C3 How does human digestion break down fats? – Saponification of edible oil

Note: This answer sheet will go into the analyses for the individual subexperiments only if experience shows that there could be particular difficulties.

1 We emulsify oil

1.5 Analysis

a) What additives can you use to stably mix oil and water?

Note: Since oils and fats are hydrophobic in general, they do not mix with water at all without an additive. Any water/oil emulsion produced mechanically by stirring will separate again after a while. An emulsifier or tenside is therefore necessary to produce a stabilized mixture.

b) Explain the effect of these additives.

Note: The reason for the emulsifier's effect is the forces prevailing in the two liquids that cause cohesion among the molecules of the respective liquid. In water, which is polar, the forces are hydrogen bonds; in the relatively nonpolar fat, the forces are van der Waals forces. The emulsifier molecules, however, have a polar (hydrophilic) and a nonpolar (hydrophobic) end and can "dock" with both the water and the oil. In this way, they surround the oil droplets floating in the water.

1.6 Questions

a) What is the name of the group of substances that includes the cooking oil you've used in this experiment?

Answer: Cooking oil is a fat or lipid. It is the only substance among nutrients that is completely insoluble in water.

b) What chemical composition do oils have?

Answer: Cooking fats in solid or liquid form ("oils") are lipids, that is, esters of the trivalent alcohol glycerol with fatty acids. This means that a fat is the product of the esterification of glycerol with three fatty acid molecules. The acid groups (COOH) of the fatty acid molecules form a chemical bond at the three OH groups of the glycerol and split off water. The three fatty acids can be different or the same. Each different combination of fatty acids produces a different fat. Depending on the length of the fatty acid molecules, the fat is solid or liquid (see also the teacher instructions).

c) What other representatives of this group of substances can you name?

Answer: Lard, fish oil, palm fat, peanut oil, sunflower oil, olive oil, castor oil, etc.

d) This experiment shows you an important principle, namely how two substances can be mixed together. Where do you find this principle applied in the human body?

Answer: In the human body, you find this principle applied to fat digestion. Fat digestion begins in the stomach. Here muscle movement mechanically reduces the fats to droplets with a diameter of 0.5 – 2 µm. Fat-splitting enzymes, the lipases, can now act on these droplets and break down the fat into its constituent parts, the long-chain fatty acids and glycerol. About 15% to 30% of fats are digested in the stomach in this way.
As soon as the bolus reaches the duodenum, the pancreas and gallbladder perform a key function in the further digestion of fats. The bile from the gallbladder ensures excellent emulsification, and pancreatic lipases are taken up by the fat droplets, forming micelles that are so small (max. 50 nm) that they can attach themselves to the microvilli of the brush border membrane.
The formation of the micelles is similar to the process observed in the experiment. When only a very small amount of tenside is added to the solution, the resulting oil droplets are relatively large. If you add enough tenside and shake well, the fat droplets are so small that you can no longer see them with your eyes.

2 Saponification of edible oil

2.5 Analysis

b) Formulate reaction equations for the steps carried out above.

Note: The steps are emulsification, saponification, and salting-out. Strictly speaking, the purely mechanical emulsification is not a chemical reaction for which you can formulate a reaction equation. The reaction equation for saponification is found in the teacher instructions for the experiment.

For the salting-out (for example, using stearic acid), the following equation could be written.

$$(C_{17}H_{35}COO^{-} + Na^{+})_{aqua} + Na^{+} + Cl^{-} \rightarrow \underline{C_{17}H_{35}COONa}\downarrow + Na^{+} + Cl^{-}$$

c) Explain the action of the table salt.

Note: The soap we produced consists of sodium salts of fatty acids. Particularly at higher temperatures, these salts are water-soluble to a certain degree, but the degree is low compared to table salt. If you add another highly soluble sodium salt (in our case, table salt), the concentration of sodium ions increases in the aqueous solution. According to the law of mass action, this results in a new equilibrium. A portion of the sodium ions now precipitate out in the form of less water-soluble fatty acid salts.

2.6 Questions

a) Find out about soap production in the past and today.

Answer: If students have Internet access, they can use the links provided in the link list for the experiment, available on the media portal of the Siemens Stiftung.

b) What chemicals reactions form the basis for soap production?

Answer: The first step is the emulsification of the fat or oil in a strong alkaline solution. Strictly speaking, this is not yet a chemical reaction.
The second step is ester hydrolysis under alkaline conditions (see the reaction equation in the teacher instructions).
The third step is the salting-out (see 2.5 “Explain the action of the table salt”).

c) What significance does the basic reaction have for human metabolism?

Answer: Hydrolysis of the fatty acid esters also takes place during digestion. However, unlike saponification, this is not alkaline hydrolysis at high temperatures. During fat digestion, enzymatic (biocatalytic) hydrolysis takes place at body temperature. This fatty acid ester hydrolysis begins in the stomach at highly acidic values ranging from pH 1.0 to pH 3.0 and is then completed in the duodenum and small intestine at slightly alkaline values up to pH 8.3. The digestion steps are described in detail in 1.6 d) above. In the teacher instructions, you will find a graphic showing fat absorption in the small intestine.