Characteristics of Milk

Unit 3
FS/ANS 324
Topics

- **Composition** – proteins, lipids, lactose, minerals, vitamins, enzymes, etc.
- **Factors affecting composition** – species breed, feed, stage of lactation
- **Physical and chemical properties** – density, freezing point, color, pH, acidity, flavor
- **Bacteria**
- **Pathogenic Bacteria**
- **Somatic Cells and Microorganisms** - lactobacilli, history, significance in cultured products
**Milk Fraction Terms**

- **Plasma**: milk - fat (skim milk)
- **Serum**: plasma - casein micelles (whey)
- **solids-not-fat (SNF)**: proteins, lactose, minerals, acids, enzymes, vitamins. It is the total solids content minus the fat content.
- **Total Milk Solids**: fat + SNF

•“Plasma” and “skim milk” are interchangeable terms, but “skim milk” is more commonly used.
The biological function of milk is to supply nutrition and immunological protection to the young mammal. In some species, milk is the only food consumed for weeks or months. Therefore, it must furnish all nutritive requirements for maintenance and growth, such as energy, amino acids, minerals, and vitamins.

This chart shows the composition of milk, detailing the major components as proportions of solids.

### Composition of Milk

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Concentration (g/L)</th>
<th>Proportion solids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>37.0</td>
<td>28.9</td>
</tr>
<tr>
<td>Protein: casein</td>
<td>27.6</td>
<td>21.6</td>
</tr>
<tr>
<td>Protein: whey</td>
<td>6.4</td>
<td>5.0</td>
</tr>
<tr>
<td>Non-protein nitrogen</td>
<td>1.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Lactose</td>
<td>48.0</td>
<td>37.5</td>
</tr>
<tr>
<td>Ash</td>
<td>7.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Total solids</td>
<td>127.9</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Technology of Dairy Products, 1998
Basic Properties of Milk

- Emulsion
- Colloidal Solution

Emulsion:
• An emulsion is a suspension of droplets of one liquid into another liquid. Milk is an emulsion of fat in water. Butter is an emulsion of water in fat. The solute is known as the dispersed phase and the solvent is known as the continuous phase. Other examples of emulsions include margarine, mayonnaise, cream, and salad dressing.

Colloidal solution:
• A colloidal solution is when matter exists in a state of division in between a true solution, which is sugar in water, and a suspension, which is chalk in water. The characteristics of a colloid are small particle size, electrical charge, and affinity of the particles for water molecules.
• In milk, the whey proteins are in colloidal solution. The casein proteins are in colloidal suspension.
Changes in milk composition

The composition of milk may change due to differences in relative rates of synthesis and secretion of milk components by the mammary gland. Variations are due to differences among species, between individuals within a strain, and between conditions affecting an individual. Conditions affecting the cows may include the weather or seasons and the stage of lactation.

Breed:
The US mostly uses milk from cows of the larger breeds, such as Holsteins and Brown Swiss because of the lower fat content and greater milk production. Breeds such as the Guernseys and the Jerseys have higher fat contents in their milks. Both the Guernseys and the Jerseys have a fat content of 5.2%, whereas the Holsteins and the Brown Swiss have fat contents of 3.5%.

Diet:
The composition of the cows’ diet and the form in which they are fed affect the composition of milk and especially milk fat. High fat and/or low roughage diets can reduce the fat content of milk. Diet has small effects on protein content and none on lactose content.

The seasonal effect is due to the changes in the diet throughout the year.

Stage of lactation

• When mammals give birth, their first secreted milk is called colostrum, and it differs greatly in composition from regular milk. Colostrum contains more mineral salts and protein and less lactose than normal milk. Also, fat content, calcium, sodium, magnesium, phosphorus, and chloride are higher in colostrum than in normal milk. Whey content is about 11% in colostrum as opposed to 0.65% in normal milk.
• Colostrum contains an extremely high immunoglobulin (Ig) content. Igs accumulate in the mammary gland before parturition and transfer immunity to the baby cow. These immunoglobulins protect the baby cow until it can establish its own immunity.

• Figure 5.1 in your assigned reading
Milk fats consist of a mixture of compounds including triacylglycerols, diacylglycerols, monoacylglycerols, phospholipids, cerebrosides, gangliosides, sterols and sterol esters and derivatives, carotenoids, tocopherol, vitamins A, D, E, C, B1, and B2 and free fatty acids. They are not soluble in water, or aqueous liquids.

Milk fat is secreted from the mammary epithelial cells as fat globules.

The average size of a milk fat globule is about 3um in diameter, but they can range from 1 to 18 um.

The milk fat globule is encapsulated by a lipid bilayer membrane made up of proteins, phospholipids, lipoproteins, cerebrosides, nucleic acids, enzymes, trace elements, and bound water. The FGM (fat globule membrane) provides stabilization for the fat globule in the aqueous environment of the milk serum.

When the FGM membrane is ruptured, the fat globules join together into a solid mass of fat. (This is what happens during the production of butter).

Milk fat globules are the largest particles in milk but they are also the lightest. They have a lower density than milk serum, so the globules rise to the surface, which is how cream is formed. The density difference is used to separate milk fat from whole milk in high speed, continuous flow, centrifugal separators.
All fats belong to a group of chemical substances called esters, which are compounds of alcohols and acids. Milk fat is a mixture of different fatty acid esters called triglycerides.

Triglycerides (triacylglycerols) account for 97-98% of the total fat in cows’ milk. The remaining lipid classes are di- and mono-acylglycerols, phospholipids, free fatty acids, and cholesterol and its esters.

A triglyceride contains a glycerol backbone. This glycerol backbone is in red on the picture on this slide. Free fatty acids are attached to the glycerol backbone by an ester bond. Each glycerol molecule can bond three fatty acid molecules. About 437 fatty acids have been identified in the milk fat of cows. These fatty acids all vary in chain length, number, position, and geometric isomerization of double bonds (cis or trans). If you have not learned about fatty acids in your other classes yet, you can refer to the Wikipedia website (http://en.wikipedia.org/wiki/Fatty_acid) or you can schedule a time to talk to me about it.

A fatty acid molecule is composed of a hydrocarbon chain and a carboxyl group. In saturated fatty acids, the carbon atoms are linked together in a chain by single bonds. In unsaturated fatty acids, there are one or more double bonds in the hydrocarbon chain.

Fatty acids in milk come from three main sources: from the feed, from the mobilization of reserve tissue, and from *de novo* (from the beginning) synthesis within the cow.
Milk Fat - Composition

- Saturated and unsaturated fatty acids
- Distribution of fatty acids

- The main source of lipid is from the cow’s food. Little synthesis of fatty acids occurs in the mammary gland. When the cow consumes food, the lipid is hydrolyzed to free fatty acids within the rumen of the cow. This means that unsaturated fatty acids are usually hydrogenated into saturated fatty acids. Hydrogenation is the addition of hydrogen on unsaturated bonds between carbon atoms.

- Although it seems that milk fat would be mostly saturated in nature, over 30% of milk fat is still unsaturated. The unsaturated milk fat is predominately oleic acid (C18:1). Stearic acid (a saturated fatty acid) enters the mammary gland, but within the gland there is a specific C18:0 desaturase which converts stearic acid to the unsaturated oleic acid. As a result, there is a significant amount of unsaturated fat in milk. Just know that a desaturase is an enzyme which removes two hydrogen atoms from the fatty acid, creating a double bond, but you can learn more about these enzymes in upper level biochemistry classes.

- From the rumen, the fatty acids have two places they can go: 1. the bloodstream to be deposited as reserve fat or to be metabolized to produce energy, or 2. the mammary gland.

Distribution of fatty acids

- Milk fat of cows can be separated into long-chain and short-chain fatty acids fractions by distillation or chromatography. The short chain fraction contains mostly butyrate.

Oleic Acid (unsaturated milk fat)
[http://www.chm.bris.ac.uk/molm/linoleic/oleic.gif](http://www.chm.bris.ac.uk/molm/linoleic/oleic.gif)

Stearic Acid (saturated fatty acid)
[http://chemlabs.uoregon.edu/GeneralResources/models/grf/stearic_full.gif](http://chemlabs.uoregon.edu/GeneralResources/models/grf/stearic_full.gif)
Milk Fat

- Changes in milk fat characteristics
  - dietary manipulation
  - seasonal changes

The characteristics of milk fat are highly dependent on the nature of the pre-formed fatty acids available in feedstuff. Therefore, it is possible to manipulate the composition of milk fat by dietary means.

The physical properties of butterfat can be controlled by dietary means because the melting properties of the triglyceride are related to fatty acid composition. For example, by dietary manipulation, butter which can be spread directly from the refrigerator can be produced. On the other hand, butter that is physically stable at high temperatures can also be made.

During colder winter months, there are more pre-formed fatty acids in the cows diet than during the summer months. During the summer, cows graze on grass and drink more water than in the winter months.
### Principal Fatty Acids in Milk Fat

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>% total fatty acid content</th>
<th>Melting Point, Celsius</th>
<th>Number of Atoms</th>
<th>H</th>
<th>C</th>
<th>O</th>
<th>State of fat at room temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Butyric acid</td>
<td>3.0 - 4.5</td>
<td>-7.9</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td></td>
<td>Liquid at room temp.</td>
</tr>
<tr>
<td>Capric acid</td>
<td>1.3 - 2.2</td>
<td>-1.5</td>
<td>12</td>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caprylic acid</td>
<td>0.8 - 2.8</td>
<td>16.5</td>
<td>16</td>
<td>8</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caprylic acid</td>
<td>1.8 - 3.8</td>
<td>31.4</td>
<td>20</td>
<td>10</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lauric acid</td>
<td>2.0 - 5.0</td>
<td>43.6</td>
<td>24</td>
<td>12</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myristic acid</td>
<td>7.0 - 11.0</td>
<td>53.8</td>
<td>28</td>
<td>14</td>
<td>2</td>
<td></td>
<td>Solid at room temp.</td>
</tr>
<tr>
<td>Palmitic acid</td>
<td>25.0 - 29.0</td>
<td>62.8</td>
<td>32</td>
<td>16</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stearic acid</td>
<td>7.0 - 3.0</td>
<td>69.3</td>
<td>36</td>
<td>16</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unsaturated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oleic acid</td>
<td>30.0 - 40.0</td>
<td>14</td>
<td>34</td>
<td>18</td>
<td>2</td>
<td></td>
<td>Liquid at room temp.</td>
</tr>
<tr>
<td>Linoleic acid</td>
<td>2.0 - 3.0</td>
<td>-5</td>
<td>32</td>
<td>18</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linolenic acid</td>
<td>up to 1.0</td>
<td>-5</td>
<td>30</td>
<td>18</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arachidonic acid</td>
<td>up to 1.0</td>
<td>-49.5</td>
<td>32</td>
<td>20</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- This table lists the most important fatty acids in milk fat triglycerides.
- Milk fat is characterized by the presence of relatively large amounts of butyric and caproic acid.
- This table shows that the four most abundant fatty acids in milk are myristic, palmitic, stearic, and oleic acids. Myristic, palmitic, and stearic acids are solids at room temperature and oleic acid is a liquid at room temperature.
- The amounts of fatty acids in milk are variable. This variation affects the hardness of fat. Fat with a high content of high-melting fatty acids, such as palmitic acid, will be hard. However, fat with a high-content of low-melting oleic acid makes soft butter.
### Fatty acid composition of human and bovine milk fat

<table>
<thead>
<tr>
<th>Fatty Acid²</th>
<th>Human Fat-free diet</th>
<th>Human Corn oil diet</th>
<th>Cow Summer</th>
<th>Cow Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>4:0</td>
<td>n/a</td>
<td>n/a</td>
<td>3.6</td>
<td>3.5</td>
</tr>
<tr>
<td>6:0</td>
<td>n/a</td>
<td>n/a</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>8:0</td>
<td>n/a</td>
<td>n/a</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>10:0</td>
<td>n/a</td>
<td>n/a</td>
<td>2.4</td>
<td>2.7</td>
</tr>
<tr>
<td>12:0</td>
<td>7.9</td>
<td>3</td>
<td>2.7</td>
<td>3.9</td>
</tr>
<tr>
<td>14:0</td>
<td>9</td>
<td>2.3</td>
<td>9.8</td>
<td>12.7</td>
</tr>
<tr>
<td>15:0</td>
<td>n/a</td>
<td>n/a</td>
<td>1.1</td>
<td>1.3</td>
</tr>
<tr>
<td>16:0</td>
<td>23.5</td>
<td>13.1</td>
<td>25.4</td>
<td>34.4</td>
</tr>
<tr>
<td>16:1</td>
<td>6.8</td>
<td>1.4</td>
<td>0.9</td>
<td>1.3</td>
</tr>
<tr>
<td>17:0</td>
<td>n/a</td>
<td>n/a</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>18:0</td>
<td>3.2</td>
<td>3</td>
<td>15.8</td>
<td>11.6</td>
</tr>
<tr>
<td>18:1 cis</td>
<td>36.9</td>
<td>31.3</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>18:1 trans</td>
<td>n/a</td>
<td>n/a</td>
<td>24.3</td>
<td>19.9</td>
</tr>
<tr>
<td>18:2+3</td>
<td>7.3</td>
<td>4.3</td>
<td>1.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>

¹ Data are weight percent taken from studies of human and bovine milks.
² Number of carbons in the chain colon number of double bonds. The cis and trans forms of 18:1 were only measured in the cow samples. The cis double bond was in the 9-position and the trans double bond in the 11-position.

• These data show the differences between the milk fat of humans and cows.

• The milk fat from the cow contains a set of unique short carbon chain fatty acids (4:0 – 10:0) and very little polyunsaturated fatty acids (18:2+3).

• These differences are a result of the digestive system of the cow. The cow has a rumen, which you all may already know about. It is basically a large fermentation tank in which food is broken down and modified by microorganisms before it goes into the intestines. The abundant polyunsaturated lipids in the grasses, legumes, silages, and grains consumed by the cow are hydrogenated (saturated) in the rumen, which is why cows milk has saturated fats.

• Acetic and beta-hydroxybutyric are products of fermentation in the rumen and they are absorbed directly from the rumen into circulation and are carried to the mammary gland where they are used to make short chain fatty acids.

• When the human mother was fed corn oil, which is rich in linoleic acid (18:2), she produced a level of 43% of linoleic acid in her milk fat.
Oxidation of fat -
• Oxidation occurs at the double bonds of the unsaturated fatty acids. The presence of iron and copper salts accelerates the onset of auto-oxidation and the development of a metallic flavor. Also, the presence of dissolved oxygen and exposure to light promotes oxidation. Oxidation of milk fat may limit the shelf life of whole milk powders, but is not usually a serious problem. Oxidation is catalyzed by light, so if milk is exposed to light for too long a period of time, off-flavors will occur. Fat oxidation can be counteracted by microorganisms in milk such as lactic acid bacteria because they consume oxygen thereby reducing oxidation. Also, pasteurization helps to reduce oxidation because reducing compounds such as sulphydryl groups are formed when milk is heated. The metallic oxidation off-flavor is more common in the winter than in the summer because of differences in the cows diet. Summer feeds are higher in Vitamins A and C. These vitamins increase the amount of reducing substances in milk.

Oxidation of protein -
• When exposed to light, the amino acid methionine is degraded to methional by riboflavin and vitamin C. Methional causes the “sunlight flavor” in milk. However, methionine is present in milk as part of the milk proteins. So fragmentation of the proteins must occur to release the free amino acid methionine. Factors that relate to sunlight flavor development are: Intensity of the light, especially light from flourescent tubes, Duration of exposure, Homogenized milk is more sensitive that non-homogenized milk, Nature of the package - opaque packages such as plastic and paper give good protection.
Changes in milk during storage

Hydrolysis -
• Hydrolysis is the liberation of free fatty acids from the glycerol backbone. This reaction requires the presence of a lipase, which is an enzyme that catalyzes the hydrolysis of ester bonds of lipids. A large amount lipoprotein lipase is present naturally in milk, but fortunately fat globules with an intact milk fat globule membrane are not susceptible to hydrolysis by the enzyme. Also, lipoprotein lipase is inactivated at temperatures required for pasteurization.
• Spoilage bacteria provide a heat stable lipase, but the spoilage bacteria must exceed normal levels, and routine bacterial control should prevent such an occurrence.

Lipolysis -
• The breakdown of fat into glycerol and free fatty acids is called lipolysis.
• Fat that has been lipolysed tastes rancid and smells rancid. This effect is due to the presence of low molecular free fatty acids such as butyric and caproic acids.
• Lipolysis is enhanced by lipases and high storage temperatures. Lipases can only act if the fat globules have been damaged so that the fat is exposed. The fat globules can be damaged by pumping, stirring, or splashing the milk. Therefore, unnecessary agitation of unpasteurized milk should be avoided to prevent the damage of the fat globules.
• High temperature pasteurization inactivates the lipases.
Milk Proteins

- Casein

Additional information to better understand the pictures:
- Casein micelle is composed of millions of casein submicelles that are clumped together
- Casein micelle almost visible under microscope
- Protein structure: different lines within structures represent different peptide structures that are well characterized (e.g. alpha helix, beta sheet)

There are two distinct types of proteins in milk, casein and whey. Caseins make up over 80% of the total protein content and they can be further divided into five groups – the alpha_{s1}, alpha_{s2}, beta, gamma, and kappa caseins. Caseins do not have an organized structure, thus they cannot be denatured by heating.

The casein molecules form polymers containing several identical and different molecules. Some molecules have hydrophilic regions and some have hydrophobic regions. The polymers are made up of many individual molecules and form into casein micelles. They are also formed into a colloidal solution, which gives skim milk its whitish-blue color.

The alpha and beta caseins account for the calcium sensitivity of milk protein. Casein coagulates when calcium is added to casein solutions. This reaction is the key to cheese making and to the formation of acidic gels such as yogurt. Casein also coagulates when rennet is added. Rennet is a proteolytic enzyme that is found in the stomachs of calves.

The amino acids in casein have hydrophobic and hydrophilic regions, allowing the caseins to act as highly effective surface active agents. In other words, caseins act as stabilizers of foams and emulsions.

If an acid is added to milk or if acid producing bacteria are allowed to grow in milk, the casein micelle will change in two ways.

First, colloidal calcium hydroxyphosphate, present in the casein micelle, will dissolve and form ionized calcium. This ionized calcium will penetrate the micelle structure and create strong internal calcium bonds.

Second, the pH of the solution will approach the isoelectric points of the individual casein molecules.

So you’re probably thinking great - what does this mean? What happens is this - the casein micelles get bigger because they aggregate with one another.

The making of cottage cheese is a great example of this principle. Alton Brown from the Food Network has a recipe for cottage cheese. You can see it at this website: http://www.foodnetwork.com/food/recipes/recipe/0,,FOOD_9936_36973,00.html

Also, the other night I did a silly thing making dinner. I tried to make a lower fat lemony alfredo sauce using 2% milk instead of heavy cream. So the lemon lowered the pH of the milk and the casein in the milk coagulated and I made cottage cheese instead!
Whey -
• Whey is the milk serum proteins. When casein is precipitated out of skim milk, whey is left over. Casein are the curds and the liquid left over is the whey.
• Whey proteins are globular proteins which may be denatured when heated above temperature above 65°C. The major components of whey are beta lactoglobulin and alpha lactalbumin. Whey is the liquid remaining after milk has been curdled and strained during the manufacture of cheese. It is used to produce ricotta and brown cheeses and is an additive in many processed foods, such as breads, crackers, pastries, and animal feed.
• Many of the important nutrients that are comprise milk are partitioned into whey. It contains many important nutrients, such as lactose, water soluble vitamins, and most of the minerals, with the exceptions of considerable calcium and phosphorus which go with the casein into the cheese curd. The amino acid composition of whey is very close to that which is considered as the optimum amino acid value.

Alpha-lactalbumin
• Alpha-lactalbumin is considered the typical whey protein. It is present in milk from all mammals and it plays an important role in the synthesis of lactose in the udder.

Beta-lactalbumin
• This protein is found only in ungulates and is the major whey protein component of milk from cows.
The most important reactions of the milk proteins are those which involve destabilization of the casein micelles.

As we previously mentioned, reactions can occur within casein micelles as the pH is reduced. As the pH if milk is reduced, the native micellar structure disintegrates. At the isoelectric point of casein, (the pH at which casein carries no net electrical charge - a pH of 4.6), the casein precipitates out of solution, along with any heat-denatured whey. This reaction may be reversed as the pH is increased, but native form of the micelle is not recovered.

Acidification of milk may be used to form many fermented products such as yogurt and to fractionate the milk proteins to produce acid casein. Acid casein can be purified and used in foods for its emulsifying and water binding properties.

At a neutral pH, milk is very chemically stable. However, when milk is heated, added to alcohol, or concentrated, stability may be reduced.

Destabilization of casein micelles also occurs when milk is subjected to selective proteolysis. In selective proteolysis, a specific enzyme, chymosin, cleaves off the part that stabilizes the kappa casein. This proteolysis results in an increase in sensitivity of the casein micelles to calcium, so the two coagulate and a firm gel is formed. These reactions form the basis of cheese production. However, this process is actually made up of two reactions: proteolysis and calcium-induced aggregation. If the reaction is carried out at refrigeration temperatures, only proteolysis occurs and the milk remains stable until heating takes place and the calcium-induced clotting can occur.
• Lactose is the most abundant of the milk solids.
• Lactose is a useful source of energy and it is thought by some to promote the absorption of calcium from the diet. However, some people lack the enzyme lactase and have a difficult time digesting lactose. When people who are lactose intolerant eat a substantial amount of lactose containing foods, they can suffer from GI distress. Some milk products are available that have lactase introduced aseptically into the previously sterile product before packaging.
• The relative sweetness of lactose is small (only 20%) when compared to sucrose (100%). (http://www.lactose.com/basic/physiological_properties.html)
<table>
<thead>
<tr>
<th>Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium: Calcium functions in the mineralization of bones and teeth, muscle contraction and relaxation, nerve functioning, and blood clotting.</td>
</tr>
<tr>
<td>Iron: Iron carries oxygen as a part of hemoglobin in blood or myoglobin in muscles, and it is required for cellular energy metabolism.</td>
</tr>
<tr>
<td>Magnesium: Magnesium is a factor involved in bone mineralization, the building of protein, enzyme action, normal muscular function, transmission of nerve impulses, proper immune function and maintenance of teeth.</td>
</tr>
<tr>
<td>Phosphorus: Phosphorus is involved with mineralization of bones and teeth, it is important in genetic material, in cell membranes as phospholipids, in energy transfer, and in buffering systems.</td>
</tr>
<tr>
<td>Potassium: Potassium facilitates reactions, including the making of protein. It is involved in the maintenance of fluid and electrolyte balance, the support of cell integrity, the transmission of nerve impulses, and the contraction of muscles, including the heart.</td>
</tr>
<tr>
<td>Sodium: Sodium, sodium chloride, and potassium (the electrolytes) maintain normal fluid balance in the body. Sodium is critical to nerve impulse transmission.</td>
</tr>
<tr>
<td>Zinc: Zinc is associated with hormones, it is needed for many enzymes, it is involved in making genetic material and proteins, immune cell activation, transport of vitamin A, taste perception, wound healing, making of sperm, and normal fetal development.</td>
</tr>
</tbody>
</table>

Calcium: Calcium functions in the mineralization of bones and teeth, muscle contraction and relaxation, nerve functioning, and blood clotting.

Iron: Iron carries oxygen as a part of hemoglobin in blood or myoglobin in muscles, and it is required for cellular energy metabolism.

Magnesium: Magnesium is a factor involved in bone mineralization, the building of protein, enzyme action, normal muscular function, transmission of nerve impulses, proper immune function and maintenance of teeth.

Phosphorus: Phosphorus is involved with mineralization of bones and teeth, it is important in genetic material, in cell membranes as phospholipids, in energy transfer, and in buffering systems.

Potassium: Potassium facilitates reactions, including the making of protein. It is involved in the maintenance of fluid and electrolyte balance, the support of cell integrity, the transmission of nerve impulses, and the contraction of muscles, including the heart.

Sodium: Sodium, sodium chloride, and potassium (the electrolytes) maintain normal fluid balance in the body. Sodium is critical to nerve impulse transmission.
Minor components and micronutrients

- Non-Protein Nitrogen
  - Nucleotides
  - Urea
  - Free amino acids
- Enzymes
  - Lipoprotein lipase
  - Lactoperoxidase
  - Xanthine oxidase
  - Alkaline phosphatase

Urea is responsible for almost all of the seasonal variation in the heat stability of milk. The concentration of milk urea is controlled by the level of urea in the blood, which is directly related to diet.

As mentioned earlier, lipoprotein lipase catalyzes the hydrolysis of triglycerides to free fatty acid. This reaction causes dairy products to have soapy, bitter, rancid, and unclean flavors. A great deal of lipoprotein lipase is present in freshly drawn milk, and under certain conditions, will spoil the milk within a few minutes. The fat globule membrane acts as a physical barrier to lipase, and it is also readily inactivated by heat. Spontaneous lipolysis is influenced by stage of lactation, season, and diet.

Lactoperoxidase is another enzyme in milk present at high concentrations. It catalyzes the oxidation of unsaturated fatty acids leading to the development of oxidized flavors. However, if thiocyanate and peroxide are supplemented in milk, lactoperoxidase acts as a powerful bactericide that can kill coliforms, Salmonellae, Shingellae, and Pseudomonads. This process has been widely used for short-term preservation of milk in developing countries where refrigeration is scarce.

Xanthine oxidase is also present in milk and can catalyze non-specific oxidation of dairy products. Other that that, its overall significance is low.

Alkaline phosphatase is almost completely inactivated by pasteurization, and it is therefore used as an index of the efficiency of such heat treatments.
Vitamins

- **Fat Soluble Vitamins**
  - Vitamins A, D, and E

- **Water Soluble Vitamins**
  - Vitamins C, B₁, B₂, B₆, B₁₂, pantothenic acid, niacin, biotin, and folic acid

- Vitamins A, D, E, C, B₁, B₂, B₆, B₁₂, pantothenic acid, niacin, biotin, and folic acid are all found in milk.

- The concentrations of fat soluble vitamins in milk (A, D, and E) are dependent on the diet and the breed of the cow.

- All of the vitamins in milk are affected by processing. Vitamins C, B₂, and A are deteriorated by light. The fat soluble vitamins are stable to heat, but the water soluble vitamins, B₁, B₆, B₁₂, and folic acid, are less stable to heat. UHT sterilization leads to a 20-30% loss of vitamin activity and sterilization leads to 50% loss of vitamin activity.
Functions of Vitamins in Milk

- **Vitamin A:** Vitamin A prevents eye problems, promotes a healthy immune system, is essential for the growth and development of cells, mucous membranes, skin, bone and tooth health, reproduction, and immunity.

- **Vitamin D:** Vitamin D strengthens bones because it helps the body absorb bone-building calcium.

- **Vitamin E:** Vitamin E is an antioxidant and helps protect cells from damage. It functions in stabilization of cell membranes, support of immune function, protection of polyunsaturated fatty acids, and normal nerve development.

- **Vitamin C (also called ascorbic acid):** Vitamin C is needed to form collagen, a tissue that helps to hold cells together. It is an antioxidant, is restores vitamin E to its active form, it helps to synthesize hormones, it supports immune cell function, and helps in absorption of iron.

- **Thiamin (also called vitamin B1):** Thiamin is part of a coenzyme needed in energy metabolism. It also supports a normal appetite and nervous system function.

- **Riboflavin (also called vitamin B2):** Riboflavin is part of a coenzyme needed in energy metabolism. It also supports normal vision and skin health.

- **Vitamin B6 (also called pyridoxine):** Vitamin B6 is part of a coenzyme needed in amino acid and fatty acid metabolism. It helps to convert tryptophan to niacin and to serotonin, and it helps make red blood cells.

- **Vitamin B12:** Vitamin B12 is part of coenzymes needed to make red blood cells, and it is important for nerve cell function.

- **Folate (also known as vitamin B9, folic acid, or folacin):** Folate is part of a coenzyme needed for synthesis of red blood cells. It is also needed to make DNA.

- **Niacin (also called vitamin B3):** Part of coenzymes needed in energy metabolism. It helps maintain healthy skin and is important for nerve function.

- **Pantothenic Acid:** Part of a coenzyme needed in energy metabolism.

- **Biotin:** A cofactor for several enzymes needed in energy metabolism, fat synthesis, amino acid metabolism, and glycogen synthesis.
Physical and chemical properties

- Density
- Appearance
- Freezing point

Density: Density is defined as an object’s mass divided by its volume. It depends on the temperature of the object, composition of the material, and whether or not the object contains air.

The density of milk products can be used to convert volume into mass and mass into volume, to estimate the amount of solids present in milk, and to calculate other physical properties. The density of cows milk usually varies between 1.028 and 1.038 g/cm³.

Appearance: The opacity of milk is due to its content of suspended particles of fat, proteins, and minerals. The color varies from white to yellow depending on the carotene content of the fat. Skim milk is more transparent and has a slightly bluish color.

Freezing Point: The freezing point of milk is lower than the freezing point of water because of the dissolved components in milk. Measuring the freezing point is used as a legal standard to determine if milk has been diluted with water. The freezing point of milk is -0.552°C or 31°F.

p. 82,83 Milk Composition
Physical and chemical properties, continued

- pH
- Titratable acidity

pH:
The pH of milk is higher, or more alkaline, outside of the cow than inside the cow due to loss of carbon dioxide to the air. The pH of milk is never determined immediately after milking because the processing milk goes through removes dissolved gasses. The pH is determined after processing the milk to assure that lactic acid is being produced at the desired rate by added microorganisms during the preparation of cheeses and fermented milk. The casein in milk forms into a curd or a gel at a pH of 4.6.

Titratable acidity:
Titratable acidity is the amount of alkali required to bring the pH to neutrality. This property of milk is used to determine bacterial growth during fermentations, such as cheese and yogurt making, as well as compliance with cleanliness standards. Naturally, there is no lactic acid in fresh bovine milk, however, lactic acid can be produced by bacterial contamination, but this is uncommon. The titratable acidity is due to the casein and phosphates.
Milk producers are required to exclude bacteria from milk, but some may still gain entry. In the US, the bacterial count in Grade A raw milk may not exceed 300,000/ml. When the cow has mastitis, microorganisms associated with infections are found, including *Staphylococcus aureus*, *Streptococcus uberis*, and *Streptococcus agalactiae*. Milk from cows with mastitis cannot be used for human consumption. Pasteurization destroys most of the microorganisms in milk and all of the pathogens. In the US, the upper limit of bacteria in pasteurized milk is 20,000/ml.

Milk has a pH of 6.6, which is ideal for the growth of many organisms. Milk is sterile at secretion in the udder, but it becomes contaminated by bacteria before it leaves the udder. At this point, the bacteria are few and harmless, unless the cow has mastitis. Further infection of the milk by microorganisms happens during milking, storage, handling, and other activities.

Pathogenic bacteria: The following pathogenic bacteria are a concern in raw milk: *Mycobacterium tuberculosis*, *Listeria monocytogenes*, *Salmonella* spp., *Bacillus cereus*, *Yersinia enterocolitica*, *Escherichia coli* 0157:H7, *Campylobacter jejuni*

These pathogenic bacteria can cause foodborne illnesses by ingesting raw milk that contains these organisms or milk that was not pasteurized properly or was contaminated after processing.
• Spoilage microorganisms: Spoilage microorganisms cause degradation of proteins, fats, and carbohydrates and the milk’s texture, color, taste, and smell is deteriorated. Psychrotrophs (bacteria that grow at refrigeration temperatures) are usually involved in spoilage reactions. Most are destroyed by pasteurization, but can still produce heat stable lipolytic and proteolytic enzymes that can cause spoilage.

• However, some strains and species of *Clostridium, Bacillus, Arthrobacter, Cornebacterium, Microbacterium, Micrococcus, Streptococcus, and Lactobacillus* can survive pasteurization and grow at refrigeration temperatures and cause spoilage.

• Coliforms: Coliforms are closely associated with the presence of pathogens, but they are not always pathogenic themselves, thus they are called indicator organisms. They are killed by proper pasteurization treatment. Their presence indicates improper or inadequate pasteurization or it indicates contamination after pasteurization. *Escherichia coli* is an example of a coliform. They are facultative anaerobes and grow best at 37°C or 98.6°F. Coliforms are able to degrade milk proteins and ferment lactose, causing milk to be spoiled quickly.

• Lactic acid bacteria: Lactic acid bacteria can produce chemical changes that are desirable in the production of fermented dairy products because they are able to ferment lactose to lactic acid. They are naturally present in the milk and are used as starter cultures in the production of cultured dairy products, such as yogurt and cottage cheese. Lactic acid bacteria include lactococci, lactobacilli, and *Leuconostoc*. 
Somatic Cells and Microorganisms

- Lactobacilli
- History
- Significance in cultured products

http://www.moomilk.com/archive/u-health-20.htm

Bovine milk contains about $10^4$ to $10^7$ cells/ml. These numbers are usually reported as somatic cell counts. Somatic cell counts are a mixture of epithelial cells (2%) and leukocytes (98%). Many enzymes, such as catalases and proteases, are found in leukocytes and many nucleic acids originate from these cells. Also, they have been used as a source of deoxyribonucleic acid and as a substrate for the polymerase chain reaction.

The proteases contained in somatic cells are capable of hydrolyzing B-Casein and they could cause proteolysis in aged cheeses if not destroyed during processing. These proteases damage raw milk quality during storage and have an adverse effect on pasteurized fluid milk and milk during cheese making.

U.S. Dairy Herd Improvement Association Programs routinely use somatic cell counts using electronic cell counters. High somatic cell counts are associated with reduced milk yields and an increasing incidence of mastitis.

p.54 - 55
References

- Dairy Processing Handbook: Page 19
- “Milk” by Stuart Patton