CHAPTER 8

HEAT TRANSFER AND METHODS OF COOKING

8.1 INTRODUCTION

There are three main reasons for cooking food:

(i) to improve its **digestibility**, that is, to make it easier to eat, break down and absorb,
(ii) to increase its **palatability**, which means to make it more attractive by improving the taste, smell and colour, and
(iii) to make it **safe** (or safer) to eat, in relation to food poisoning and food spoilage micro-organisms (see Chapters 9 and 10).

Cooking food requires the transfer of heat to the food or the generation of heat within the food, both of which can be achieved in many ways. In fact, most of the common cooking methods, such as boiling, frying, and roasting, involve more than one of the types of heat transfer which are *conduction, convection* and *radiation*.

In conduction and convection, heat transfer is *indirect*, since it is transferred by a solid, air or a liquid, whereas in radiation (infra-red or microwave) heat transfer is *direct*, requiring no medium for travel.

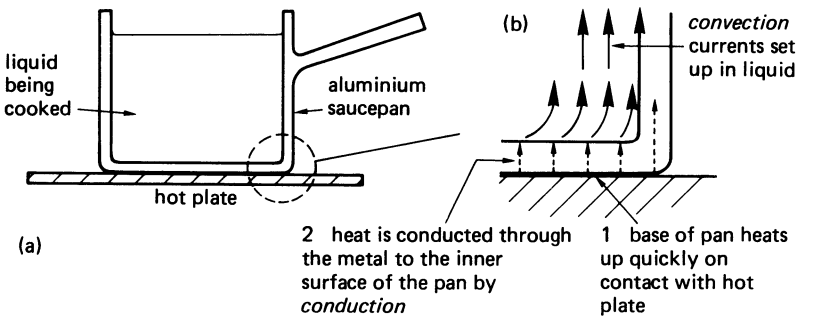
8.2 CONDUCTION

This is the process by which heat energy flows through an object from a high temperature to a lower temperature. For example, if a cold aluminium saucepan is placed on a hotplate or gas ring, the base of the pan heats up and heat travels to the inner surface of the pan by conduction. The heat is then transferred to the food inside the saucepan (see Figure 8.1).

Different materials have different rates of conduction and are therefore suitable for different functions in catering. Metals are

S. R. Dudley, *Mastering Catering Science*

Figure 8.1 *Conduction through the base of a saucepan*



usually good conductors and are used for the manufacture of saucepans, large pots, roasting and baking trays, boilers, and kettles. Where the transfer of heat needs to be slow, as with the linings to ovens and refrigerators, gloves, handles, stirrers and spatulas, poor conductors are required such as air, cloth, wood, rubber and plastic. Table 8.1 shows some good and poor conductors of heat.

Table 8.1 *Conductors and insulators in catering*

	Material	*Uses*
Good conductors	Silver	Expensive. Uses normally involve presentation of food.
	Copper	Pans, pots and kettles. Saucepans often lined with tin (copper pans may be unlined, lined with tin or even lined with silver as in flambé cookery)
	Aluminium	Pans, pots and kettles
	Iron	Fritures, frying pans, baking sheets.
Poor conductors (insulators)	Plastic	Handles, control knobs
	Wood	Handles, trivets, etc. Use is severely restricted now because of fire and hygiene hazards
	Air	Insulating layer in refrigerators and ovens

The choice of metal used for saucepans and other equipment is not just governed by conduction rate, however. The cost, weight and durability of the metal are also important, and lead to the selection of aluminium and copper pans in most cases.

'. . . usually good conductors and are used for the manufacture of saucepans . . . '

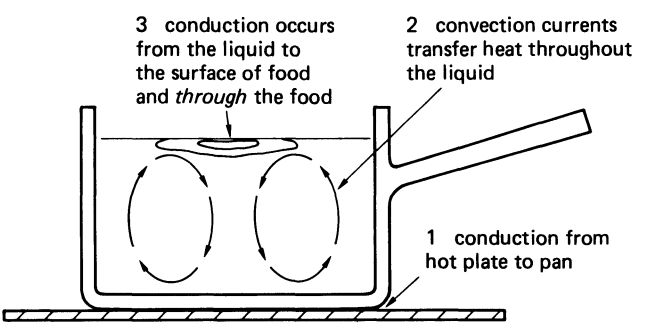
Task 8.1 By referring to a catering theory textbook, or visiting a restaurant kitchen, make a list of the different types of pan used in a restaurant kitchen. Next to each one state which metal(s) is/are used, and explain what the pan is used for, and how the type of metal is suited to its use. Compare the approximate costs for one type of pan if different metals can be used.

Conduction is the main type of heat transfer in two types of cooking: *griddling* and *shallow frying*. However, it is also involved in the transfer of heat to the container in boiling, poaching and stewing, as well as being responsible for the penetration of heat in solid foods. For example, although heat transfer to a roasting chicken is mainly by convection and radiation, heat travels from the outside of the chicken to the inside by conduction.

8.3 CONVECTION

This is the process by which heat energy flows in a fluid (a gas or a liquid), due to temperature differences in it. For example, in a pan of water, if heat is applied to the base of the pan, water at the bottom of the pan expands and becomes *less dense* (that is it has a larger volume but the same mass), causing it to rise to the surface. Cold surface water is displaced and falls, until it reaches the bottom of the pan and is itself heated, causing it to rise and become part of the convection currents that are set up in the liquid. In this way heat energy travels through a fluid and can be transferred to the surface of food, for example in the poaching or boiling of an egg. Convection, as seen in Figure 8.2, is responsible for heat transfer in boiling and poaching.

Figure 8.2 *Heat transfer during the poaching of an egg*



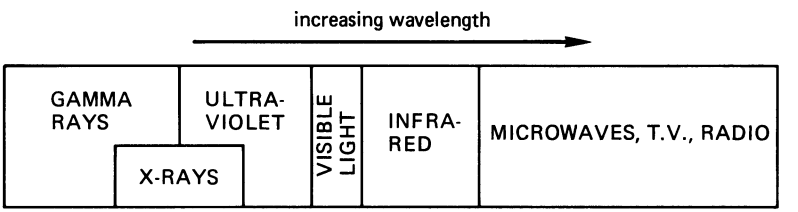
In the same way, convection is the main method of heating in stewing and braising (which involve convection currents in water), steaming (in water vapour), roasting and baking (in air) and deep frying (in oil).

Task 8.2 Observe the convection currents set up in water when it is heated in a glass container, by holding a piece of white card behind the cooking vessel.

8.4 RADIATION

Radiation is the transfer of heat energy from one place to another by electromagnetic waves. The spectrum of electromagnetic waves is shown in Figure 8.3 and includes X-rays, ultra-violet light, visible light, infra-red, microwaves and radio waves.

Figure 8.3 *The electromagnetic spectrum*



The two types of radiation applicable to catering are infra-red radiation and microwave radiation:

(i) Infra-red radiation

Infra-red rays are produced by grills (and salamanders), electric ovens (in which about 40 per cent of the heat is radiation), toasters and barbecues. The food needs to be near the heat source and is heated directly when infra-red rays are absorbed. It is a fast and efficient method of heat transfer and should be used with 'thin' foods, since the surface of the food heats up quickly but conduction of heat to the centre is slow.

(ii) Microwave radiation

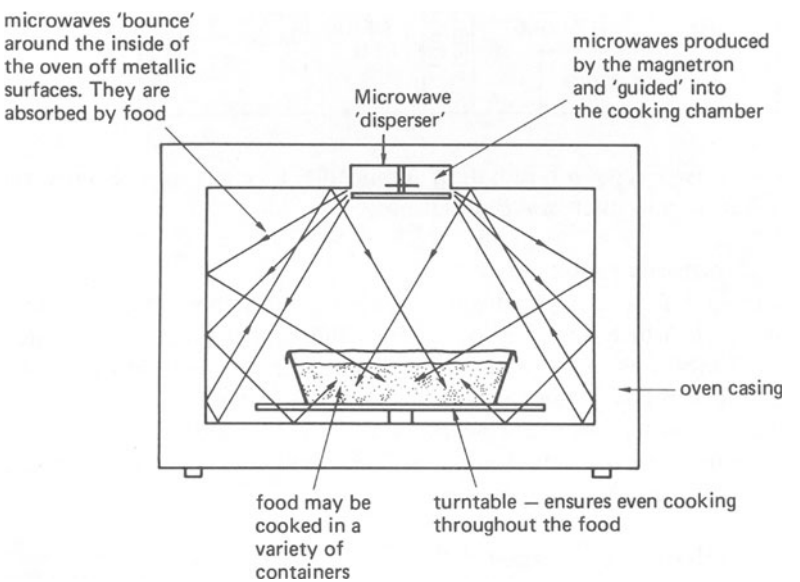
The major difference between microwave cooking and conventional cooking is that *heat is generated within the food itself* in microwave cooking. Microwaves, as can be seen from Figure 8.3, are similar to infra-red and radiowaves. They are produced by converting electrical

energy into radiation, which occurs in the *magnetron* of a microwave oven. Like other radiations, microwaves may be absorbed, transmitted or reflected by different substances; they are absorbed, for example, by food. In particular, the water in food is a good absorber of microwaves. When microwaves are absorbed, the energy is converted into the vibration of molecules in food, leading to the production of heat, which cooks the food (see Figure 8.4).

Metals reflect microwaves and cannot be used in this type of oven, whereas glass, china and some plastics transmit microwaves and are ideal containers.

Unlike conventional methods of heat transfer, microwaves bring about rapid cooking and do not rely on conduction within the food itself, unless the food is particularly 'thick' (microwaves penetrate about 4 cm into the food). It is not true that microwaves cook from the inside out. Because of the speed of cooking, the surface of food does not turn brown as in conventional cooking, although some microwave ovens achieve 'browning' with additional radiation.

Figure 8.4 *The microwave oven*



Microwave ovens are useful for defrosting and reheating foods, and are being used increasingly for many dishes originally prepared conventionally.

Task 8.3 Compare the speed of cooking achieved by microwaves and a conventional method, by noting the time it takes for a set volume of water to boil in identical cooking vessels, for example, pyrex beakers/dishes or the time it takes for identical-sized potatoes to cook.

8.5 TYPES OF COOKING

The previous sections have covered the scientific aspects of heat transfer. It is now necessary to relate heat transfer to the common cooking methods and to discuss how food is cooked in each case. The common methods of cooking can be divided into two groups: moist methods and dry methods:

(i) **Moist methods** – these include boiling, poaching, steaming, braising and shallow poaching.
(ii) **Dry methods** – these include grilling, roasting, pot roasting, baking, shallow frying and deep frying.

8.6 BOILING AND POACHING

These two methods involve cooking in a liquid containing water. In the case of boiling, the temperature is 100°C, whereas in poaching lower temperatures of between 75° and 93°C are used, when 'simmering' takes place. Poaching enables delicate foods such as white fish or eggs to be cooked without being broken up by vigorous action in the boiling water.

In both cases the minimum amount of water should be used to prevent dilution of flavour and reduction of nutritional value unless the liquid itself is required, as in soups or stocks. The nutrients most likely to be lost are the vitamins B and C, although in the production of soups and stews, which involves boiling, the nutrients lost from meat or vegetables are retained in the water.

One consideration to be made when boiling or poaching is whether to add the ingredients to cold or hot water. Some of the advantages of both are given in Table 8.2

Task 8.4 After studying Table 8.2 make a list of foods that should be cooked by being placed directly into hot water and those that are best cooked from cold.

Table 8.2 *Advantages of cooking from cold or in hot water*

Advantages of placing ingredients directly into hot water and cooking	*Advantages of placing ingredients into cold water and heating*
1. The nutritional value of the food remains high since fewer water soluble vitamins are lost	1. Impurities (which form a scum and discolour the food(can be removed as the food cooks, giving maximum clarity
2. There is less loss of colour particularly with green vegetables	2. It is safer than dealing with boiling water since hot splashes can be avoided
3. Foods coagulate quicker and retain shape. This is important with eggs and meat	
4. Cooking time is reduced	
5. There is less chance of burning, for example, with starch thickened foods	

Plunging foods, particularly vegetables, into hot water for a very short period of time is called *blanching* and is useful because it inactivates enzymes that break down the food or cause colour changes.

Since the temperature of boiling is quite low in comparison to roasting, baking and grilling, the coagulation of protein, which occurs in meat, for example, is less extensive than at higher temperatures. Boiling or stewing is therefore a good method of cooking less expensive meats.

Examples of dishes or foods that are boiled or poached are: stocks, soups, stews, less expensive cuts of meat and poultry, fish, shellfish, vegetables, jams, sugar products, eggs, rice and pasta.

Boiling and poaching involve conduction through the container, convection in the cooking medium and conduction through the food.

8.7 STEAMING

Food can be cooked using steam at atmospheric pressure (see Plate 8.1) in which case temperatures between 100° and 103°C are likely, or at high pressure (70–105 kN/m or 10–15 psi – pounds per square inch), in which case the temperature can rise to 121°C. (kN/m is a metric unit of pressure – kiloNewtons per metre.) In both cases, cooking occurs more quickly than in boiling and there is a reduction in nutrient loss; less water is used which also reduces nutrient loss.

This method of cooking is applicable to vegetables and some puddings, such as steamed sponge pudding, Christmas pudding and

Plate 8.1 A steam-boiling pan (*Zanussi: CLV Systems Ltd*)

steak and kidney pudding. Meats are generally not steamed because of colour loss which makes them look less attractive. But since there is good nutrient retention, steaming is often used in hospital and school catering.

Heat transfer is by convection of steam and conduction through the food.

8.8 BRAISING AND SHALLOW POACHING

Braising and shallow poaching involve cooking food in a small amount of liquid in a covered container in an oven. The temperatures used are usually between 175°C and 200°C and cooking times vary depending on the type of food. Casseroles and hotpots are cooked in a similar way but contain slightly more liquid and may be uncovered for colour development of the food. However, unlike braised dishes, they are served in the container.

In all cases heat transfer *to* the container involves convection, radiation and conduction, while heat transfer *in* the container is by convection. Cooking with the lid on traps steam which also aids cooking by convection.

Foods cooked in this way include fish, less expensive cuts of meat, offal and vegetables.

8.9 GRILLING

Grilling is a dry, fast, high temperature method of cooking. The heat source may be below the food as in the over-heat grills or above the food as in the under-heat grills or salamanders.

The high temperatures, which may be between 150°C and 210°C on the surface of the food, mean that only thin, tender foods can be grilled satisfactorily. These include fish and tender cuts of meat, poultry and game.

The method of heat transfer is mainly infra-red radiation, but some conduction from the metal grill bars and some convection take place.

8.10 ROASTING AND POT ROASTING

Oven roasting is the cooking of food in dry heat with fat or oil present. The temperatures of roasting vary up to about 240°C, but it would appear that the higher temperatures produce a drier, tougher product due to the greater shrinkage and loss of juices.

The high temperatures of roasting are also responsible for the loss of heat sensitive vitamins.

Heat transfer in roasting is mainly through convection, although radiation plays a significant role, particularly in electric ovens. Conduction from the container to the base of the food which could cause burning is avoided if the food is raised,for example on a bed of vegetables.

Spit roasting is similar to oven roasting but more radiation takes place and heating is less controlled.

Pot roasting is quite different, however, since it occurs in a closed container, which traps steam rather like braising.

Foods suitable for roasting include the better cuts of meat, poultry and game and vegetables, particularly potatoes.

Task 8.5 Obtain a range of meats such as stewing beef, rump steak, pork steak, leg of lamb, and weigh similar portion sizes accurately. Roast them in a tray in an oven at 180°C for 30 minutes. Re-weigh the pieces of meat and calculate for each the percentage weight loss due to roasting:

$$\frac{\text{Weight loss}}{\text{Original weight}} \times 100 = \text{Percentage weight loss}$$

Which type of meat shrank most during roasting?
Variations can be made to this experiment by sealing the meat, by including fish and poultry or by comparing weight loss at different roasting temperatures.

8.11 BAKING

Baking is similar to roasting in that it occurs in an oven with dry heat; however, the food is not cooked in fat, but steam may be produced, by the food itself, and modify the cooking.

Flour products form the bulk of foods that are baked.

8.12 SHALLOW FRYING

Shallow frying, which includes griddling, is a dry method of cooking where thin foods are cooked in a very small amount of fat (sometimes provided by the food itself). The temperatures used may be as low as 95°C, are usually between 150°C and 175°C, but are in some cases as high as 195°C.

One important aspect of shallow frying is the development of

colour and flavour in the food, which may be enhanced by using a high quality fat, such as butter.

Shallow frying is a quick method of cooking and is suitable for tender foods such as meat, poultry, fish, shellfish, eggs and fruit.

The amount of fat used is very small, which means that food is in contact with the pan or plate, and conduction is therefore the method of heat transfer.

8.13 DEEP FRYING

This is the immersion of food into hot oil and is a quick, dry method of cooking. High temperatures are often used, up to 195°C, and the food cooks rapidly because there is uniform heating over the whole surface. The average temperatures are between 165°C, which would be suitable for the blanching of French fried potatoes, and 185°C, which would be used to brown French fried potatoes. Care must be taken when deep frying because of the high temperature of the fat, the possibility of splashing, and the risk of rapid water vaporisation when large quantities of watery foods are added. The fat should be changed regularly and should not be used above its smoke point, which is reduced with continuous usage.

Deep frying increases the energy of food since some fat is absorbed during the cooking process. It is a suitable method of cooking for potatoes, other vegetables, fish and white meats.

Convection currents are set up in the oil, which cause conduction to heat the food, in deep frying.

8.14 CHANGES DURING COOKING

It would be impossible to list all the changes that occur during cooking. However, there are three groups of changes that are of interest: structural changes, changes in appearance (colour, flavour and smell), and changes in nutritional value. Some of the more obvious changes brought about during cooking are shown in this section.

(i) Structural changes

As well as the changes that occur during the preparation of food, such as foaming, and the formation of emulsions, the heat during cooking alters the structure of food quite significantly. Table 8.3 describes some changes to structure.

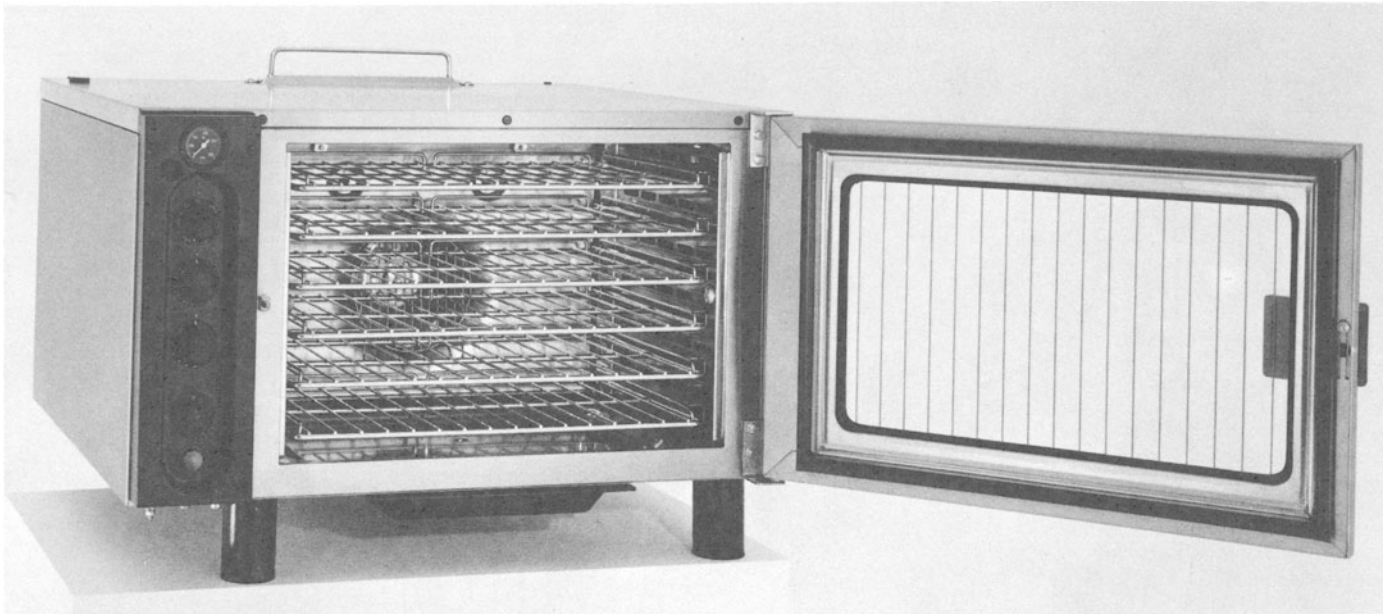


Plate 8.2(a) A forced air convection oven (*Zanussi: CLV Systems Ltd*)

Plate 8.2(b) Modular cooking tops (*Zanussi CLV Systems Ltd*)

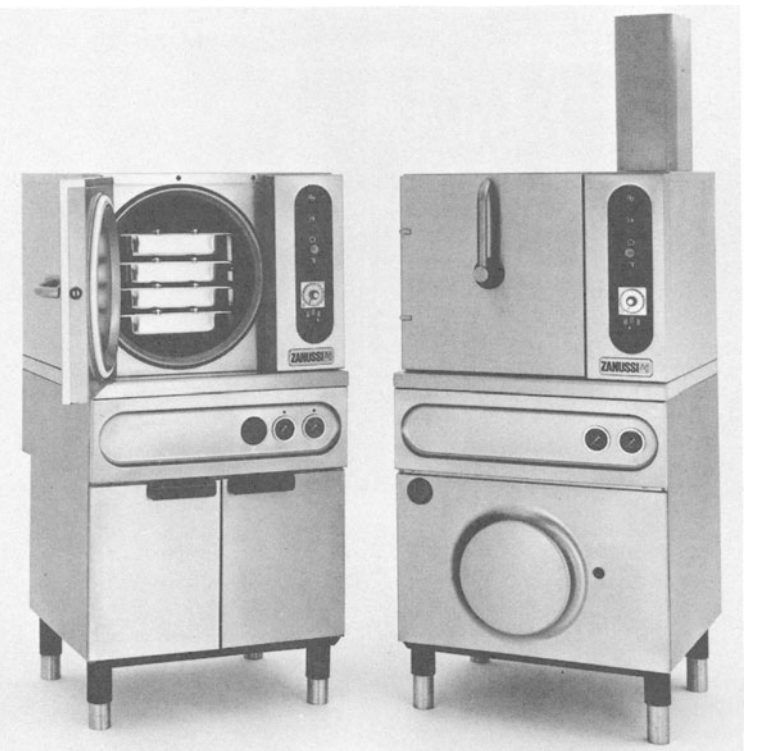


Plate 8.2(c) Pressure steamers (*Zanussi CLV Systems Ltd*)

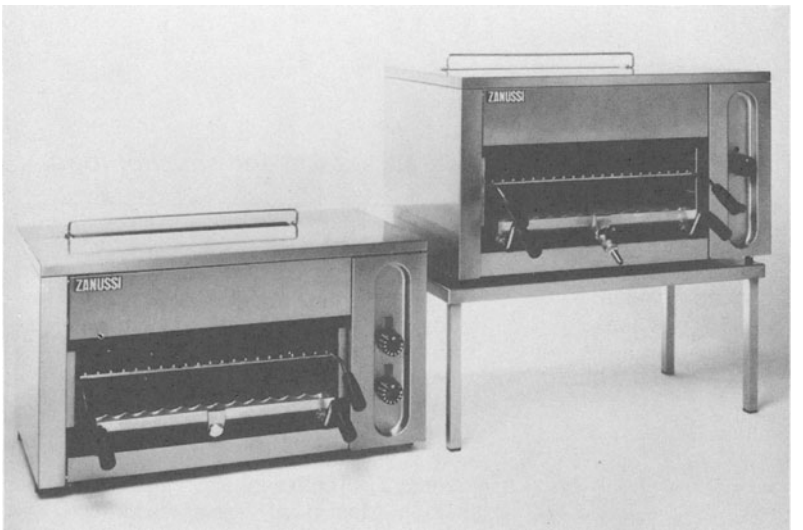


Plate 8.2(d) Salamander grills (*Zanussi CLV Systems Ltd*)

Table 8.3 *Some structural changes in food brought about by cooking*

Structural change	*Examples*
Cells soften and separate	Fruits and vegetables
Gelatinisation and gelation take place	Fruits, vegetables and cereals
Thickening due to pectin occurs	Fruits, jams and jellies
Crystallisation and formation of non-crystalline confectionery occur	Sugar
Proteins denature and coagulate	Meat, fish, poultry, cheese, eggs and milk
Collagen (connective tissue protein) melts	Meat, poultry and fish

(ii) **Changes in aesthetic qualities**
As food is cooked the colour changes, and depending on the skill of the cook, the taste and smell of the food improve (see Table 8.4).

(iii) **Nutritional changes**
The value of proteins does not usually deteriorate when denaturation and coagulation take place; but other nutrients, particularly vitamins and minerals are affected by cooking (see Table 8.5).

Table 8.4 *Changes in appearance, taste and smell of food*

Change	*Example*
Browning (Maillard reaction)	The surface of meat, bread and many other foods
Browning (caramelisation)	Sugar when heated in small amounts of water is converted into caramel which is brown
Pigment changes	Various pigments in fruits and vegetables alter as a result of cooking, e.g., green peas become a dull olive green in normal cooking. Meat pigments are also affected by heat
Flavour/aroma	Cooking involves a complex set of chemical changes which involves the production of new substances that stimulate the taste and smell senses of the body

Table 8.5 *Some nutritional losses that occur during cooking*

Nutrient	*Losses*
Proteins	Some amino acids can be lost if cooking is excessive, and some may be less easily obtained by the body due to changes in the protein structure
Fats	Some essential fatty acids may be lost due to breakdown with heat
Carbohydrates	Cooking usually makes carbohydrates more easily digested by the body
Minerals	Some minerals may be lost from foods such as fish, meat and vegetables into the cooking liquid
Vitamins	Vitamins B and C are lost into cooking water, are also destroyed by heat and may react with oxygen. Vitamin A is also sensitive to heat

In some instances the nutritional value of a food may increase during cooking. This is best illustrated in frying of French fried potatoes for example, where fat is absorbed by the food and the energy value is therefore increased.

EXERCISES

1. What are the main reasons for cooking food?
2. Describe the process of conduction, giving examples of where it occurs in cooking.
3. Explain how convection occurs in a warm liquid and how a boiled egg is cooked in this way.
4. Which types of radiation are used for cooking food? Explain how each type works and make a list of foods suitable for each type.
5. Describe the principles involved in boiling and list foods suitable for boiling.
6. Outline the main differences between boiling and steaming, listing the main advantages of steaming in a commercial operation.
7. List the types of heat transfer at different points when a meat dish is braised in the oven.
8. What types of food are suitable for grilling?
9. Which methods of cooking produce the greatest amount of brown colour on the surface of foods?
10. List some of the safety risks associated with deep fat frying.