- more generally, "molecular cuisine" (that is the use of new methods and new instruments imported from laboratories) has amply demonstrated the possibilities for innovation. These innovations are based on modelling of definitions, which modelling can be obtained at the end of research carried out using a method that is now presented.

## 4. Mechanisms are essential in science and technology

The study of phenomena, that is research into their mechanisms, has as the main advantage to "understand the world", to no longer live in a disordered and incomprehensible set of phenomena, to which our ancestors attributed "divine", "magical" causes. For example, in the



*Figure 1. Food systems named würtz (*top*) are physically gelled foams obtained after heating an aqueous solution (here raspberry juice), dissolving gelatine and whipping while cooling. The name is from the Alsatian chemist Charles Adolphe Würtz (1817-1884) (*bottom*).*

past, it was believed by ancient Greeks that the god Zeus was the one who sent lightning or the god Poseidon storms, that divinities called will-o'-the-wisps surrounded the dead (Hesiod, 1983); it was believed in the laying on of hands to cure diseases, and, even today, beliefs unfortunately persist about extreme dilutions of potentially dangerous active biological principles that are supposed to cure while their concentration in the preparations is so low that no molecule is present (Zawiła-Niedźwiecki and Olender, 2016; EASAC, 2017); some believe in a supposed "memory" of water (Maddox *et al.,* 1988); people of dubious honesty sell supposed remedies that are both irrational and inefficient, etc.

If scientific research into mechanisms helps to eradicate magical thinking (Wilson, 2018), it also has essential technical consequences: global positioning by satellite, for example, would not exist without the theory of relativity (discovered for purely purely scientific reasons, with no idea of application) (Ashby, 2003). Also, as indicated above, many "molecular cuisine" preparations are based on understanding the mechanisms of the phenomena implemented during culinary transformations, not to mention that traditional techniques, often faulty, have been renovated (This vo Kientza, 2021b).

Examples:

- Prior 2002, major international cooking schools taught that egg whites make more foam when always whisked in the same direction (which is wrong: air bubbles are introduced in the liquid egg white regardless the whisking direction) (This, 2002).
- It was claimed (and written) that fish stock would become bitter when cooked for more than 20 minutes (which is wrong: no bitterness was perceived during sensory tests) (This, 2024b).
- It was claimed (in particular by an internationally known chef, 3 Michelin stars) that the temperature in a pan of water could reach 130 °C if a lid was put over the pan (which is false: the experiment refuted this culinary precision, but any person trained in physics knows that the boiling temperature cannot be higher than 100 °C under a pressure of 1 atm) (This vo Kientza, 2023a).

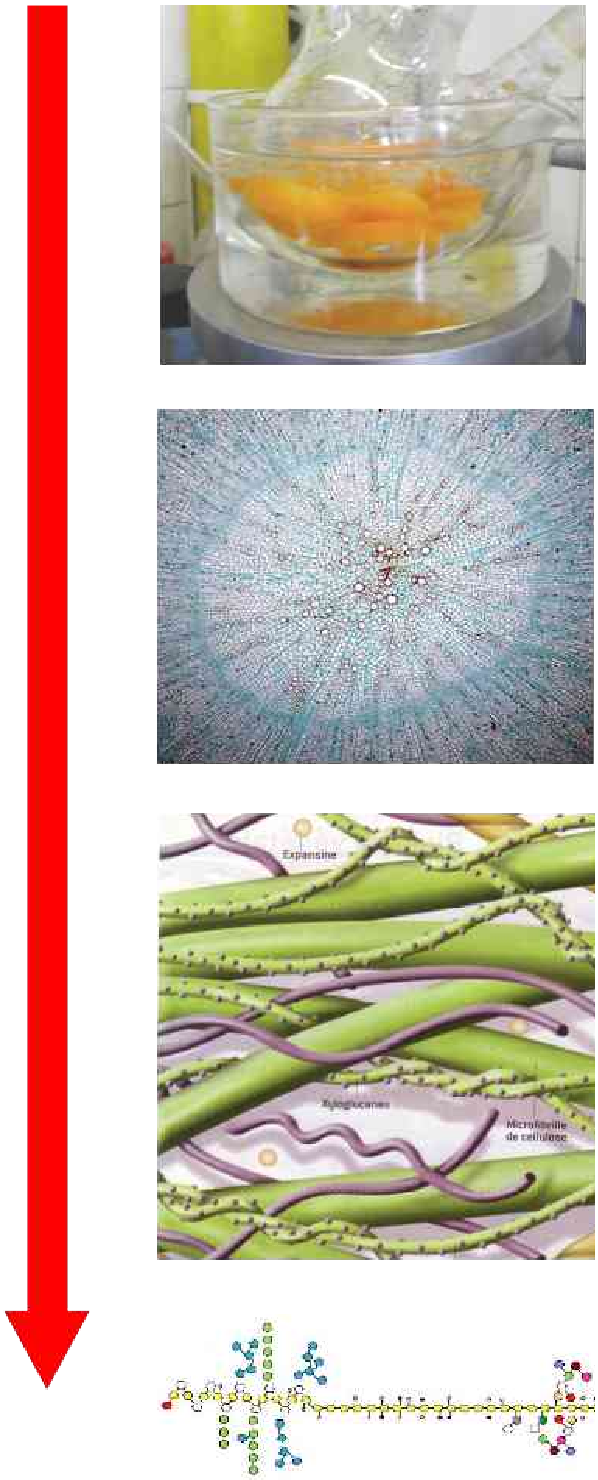


*Figure 2. The descending method applied to cooking the roots of* Daucus carota *L. (“carrots”).*

- And so on: see https://icmpg.hubinrae.fr/travaux-en-francais/seminaires/resultats .

## 5. The descending approach: macroscopic description, microscopic description, supramolecular description, molecular description

How to explore the mechanisms of culinary preparations? And more precisely, how to study "culinary definitions"? In classical science and technology studies, students take physics courses, chemistry courses and biology courses in parallel, and they risk putting all this knowledge on the same level, when they are faced with phenomena occurring during culinary processes, where chemical, physical, biological aspects are mixed. Here, the goal is to show that it is better to move stepwise from the observation of macroscopic transformations to the analysis of molecular transformations (Figure 2). This method can be studied using an example: making mashed potatoes.

### 5.1. Macroscopic phenomena

Macroscopic observation, with the naked eye, of potatoes (more precisely: tubers of *Solanum tuberosum* L.) thermally processed in water at 100 °C ("boiling") shows only a slight surface modification, that is a minor physical change. But, when potatoes are mashed (macroscopically), the solid tuber is transformed into a thick preparation, something that would not have been possible without the softening effect of cooking. This is a first phenomenon that can be studied (Colin-Henrion *et al*., 2003).

*[Exercise 5: Find an order of magnitude of the energy reduction corresponding to this softening. Try to validate it, using a second different calculation, or data on the internet.]*

To make mashed potatoes, professionals recommend crushing the cooked potatoes with a

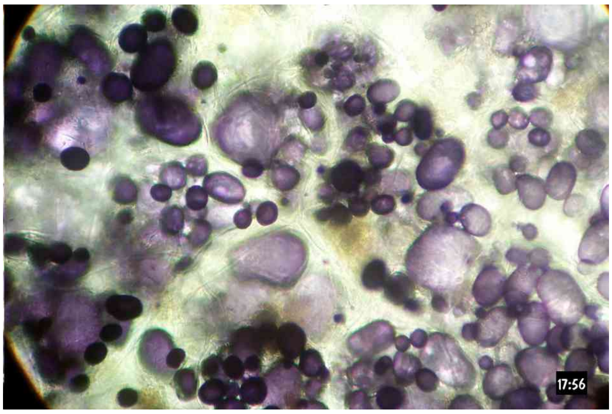

*Figure 3. Such a picture can be simply obtained by cutting a thin slice of potato (*Solanum tuberosum L.*) tuber, putting it on a glass slide, and adding a drop of iodine tincture. The size of the starch granules* (in purple) *is between 5 and 85 µm, with variations depending on potato cultivar.*

liquid (often milk), in order to get a softer puree: this is a second phenomenon that can be analysed. Professionals also recommend pressing the cooked potatoes, not mixing them, otherwise, they indicate, the puree would become sticky, which is considered a sign of poor culinary work (Bocuse, 1976): there is an experimental verification to be made here, and, if the "culinary precision" is proven (indeed it is), then there is a third phenomenon to investigate using the scientific method.

The physical observations lead to questions: why does the plant tissue, which resists mashing before cooking, crush so easily after cooking (the presence of the adverb "easily" in the previous sentence is an invitation to compare quantitatively the breaking forces of raw or cooked potatoes)? To explore the culinary precision about mixing instead of mashing, how does "stickiness" changes before and after mixing, before and after addition of a liquid?

### 5.2. Microscopic analysis

To look for the mechanisms of the macroscopic

phenomena and to answer the above questions, it is wise to move first from the macroscopic to the microscopic scale: start by making (or looking for) microscopies of the plant tissue before and after cooking. Using a simple iodine staining and optical microscopy (Rundle, 1943), one can observe:
- the presence of well defined starch granules in the potato cells before cooking (dark blue shapes, Figure 3),
- a diffuse blue colour in the cells after cooking,
- the separation of cells into clusters of cells that are most often intact, after cooking and gentle pressing,
- the opening of a proportion of cells when purees have been mixed, releasing their content in the continuous aqueous solution of the "suspension" made by mashing (Leverrier, 2021).

*[Exercise 6: Search the internet to find out why starch turns blue when it comes into contact with iodine dye.]*

Here again, the phenomena can be followed quantitatively, in particular by image processing, which allows a characterization of the starching (Singh and Kaur, 2004).

### 5.3. At the supramolecular level

After this microscopic analysis, it is a question of understanding how cells or groups of cells can separate, which will require examining the plant cell wall, namely examining the phenomena on a supramolecular level, that is at which molecules associate (Lehn, 1993). For this example, if the cells are intact (which is shown by microscopy), it is the "intercellular cement" that deserves to be explored.

Plant biology has shown that cellulose molecules provide the tensile strength of the primary cell wall (Alberts *et al.*, 2002). Each cellulose molecule is a linear chain of at least 500 D-glucose residues that are covalently linked to each other to form a ribbon-like structure, stabilised by hydrogen bonds within the chain (Figure 4).

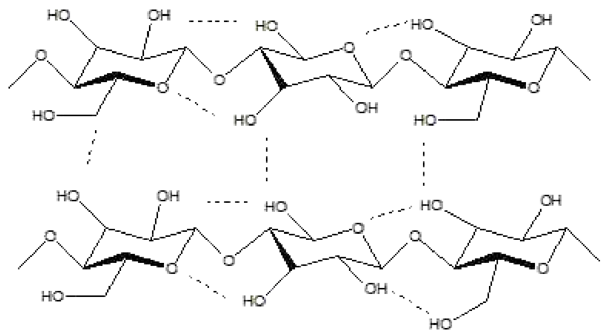

*Figure 4. Assemblies of cellulose molecules are stabilised by intra- and extramolecular hydrogen bonds* (dotted lines).

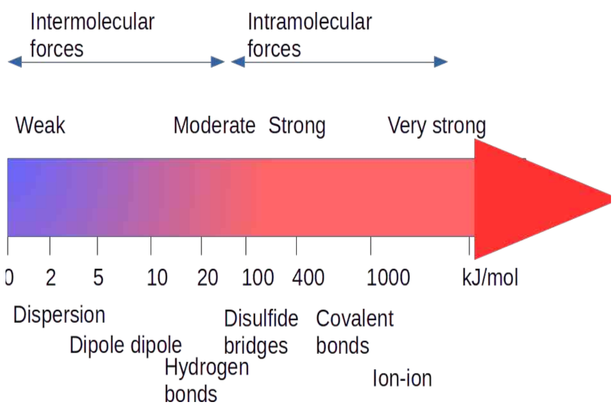


*Figure 5. The arrow of chemical energies. The chemical details of the interacting objects can change the energy of the bonds between them, but anyway it is good to remember the order of magnitudes when analyzing a physical and chemical question (This vo Kientza, 2023).*

In addition, intermolecular hydrogen bonds between adjacent cellulose molecules glue them together in parallel, overlapping networks, forming bundles of about 40 cellulose chains. These ordered "crystalline" aggregates, several micrometers long, are called cellulose microfibrils. The microfibril clusters are arranged in layers, or "lamellae", with each microfibril about 20 to 40 nanometres apart from its neighbours and connected to them by long, cross-linked pectin molecules that are hydrogen bonded to the surface of the microfibrils. The primary cell wall consists of several such lamellae, arranged in a plywood-like network. If one wants to add quantitative information about this description, the “arrow of chemical energies” is helpful (Figure 5) (Cottrell 1959; Benson, 1965).

### 5.4. Molecular analysis

During cooking, the cellulose fibres are not modified, but the pectin molecules are hydrolysed, which allows the cells to separate (Neukom and Duel, 1958; Heim and Neukom, 1962). This chemical process is called beta elimination and it depends on pH (Figure 6).

*[Exercise 7: Search the internet for the energy to be given in order to hydrolyse a bond between saccharide residues in a polysaccharide, and place it on the energy arrow. Compare the energies for different polysaccharides.]*

Thus, by this downward movement (macroscopic → microscopic → supramolecular → molecular), the initial phenomenon is interpreted (why a puree can be made by cooking potatoes in an aqueous solution), at the same time as a whole series of new scientific questions can be raised:
- What is the pH in the potatoes that are cooked (as it is important for beta elimination of pectins)?
- How fast is the beta elimination of pectins in the real case of potatoes?
- Does the beta elimination reaction of pectins depend on the cultivars?
- How to calculate the firmness of potatoes according to the state of the pectins?
- What is the energy needed to separate cells, and how does it compare to the energy of cell rupture?
- etc.

Finally, it can be observed that an example was considered here, but that all culinary preparations are structured around a "definition" that must be interpreted in this way.
Mostly, one has to consider:
- heat treatments of plant tissues,

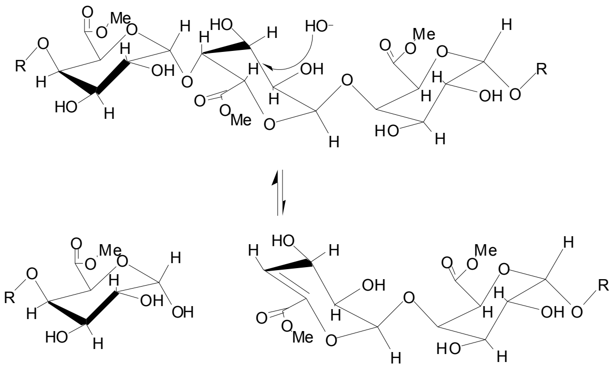


*Figure 6. Beta elimination of pectins (from Keijbets, 1974)*

- heat treatments of animal tissues,
- formations of colloidal systems (including pastes, batters, doughs, sauces, etc.)
- and others.

This set of descriptions deserves to be known by food engineers because they will have to use this information when dealing with food preparation, classic or innovating.

### 6. There is always chemistry, even when one believes that there are only physical transformations.

Having outlined the proposed strategy for the study of culinary transformations, it is worth highlighting the importance of chemistry in molecular and physical gastronomy (This vo Kientza *et al.*, 2021a). More precisely, it is proposed to examine how chemistry is present in the studies even when it does not appear at first sight. Examples will be analysed: roasting meat and cutting carrots.
When meat is roasted, first, the main macroscopic effects are:
- browning of the surface,
- contraction of muscle tissue,
- release of "juice".

The browning of the surface is often directly interpreted chemically, but one gets more understanding applying the descending approach. First a microscopic observation shows that “meat” - that is muscular tissue of animalsis made of bundles of bundles of elongated cells called muscular fibres (Figure 7) (OpenStax, 2016). When this tissue is heated at more than 100 °C, water evaporates at the surface (having the temperature of the heating environment), and a peripheral “crust” (that is a layer of dried tissue) is formed (Portanguen *et al.*, 2014). At the inner side of this crust, the temperature is limited to about 100 °C. The brown colour is on the outside of the meat, where chemical reactions are promoted because of a high activation energy (McQuarrie and Simon, 1997).

*[Exercise 8: Propose mechanisms for changes in meat structure at microscopic and supramolecular level.]*

Finally, the browning can be interpreted at molecular level, with many chemical reactions. Often, this colour change is attributed to “Maillard reactions”, but (1) this name is unjustified and illegitimate (IUPAC, 2019) and (2) glycation and amino-carbonyl reactions are only two possibilities of generating a brown colour, among many others, including pyrolysis of proteins, which is probably more important than what has often been said without quantification (This vo Kientza, 2023b).
For meat shrinkage (macroscopic phenomenon), microscopy is not enough, as it shows only a disorganization of the collagen connective tissue and changes in the interior of the muscle fibres (Marin *et al.,* 1991; Latorre and Velazquez, 2021). The explanation of the phenomenon comes at supramolecular level: there is (1) a denaturation followed by a degradation of collagen (separation of the three polypeptide chains that make up the triple helix of the collagen molecule, and a partial hydrolysis of polypeptides) and (2) a coagulation of myofibrillar proteins (mainly actins and myosins) (Bozec and Odlyha, 2011).
Of course, physics calculations can be performed to determine the heat transfer inside the meat and to explore the temperature distribution in the tissue; the release of juices can be linked to the volume change of the meat, but to understand the phenomena more deeply, one must study the coagulations of actins, myosins, as well as the denaturation, followed by the degradation of collagen molecules: all this ultimate exploration is a matter of chemistry (Bendall and Restall, 1983).

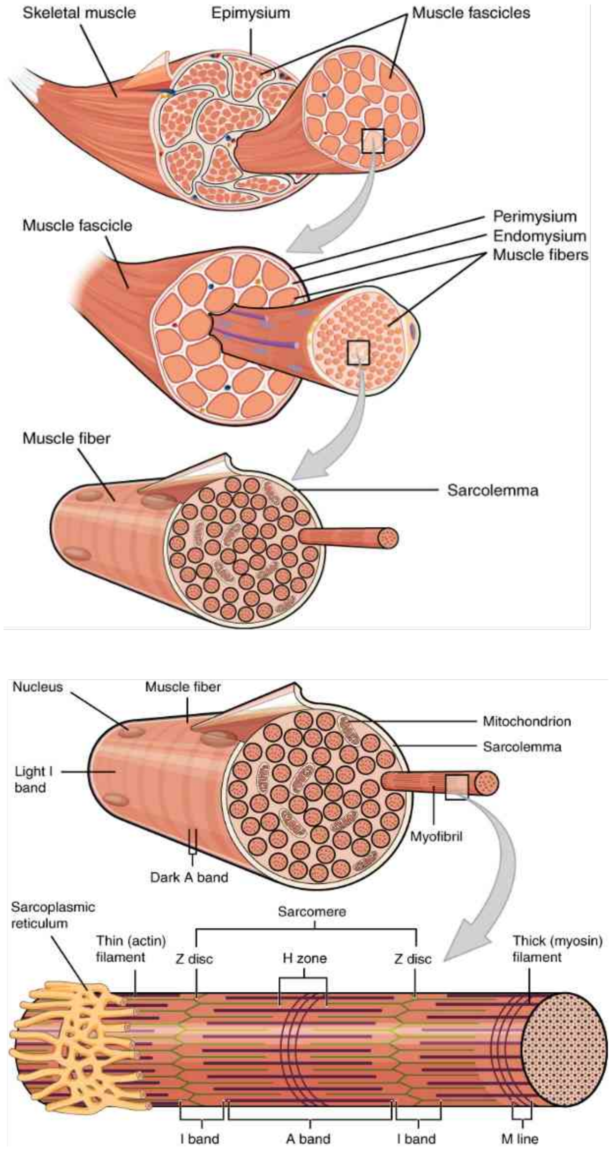


*Figure 7. The organization of muscular tissue (*top*) and of muscular fibres (*bottom*) (OpenStax, 2016).*

*[Exercise 9: Assuming that the thermal capacity of meat is the same as for water, calculate the quantity of energy for heating a roast (mass*

*1 kg) to the temperature of 80 °C. Compare it to an estimation of the electric energy needed for heating the roast in an oven.]*

The second example in this paragraph is about cutting carrots (more precisely: the roots of *Daucus carota* L.). Here chemical changes are less easy to recognize than for meat cooking, but again they are important for consistency and flavour. This examples hints to show that there are molecular transformations in any culinary process.
Indeed, when preparing a carrot salad, the first step is to peel the roots, then divide them into filaments ("julienne") (Bocuse, 1976). Microscopy shows (or can show) that, during these two operations, the knife blade passes through at least one layer of cells, releasing their contents, which can be seen in the liquid that appears on the surface (Dobranszki, 2021).

[*Exercise 10: On the internet, look up the width of the edge of a knife and compare it to the size of a plant cell in the parenchymal tissue of a carrot.]*

During this cellular degradation, phenols (one should speak of "phenols", and not of "polyphenols", see This vo Kientza, 2021d) are released and come into contact with phenol-oxidase enzymes (E.C. 1.14.18.1): the enzymatic modifications of phenols generates compounds that ultimately evolve into melanoidins, responsible for browning of the surface (Macheix *et al.*, 2005).
In this transformation again, there is (1) a physical action (the division of the plant tissue), (2) a microscopic modification (cell degradation), (3) supramolecular changes (release of compounds from their initial cell environment), and (4) molecular transformations (enzymatic changes, among others). Here only a limited number of cells are involved.

## 7. The universality of reactions in chemistry

The chemical interpretations of phenomena were short, in the previous section, because this question deserves a longer discussion, which is made now.
Firstly it can be observed that, over the past years, in the physical chemistry course as in the molecular and physical gastronomy course given in two Master programmes (Food Innovation and Product Design, https://fipdes.eu/; Ingénierie Produits Procédés, https://www.agroparistech.fr/formations-master/mention-genie-procedes-biopro cedes-parcours-m2-pba-procedes-biotechnologies -aliments), students often limited their interpretation of phenomena at macroscopic or microscopic level. For example, they applied the physical laws of heat transfer, they envisioned the physical behaviour (macroscopic) using rheology, but sometimes stopped their analyses before moving to the supramolecular and molecular level. This current course invites them to go further, trying first to understand why the chemical analysis was avoided or omitted.
Firstly it is worth pointing out that there has been a rivalry between physics and chemistry (Duhem, 1899): some considered that physics produce great general, algebraic laws, while chemistry would have been a series of "recipes". This criticism is unjustified, because the classical reactions, either general (addition, elimination, condensation, substitution, etc.) or more particular (Diels-Alder, Mannich, amino-carbonyl, etc.), are the strict counterpart of the great laws of physics (Newton's equation, Ohm's, Fourier's, etc.): in chemistry as in physics, scientists of the past have patiently arrived at the discovery of regularities of the world. Chemistry is not a sum of detailed facts, but rather an organized array of general ideas based on electron transfers, among others.
Secondly, for some students of the previous cohorts (but this seems to be quite general, see Schweiker *et al.,* 2020), chemistry had the bad reputation that it would be a science of "by heart", less general than physics, with a long series of particular reactions; however engaging students in the theory behind organic reaction mechanisms can spark their interest for chemistry. Research into enhancing students'

understanding of organic reaction mechanisms includes the subject's curriculum design, and the explanation around electron movements (Schweiker *et al.*, 2020).

It is true that until the early 1950s, chemical reactivity was described using Lewis diagrams, with arrows showing the transfer of a group of atoms from one place to another by surrounding it with a circle: this was known as "lasso chemistry" (Foulon, 2023). Based on the idea that reaction mechanisms involve the movement of electrons from atoms during a chemical reaction, chemistry has become very mechanistic, very logical, and the representation of molecules should in reality only aim at the identification of donor or acceptor groups, of electronic distributions, which condition the possibilities of reaction (Anslyn and Dougherty, 2006).

Finally, it is useful to observe that physics and chemistry both use formalisms, although different: algebraic equations for physics, chemical formulas and equations for chemistry, which does not, today, save on algebraic calculations as in physics (McQuarrie and Simon, 1997). To conclude about this question, it will be now shown how modern food science gains from not forgetting chemistry, considering the important health issue of formaldehyde (Figure 8) production during grilling meat.

Aldehydes, with an intermediate oxidation state between alcohol and carboxylic acid, can interact by reduction or oxidation with various compounds in the body (Figure 9). Toxic aldehydes are contained in foods, naturally produced by the metabolism of fruits, vegetables, meat, fish, shellfish, mushrooms (Bi *et al.*, 2024). In addition, ingredients containing proteins or unsaturated fatty acids can release formaldehyde during heat treatments, particularly through Strecker degradation of amino acids or oxidation of polyunsaturated fatty acids (Figure 10). Formaldehyde is the predominant aldehyde in meat cooking; it is classified as carcinogenic by the International Agency for Research on Cancer (IARC) (Goldstein and Smith, 2006), and its control in foods seems important.

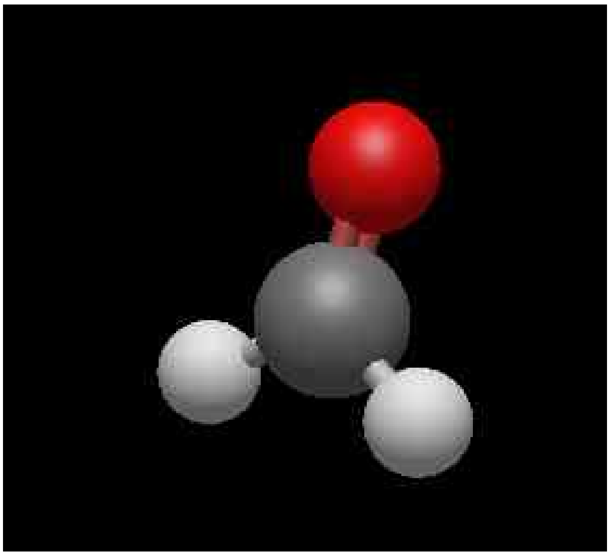

*Figure 9. Formaldehyde (methanal).*

However, it has been discovered for several years that the addition of phenolic compounds can reduce the formation of aldehydes (particularly formaldehyde) during heat treatments. Why? By how much? Are all phenols effective? Among the mechanistic hypotheses, there are:

1. The anti-radical action of phenolic compounds (Sroka, 2005) : chlorogenic acid - as a prototype of other phenols - is an important dietary anti-oxidant component (Figure 11). The antioxidant

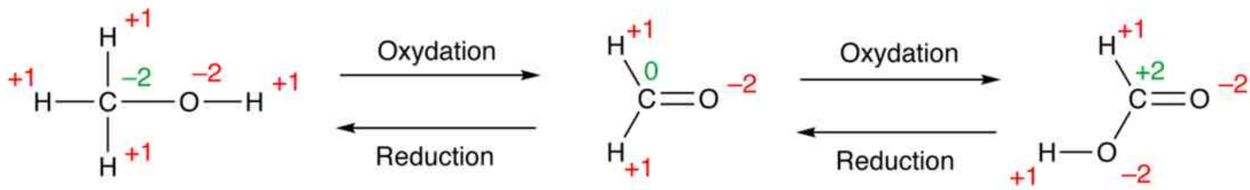


*Figure 8. Formaldehyde (*centre*) can be either reduced into an alcool (methanol,* left*) or oxidised into a carboxylic acid (formic acid,* right*). Here the oxidation numbers used for the calculation are in red, and the result is in green.*

activity of chlorogenic acid mainly derives from its ability to scavenge free radicals, but is also related to the lipid peroxidation level in the body. Studies have shown that chlorogenic acid can supply hydrogen atoms to free radicals; it is oxidized to a phenoxy radical (ArO•, where Ar is an aromatic group) and subsequently reaches a steady state by mesomerism (sometimes called "resonance", see Kerber, 2006).

2. Michael addition reactions (Figure 12): the meta-donor hydroxyl (-OH) groups of phenols, by creating electron-rich centres on the unsubstituted carbon atoms, could facilitate electrophilic substitutions with the electrophilic moieties of the aldehydes.

3. A series of three-partner adducts (gallic acid-formaldehyde-amino acid) could be formed by the Mannich reaction. In Figure 13 top, the general Mannich reaction is shown; at the bottom, a Mannich reaction is depicted between phenol, formaldehyde and amino acid.

The question of the mechanisms is essential here, because, depending on the mechanisms, it will not be the same solutions that can be efficient to reduce the quantities of aldehyde in food. In the study by Bi *et al.* (2024), it was shown that, in tea extracts, known to reduce the quantities of aldehydes, catechins were particularly active. These particular compounds were demonstrated to participate in Mannich reactions. But since the quantity of acetaldehyde was also reduced, while this compound cannot participate in Mannich reactions, it must be concluded that the anti-radical action of phenols was added to the Mannich reaction.

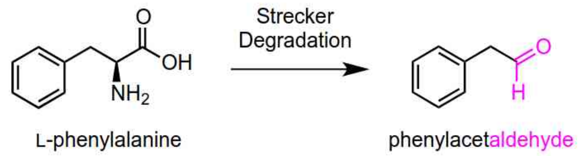


*Figure 10. The Strecker degradation of L-phenylalanine generates phenylacetaldehyde, with a honey flavour.*

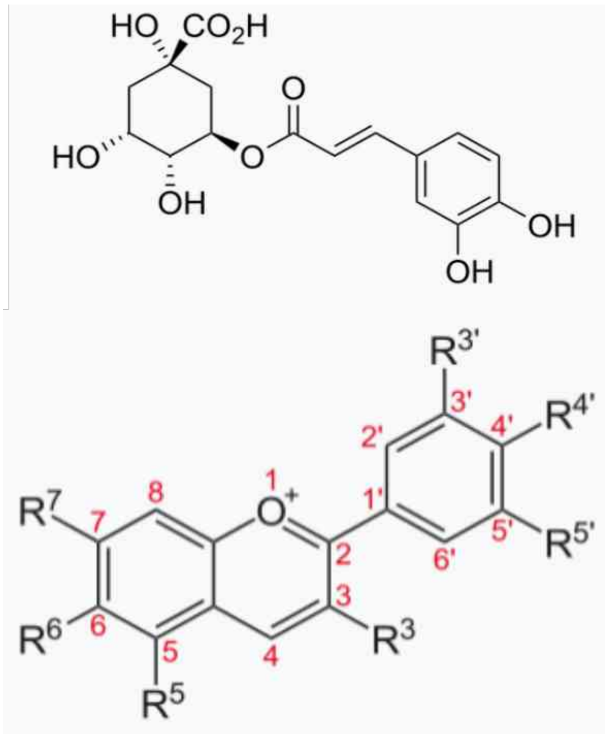


*Figure 11. Chlorogenic acid (*top*), and anthocyanidins (*bottom*), that is the aglycone part of anthocyanins. Both (and others similar compounds) are radical scavengers.*

## 8. Order phenomena by quantity of transformation

It was said above that the study of phenomena is improved if it is quantitative. For example, it was previously observed that, for certain culinary transformations, the effect on the ingredients seems "limited". However scientific studies are upgraded when adjectives and adverbs are replaced by the answer to the question "How much?" (This vo Kientza, 2023). Can the importance of effects be quantified? And, if so, is it possible to distinguish culinary transformations by quantities or proportions (order of magnitudes) of modified matter? For example, how would one rank grilling meat, making of a carrot salad, whipping of egg whites or making of lettuce salad?

(1) Grilling meat can be first considered: if the meat is not rare, and more precisely if the

temperature inside meat is above 60 °C, the proportion of modified tissue is 100%, because myofibrillar proteins (especially myosins) are denaturated above 40 °C (Christensen *et al.*, 1999).
(2) Now, for the determination of modified tissue during the making a carrot salad, a longer calculation is needed. This involves dividing a carrot into a julienne, starting with a mass *M* of plant tissue. As a first approximation, the density of the carrot is equal to that of water ($\varrho$): a carrot is made of 80% water (Ciqual, 2024a).

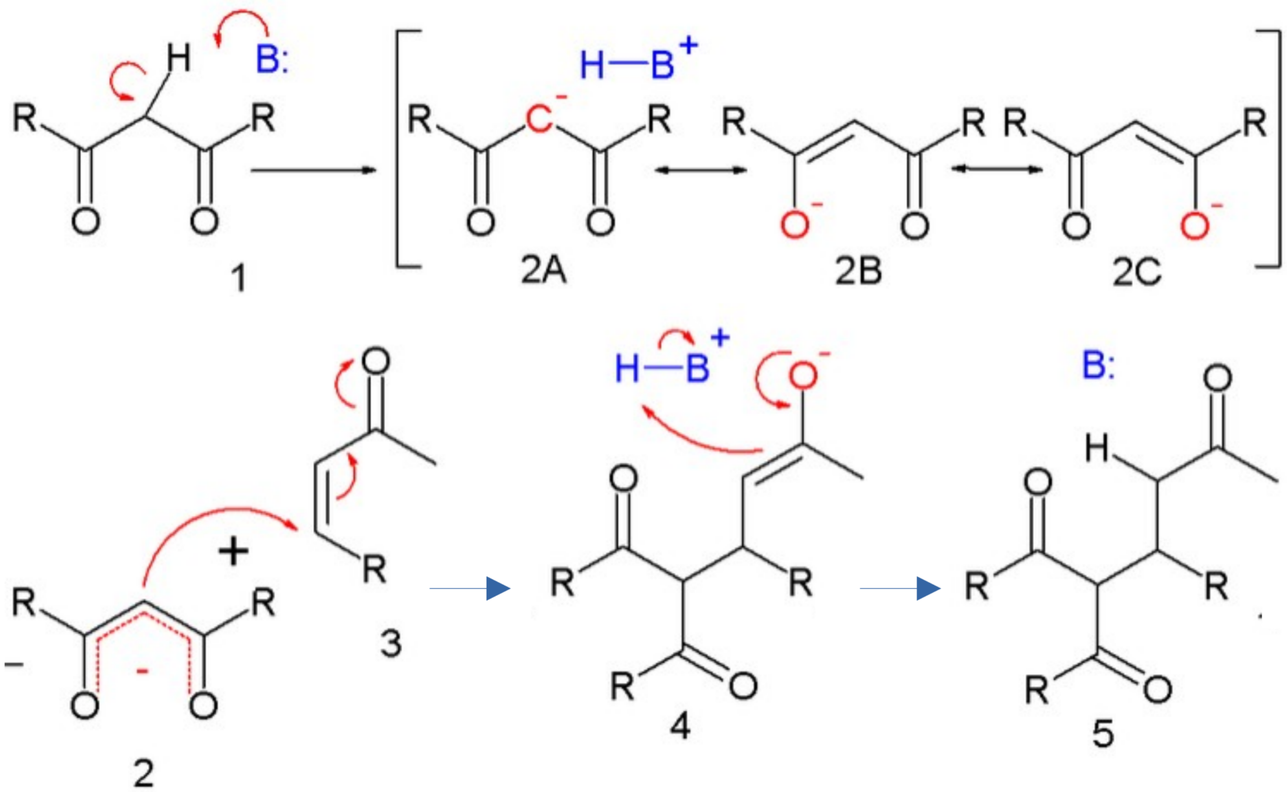

*Figure 12. The Michael addition involves a Michael donor (an enolate or other nucleophile) and a Michael acceptor (usually an α,β-unsaturated carbonyl) to produce a Michael adduct by creating a carbon-carbon bond at the acceptor's β-carbon. B is a base (Tokoroyama, 2010).*

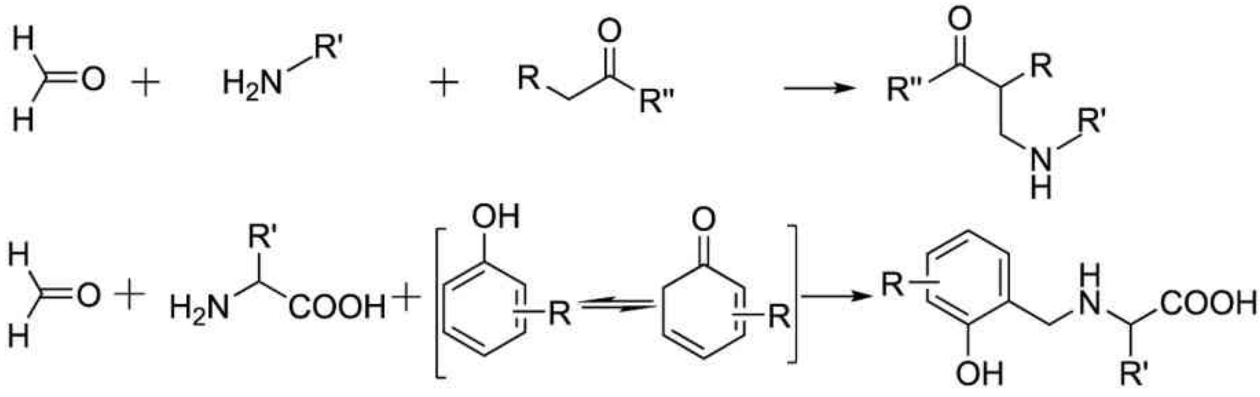

*Figure 13. The Mannich reaction involves an enolizable carbonyl, an amine and formaldehyde (Bi* et al.*, 2024).*

Let a volume *V* of carrot be given by:

$$\rho = \frac{M}{V} \quad (1).$$

The carrot is considered to be a parallelepiped volume of length *L* and square section of side *C*, so that:

$$V = L\ C^2 \quad (2).$$

It is assumed that juliennes are made of filaments with a length *L* and a section of side *c*. The number *N* of filaments is obtained by dividing the volume of the root by the volume of one filament:

$$N = \frac{C^2}{c^2} \quad (3).$$

For a validation, one could also divide the section of the carrot by the section of one filament.

For each filament, there is, on each of the four lateral faces, a half layer of cut cells (the other half belonging to the adjacent cell). With four faces per filament, the cut area per filament *a* is :

$$a = 4\,L\,c \quad (4).$$

And the total cut area *A* is equal to the cut area of a filament multiplied by the number of filaments:

$$A = \left(\frac{C^2}{c^2}\right)(4\,L\,c) \quad (5).$$

If the cells are like cubes of side *σ,* the number of cut half cells on all the cut faces:

$$n = \frac{\left(\frac{C^2}{c^2}\right)(4\,L\,c)}{\sigma^2} \quad (6).$$

But as cells are counted twice, the number should be divided by two. For the proportion *p* of modified volume, one has to divide the volume of cut cells (the number of cut cells by their volume) by the total volume of the root:

$$p = \frac{2\,C\,\sigma}{c^2} \quad (7).$$

Digital application:

Using the data (SI units) *C* = 0.02, *c* = 0.001, σ = 0.1e-5, the proportion of modified tissue is calculated to 0.04: 4% is far from being negligible.

(3) Whipping egg white is another practical case that can be studied. The egg white is an aqueous solution of 90% water and 10% proteins (more than 398), often globular (Arena *et al.*, 2020; Jalili-Firoozinezhad *et al.*, 2022; Meng *et al.,* 2022; Sarantidi *et al.,* 2023; Zang *et al.*, 2023; Ciqual, 2024b).

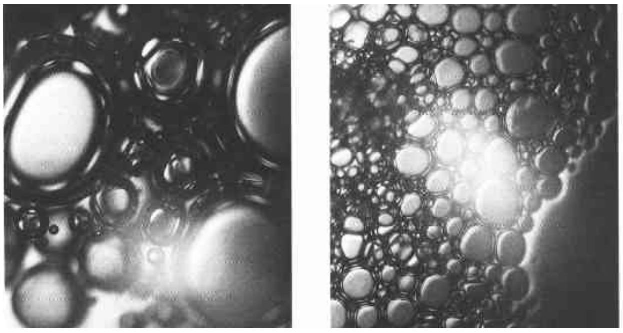

*Figure 14. Whipped egg white at the beginning (*left*) and end (*bottom*) of the whipping process. The diameter of the largest structures, for these two images at the same magnification, is about 0.1 mm.*

Macroscopically it appears that air bubbles are introduced into the liquid and divided by the whisk. Then, as the system whitens, the bubbles are no longer visible, and a microscope is needed to show them: initially, the bubbles that are dispersed in the liquid are spherical, but gradually, their size decreases, and there are so many of them in the liquid that they deform (Figure 14).

To understand why a foam with a stability of some hours is obtained (whereas whipping pure water would make a foam whose stability would be reduced to a few tens of a second), the analysis at supramolecular and molecular levels is needed. Chemically, the air is not modified during whipping, but the proteins are: shearing denaturates them (Charm and Wong, 1970), improving their surface active properties, so that they stabilise (especially ovalbumins) the air-liquid interface (Lechevalier *et al.*, 2005).

The amount of proteins needed to make a whipped egg white can be calculated as follows: considering a foam volume of 1/3 L, a bubble diameter of 0.1 mm and two layers of proteins on the surface of each bubble (Le Floch-Fouéré *et al.*, 2010), one can determine a minimum proportion of modified proteins of 1/10,000.

*[Exercise 11: Try to make this calculation by yourself.]*

Thus, while the macroscopic transformation is total, the calculation shows that the chemical transformation is less important than what could have been expected.
(4) The next example is the preparation of lettuce to eat it in salad. Here, if leaves have a surface area of 10 cm², cells of 1 µm in diameter, and if they are divided into two parts where the knife blade passes, with a damage size of about 10 cells, the proportion of modified plant tissue is 1/10,000,000 (again, students are invited to calculate this by themselves).This is very little, but the effect is visible. If we add vinaigrette, the effect can be even greater, because the oil adheres to the surface waxes, which has the effect of softening the tissues (Michalski *et al.,* 1998).

*[Exercise 12: Calculate the proportion of modified tissue:*
*1. when making French fries;*
*2. when making carrot puree.]*

More generally, if there is a culinary transformation, it is because there is chemistry at play, and it was shown that it was always possible to quantify the proportion of chemically modified tissue.
Does this mean that a degree of "transformation" of foods could be calculated or measured? A questionable classification has been proposed (This, 2022), but comparing a cassoulet with a rare grilled steak shows how difficult (perhaps impossible) it is to find a “degree of naturalness” (the inverse of a degree of transformation):
- for a cassoulet, cooking is performed at only 95 °C, but it lasts for 8 hours (Bocuse, 1976);
- for the steak, grilling lasts only 2 minutes, but the surface of the meat is heated at 300 °C (Bocuse, 1976).
From a health and nutritional point of view, cassoulet and steak cannot be compared, because -there are many competing effects in both. For example, raw beans contain toxic lectins, which are thermally degraded over time (Zhang *et al.*, 2008); starch can be hydrolysed, releasing smaller saccharides, and creating other compounds such as toxic hydroxymethylfurfural or other products through hexose dehydration. Cooking of meat generates various new compounds at the surface, either as a result of protein pyrolysis or glycation, for example (Goldstein and Smith, 2006). However meat provides proteins, iron, zinc, selenium and vitamin B12. The quantity of modified tissues is 100% for beans, but it can be as low as 50% if the meat is extra rare.
Finally, with different compounds having different advantages and drawbacks, and different levels of transformation (macroscopic, microscopic, supramolecular, molecular), comparison is theoretically impossible. This is a particular case of a general rule, that is that comparison of objects in a space with two (or more) dimensions calls for an arbitrary criterion: for there to be a classification, an “order relation” is required, namely that this relation (R) on the elements of a set E must be:
- reflexive : $\forall x \in E, xRx$;
- antisymetrical : for all $x,y \in E$, if $x R y$ and $y R x$, then $x = y$;
- transitive : for all $x,y,z \in E$, if $x R y$ and $y R z$, then $x R z$.
And this question of the "dimensions" of food will lead to discussing the fact that the choice of study perspective is essential.

## 9. Various "dimensions"

As seen above, the proportion of transformed tissue is not always relevant in cooking: for example, for rare grilled meat, the proportion of transformed tissue (either coagulation or browning) may be very low, but its flavour can be considerably changed, and it is the flavour that makes food appreciated. More generally one should remember that there are many "dimensions" for foods, such as (This vo Kientza, 2021e):
- chemical composition,

- consistency (avoid the confusion with texture, see Steele *et al.*, 2015) of the different parts of the dish,
- their organization in the three-dimensional space,
- their tastes,
- their content in odorants (Dunkel *et al.*, 2014),
- their release of odorants reaching the olfactory system by the antenasal route,
- their release of odorants reaching the olfactory system by the retronasal route,
- their colours,
- their visual textures,
- their content in trigeminal active compounds,
- the presence of calcium ions (Tordoff, 2001),
- the presence of long-chain unsaturated fatty acids, or triglycerides containing residues of this type ("oleogustation") (Gaillard *et al.*, 2008),
- nutrients and their bioavailability,
- toxic compounds,
- and much more (This, 2014).

For each characteristic, the relationship between the quantity of molecules and the sensation is different: the raw chemical composition is not enough because it says nothing about the effect of these compounds on the organism, namely the sensory apparatus and the digestive system.
For example, for the “dimension” of the chemical composition, wine is the same as water to the first order of magnitude (then, in order, there will be ethanol, glycerol, tartaric, malic, succinic acids, phenols, etc.). The consistency of the wine is another “dimension”. It is due, in order, to water, ethanol, glycerol, for example. For the taste of the wine (another dimension), there will be, in order, ethanol, organic acids, certain phenolic compounds (tannins, in particular), mineral ions (and water is far away in the list). For the odour of wine, ethanol is important, as well as a whole series of odorant organic compounds present by weight in very small quantities: some very important odorous compounds (first order of magnitude of the odour) can be present at concentrations as low as one part per billion.

## 10. Conclusions and perspectives

Because many different aspects were considered in this course, it is useful to focus finally on the five main ideas that were discussed:
1. a descending analysis is useful for exploring phenomena,
2. it is wise to make the analyses step by step, without skipping any,
3. ultimately the phenomena are to be interpreted in chemical terms,
4. quantitative characterization at all levels is fruitful.
5. ranking is not always straightforward, in particular when problems have to be analysed in more than one dimension.

Finally the students are invited to apply the descending approach to a case of their choice. Of course, during this exercise, some bibliographical research will be needed.

*[Exercise 13: Select a recipe and propose a descending analysis. Keep track of all references in a table, using the following format:*

| *Keywords of research* | *Reference of the article found* | *Evaluation* | *Is it relevant* | *Main information* |
|---|---|---|---|---|

*For more information on how to carry out a bibliographic search, see This, 2024c).*

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**Courses**
**(Molecular Gastronomy and Education/Communication)**

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