LECTURE 1

Milk

Milk is defined as the secretion of the mammary glands of mammals, its primary natural function being nutrition of the young. Milk of some animals, especially cows, buffaloes, goats and sheep, is also used for human consumption, either as such or in the form of a range of dairy products. In this book, the word milk will be used for the ‘normal’ milk of healthy cows, unless stated otherwise. Occasionally, a comparison will be made with human milk.

COMPOSITION AND STRUCTURE

PRINCIPAL COMPONENTS

The principal chemical components or groups of chemical components are those present in the largest quantities. Of course, the quantity (in grams) is not paramount in all respects. For example, vitamins are important with respect to nutritive value; enzymes are catalysts of reactions; and some minor components contribute markedly to the taste of milk.

Lactose or milk sugar is the distinctive carbohydrate of milk. It is a disaccharide composed of glucose and galactose. Lactose is a reducing sugar. The fat is largely made up of triglycerides, constituting a very complicated mixture. The component fatty acids vary widely in chain length (2 to 20 carbon atoms) and in saturation (0 to 4 double bonds). Other lipids that are present include phospholipids, cholesterol, free fatty acids, monoglycerides, and diglycerides.
About four fifths of the protein consists of casein, actually a mixture of four proteins: a S1 -, a -, ß-, and κ-casein. The caseins are typical for milk and have some rather specific properties: They are to some extent phosphorylated and have little or no secondary structure. The remainder consists, for the most part, of the milk serum proteins, the main one being ß-lactoglobulin. Moreover, milk contains numerous minor proteins, including a wide range of enzymes.
S2
The mineral substances — primarily K, Na, Ca, Mg, Cl, and phosphate — are not equi-valent to the salts. Milk contains numerous other elements in trace quantities. The salts are only partly ionized. The organic acids occur largely as ions or as salts; citrate is the principle one.

Furthermore, milk has many miscellaneous components, often in trace amounts. The total content of all substances except water is called the content of dry matter. Furthermore, one distinguishes solids-not-fat and the content of fat in the dry matter. The chemical composition of milk largely determines its nutritional value; the extent to which microorganisms can grow in it; its flavor; and the chemical reactions that can occur in milk. The latter include reactions that cause off-flavours.

MILK FORMATION

Milk components are for the most part formed in the mammary gland (the udder) of a cow, from precursors that are the results of digestion. Digestion. Mammals digest their food by the use of

enzymes to obtain simple, soluble, low-molar-mass components, especially monosaccharides; small peptides and amino acids; and fatty acids and monoglycerides.
These are taken up in the blood, together with other nutrients, such as various salts, glycerol, organic acids, etc. The substances are transported to all the organs in the body, including the mammary gland, to provide energy and building blocks (precursors) for metabolism, including the synthesis of proteins, lipids, etc.

In ruminants like the cow, considerable predigestion occurs by means of microbial fermentation, which occurs for the most part in the first stomach or rumen. The latter may be considered as a large and very complex bio-fermenter. It contains numerous bacteria that can digest cellulose, thereby breaking down plant cell walls, providing energy and liberating the cell contents. From cellulose and other carbohydrates, acetic, propionic, butyric and lactic acid are formed, which are taken up in the blood. The composition of the organic acid mixture depends on the composition of the feed. Proteins are broken down into amino acids. The rumen flora uses these to make proteins but can also synthesize amino acids from low-molar-mass nitrogenous components. Further on in the digestive tract the microbes are digested, liberating amino acids. Also, food lipids are hydrolyzed in the rumen and partly metabolized by the microorganisms. All these precursors can reach the mammary gland.

Milk Synthesis. The synthesis of milk components occurs for the greater part in the secretory cells of the mammary gland.
At the basal end precursors of milk components are taken up from the blood, and at the apical end milk components are secreted into the lumen. Proteins are formed in the endoplasmic reticulum and transported to the Golgi vesicles, in which most of the soluble milk components are collected. The vesicles grow in size while being transported through the cell and then open up to release their contents in the lumen. Triglycerides are synthesized in the cytoplasm, forming small globules, which grow while they are transported to the apical end of the cell. They become enrobed by the outer cell membrane (or plasmalemma) while being pinched off into the lumen. This type of secretion is called merocrine, which means that the cell remains intact.

Fat globules. To a certain extent, milk is an oil-in-water emulsion. But the fat globules are more complicated than emulsion droplets. In particular, the surface layer or membrane of the fat globule is not an adsorption layer of one single substance but consists of many components; its structure is complicated. The dry mass of the membrane is about 2.5% of that of the fat. A small part of the lipids of milk is found outside the fat globules. At temperatures below 35°C, part of the fat in the globules can crystallize. Milk minus fat globules is called milk plasma, i.e., the liquid in which the fat globules float.

Casein micelles consist of water, protein, and salts. The protein is casein. Casein is present as a caseinate, which means that it binds cations, primarily calcium and magnesium. The other salts in the micelles occur as a calcium phosphate, varying somewhat in composition and also containing a small amount of citrate. This is often called colloidal phosphate. The whole may be called calcium-caseinate/calcium-phosphate complex. The casein micelles are not micelles in the colloid-chemical sense but just ‘small particles.’ The micelles have an open structure and, accordingly, contain much water, a few grams per gram of casein. Milk serum, i.e., the liquid in which the micelles are dispersed, is milk minus fat globules and casein micelles.

Serum proteins are largely present in milk in molecular form or as very small aggregates.

Lipoprotein particles, sometimes called milk microsomes, vary in quantity and shape. Presumably, they consist of remnants of mammary secretory cell membranes. Few definitive data on lipoprotein particles have been published.

SOME PROPERTIES OF MILK

Milk as a solution.

Milk is a dilute aqueous solution and behaves accordingly. Because the dielectric constant is almost as high as that of pure water, polar substances dissolve well in milk and salts tend to dissociate (although this dissociation is not complete). The ionic strength of the solution is about 0.073 M. The pH of milk is about 6.7 at room temperature. The viscosity is low,

about twice that of water, which means that milk can readily be mixed, even by convection currents resulting from small temperature fluctuations. The dissolved substances give milk an osmotic pressure of about 700 kPa (7 bar) and a freezing-point depression close to 0.53 K. The water activity is high, about 0.995. Milk density (ρ) equals about 1029 kg· m at 20°C; it varies especially with fat content.

Milk as a Dispersion.

The fat globules have a membrane, which acts as a kind of barrier between the plasma and the core lipids. The membrane also protects the globules against coalescence. The various particles can be separated from the rest. The fat globules can be concentrated in a simple way by creaming, which either occurs due to gravity or — more efficiently — is induced by centrifugation. In this way cream and skim milk are obtained. Skim milk is not identical to milk plasma, though quite similar, because it still contains some small fat globules. Cream can be churned, leading to butter and buttermilk; the latter is rather similar in composition to skim milk.

Likewise, casein micelles can be concentrated and separated from milk, for instance, by membrane filtration. The solution passing through the membrane is then quite similar to milk serum. If the pores in the membrane are very small, also the serum proteins are retained. When adding rennet enzyme to milk, as is done in cheese making, the casein micelles start to aggregate, forming a gel; when cutting the gel into pieces, these contract, expelling whey. Whey is also similar to milk serum but not quite, because it contains some of the fat globules and part of the κ-casein split off by the enzyme. Casein also aggregates and forms a gel when the pH of the milk is lowered to about 4.6.

Moreover, water can be removed from milk by evaporation. Altogether, a range of liquid milk products of various compositions can be made.

Flavor. The flavor of fresh milk is fairly bland. The lactose produces some sweetness and the salts some saltiness. Several small molecules present in very small quantities also contribute to flavor. The fat globules are responsible for the creaminess of whole milk.

Nutritional value. Milk is a complete food for the young calf, and it can also provide good nutrition to humans. It contains virtually all nutrients, most of these in significant quantities. However, it is poor in iron and the vitamin C content is not high. It contains no antinutritional factors, but it lacks dietary fibre.

Milk as a Substrate for bacteria. Because it is rich in nutrients, many microorganisms, especially bacteria, can grow in milk. Not all bacteria that need sugar can grow in milk, some being unable to metabolize lactose. Milk is poor in iron, which is an essential nutrient for several bacteria, and contains some antibacterial factors, such as immunoglobulins and some enzyme systems. Moreover, milk contains too much oxygen for strictly anaerobic bacteria. Altogether, the growth of several bacteria is more or less restricted in raw milk, but several others can proliferate, especially at high ambient temperatures.

CHANGES IN MILK

Milk is not a system in equilibrium. It changes even while in the udder. This is partly because different components are formed at various sites in the mammary secretory cell and come into contact with one another after their formation. Furthermore, several changes can occur due to the milking, the subsequent lowering of the temperature, and so on. Changes may be classified as follows:

1. ***Physical changes occurring***, for instance, when air is incorporated during milking: Because of this, additional dissolution of oxygen and nitrogen occurs in milk. Moreover, a new structural element is formed: air bubbles. Milk contains many surface-active substances, predominantly proteins, which can become attached to the air–water interface formed.
Furthermore, by contact with the air bubbles, fat globules may become damaged, i.e., lose part of their membrane. Fat globules may cream. Creaming is most rapid at low temperature because the globules aggregate to large flocs during the so-called cold agglutination. On cooling, part of the milk fat starts to crystallize, the more so at a lower temperature. But even at 0°C part of the fat remains liquid. The presence of fat crystals can strongly diminish the stability of fat globules against clumping.

2. ***Chemical changes*** may be caused by the presence of oxygen: Several substances may be oxidized. In particular, light may induce reactions, often leading to off-flavors. Composition of salts can vary, for example, with temperature.

3. Biochemical changes can occur because milk contains active enzymes: Examples are lipase, which causes lipolysis; proteinases, which cause proteolysis; and phosphatases, which cause hydrolysis of phosphoric acid esters.

4. Microbial changes are often the most conspicuous: The best-known effect is production of lactic acid from lactose, causing an obvious decrease in pH. Numerous other changes, such as lipolysis and proteolysis, may result from microbial growth.