Milk

Model 1. Milk is a liquid produced by animals called *mammals* to nourish their babies. Animals from goats to buffalo, sheep and cow, even humans produce milk! Milk is a rich and complex source of nutrition. So what exactly *is* milk?

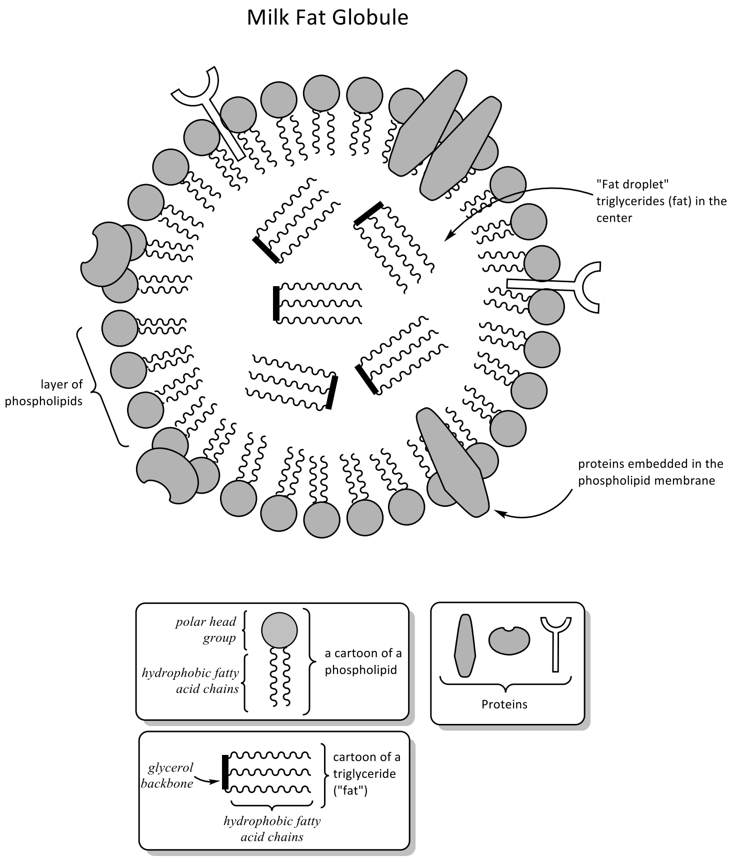

Figure 16.1. A milk-fat globule is a droplet of fat coated with a membrane of phospholipids and protein.

Milk is a *mixture* consisting of two different phases: a water phase – also called an *aqueous phase* -and a fat/oil phase (Table 16.1). When a mixture is composed of two different types of phases, it is called heterogeneous – where “hetero” means different. The water phase and the molecules dissolved in it are *polar* or *hydrophilic*, while the fat/oil phase and the molecules dissolved in it are *non-polar* and *hydrophobic*. The water/aqueous phase is often called the *serum* – it contains proteins and sugar *dissolved* in the water. Milk protein is comprised of largely *casein* and *whey* proteins, while the most abundant sugar in milk is *lactose.* Milk fats are dispersed as fat droplets (also called fat *globules)* within the aqueous/water phase – these fat droplets are encased in a membrane of phospholipids and proteins.

Normally, we would expect there to be a distinct boundary between these two phases – since "oil and water don't mix," but when you buy milk from the grocery store, you don't *see* two phases – that is because the mixture has been *homogenized*, that is – made into an *emulsion*[1].

Table 16.1. The components of milk

Water (Aqueous) Phase = *Serum*			**Fat/Oil Phase**		
Water	Protein Casein, whey	Lactose	Fat droplets (globules)	Fat *soluble* vitamins	Select proteins
Minerals	Water *soluble* Vitamins	Some cells	The *enzyme* lipase		

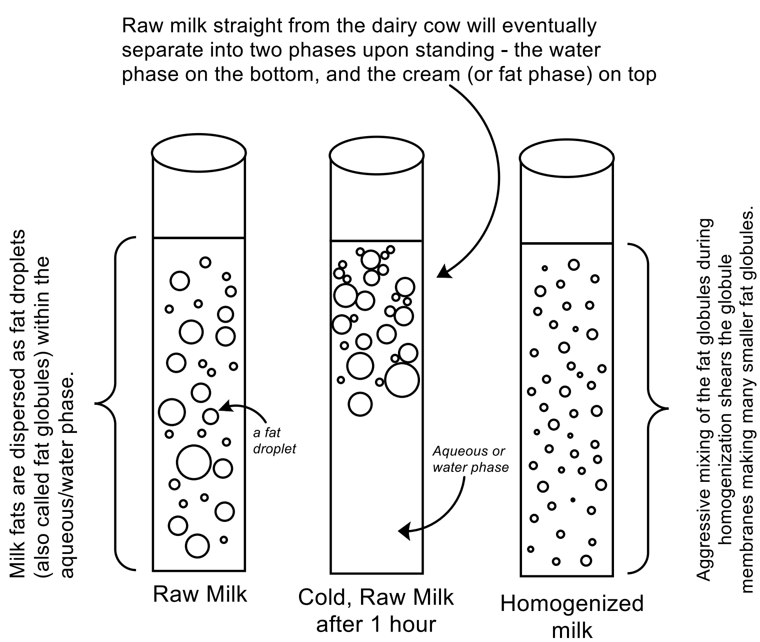

Figure 16.2. Fat droplets dispersed in the water/aqueous phase of milk.

Raw milk straight from the dairy cow will eventually separate into two phases upon standing – the water phase on the bottom, and the cream (or fat phase) on top – hence the expression, "*the cream will rise to the top.*" When fats/oils and water are aggressively mixed until they form a stable mixture (i.e. one that is not separated into two phases) it is called an *emulsion*.

Aggressive mixing of the fat globules during *homogenization* shears the globule membranes making many smaller fat globules. There aren't enough phospholipids to coat the many, smaller fat droplets – so clumps of casein protein stick to the exposed areas of the fat droplet, and help to *emulsify* the fat and water phases.

[1] See Activity 12 for a lesson on emulsions

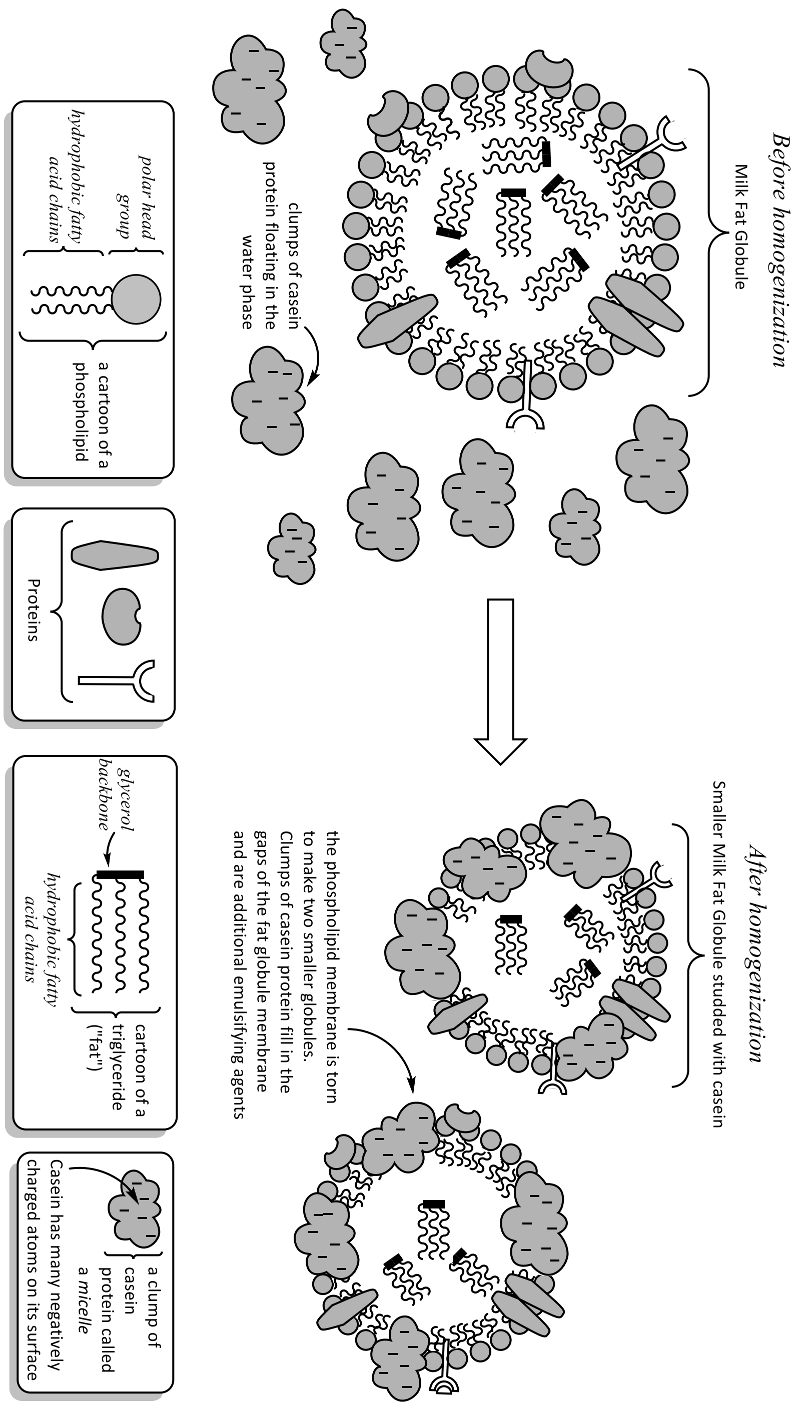

Figure 16.3. What happens to a milk-fat globule during homogenization.

Questions:

1. Milk is a heterogeneous mixture. The word heterogeneous comes from the Lain *heter-* meaning *different* and *genos* meaning *kind* – essentially, milk is not uniform throughout. Explain the chemical reasoning behind why milk is classified as a heterogeneous mixture. Use the word *phases* in your answer.

2. Whole milk contains 3.5% fat while skim milk contains 0.5% fat, while heavy/whipping creams contain 30-40% fat. Skim milk and heavy cream are both made from whole milk while the milk is still "raw" (that is, before *homogenization*).

    a. Propose a method for making a lower-fat milk use raw, whole milk as the starting point.

    b. Propose a method for making heavy cream using raw, whole milk as the starting point.

    c. Why must the milk be un-homogenized?

3. The result of homogenization is many smaller milk-fat globules whose fat droplets are only partially covered by membranes. The exposed lipid droplets quickly become covered with casein proteins from the liquid phase of the milk. These “casein-studded” particles prevent the globules from merging together into a single layer of fat. Why are the casein-studded fat globules less likely to combine with one another? What keeps them separate? (and keeps *your milk* from separating into water and cream!)

Model 2. *Milk Proteins* –While there are thousands of individual proteins in milk, they are often divided into two classes: *casein* protein or *whey* protein. If you were to add acid[2] (such as vinegar) to milk you would create soft white clumps surrounded by a yellowish white liquid. The white clumps are made of denatured, coagulated protein and fat. The addition of acid unravels the protein by adding protons (H^+) that change the charges of some amino acid residues – like glutamate, shown below (Figure 16.4). The disruption of charge disrupts the non-covalent interactions that hold the protein structure together – this is called, *denaturation*. The three-dimensional protein structure has water-loving (hydrophilic) parts on the outside and water-hating (hydrophobic) part on the inside of the folded protein.[3] The acid *denatured* protein *coagulates* with other unraveled protein and fat (remember, fat is hydrophobic) by sticking the exposed hydrophobic areas together. The *coagulation* makes soft lumps of insoluble protein and trapped fat.

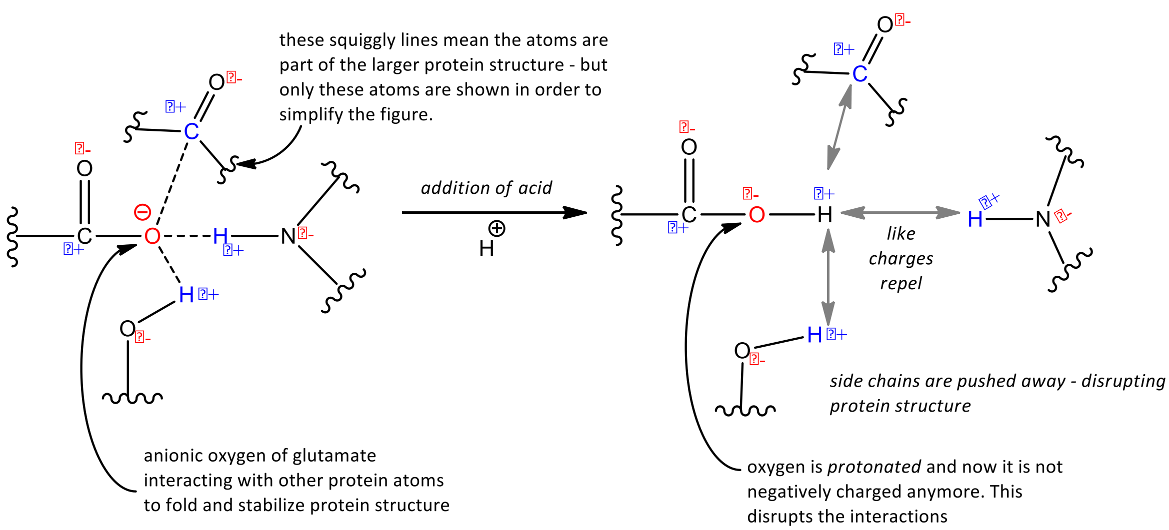

Figure. 16.4. Acidic conditions *protonate* glutamate and disrupt its non-covalent interactions.

2 For a lesson on acids, see activity 8
3 See activity 6 for a lesson on higher order protein structure

The protein in curds is made entirely of casein. The protein casein is particularly unstable to *acid denaturation* because it has so many negative charges (as shown in the cartoon, Figure X.X). Interestingly, while the casein proteins denature and coagulate under acidic conditions, *both* casein and whey proteins are surprisingly stable to heat. This is why milk can be added to hot coffee or hot tea without producing clumps of denatured and coagulated protein.

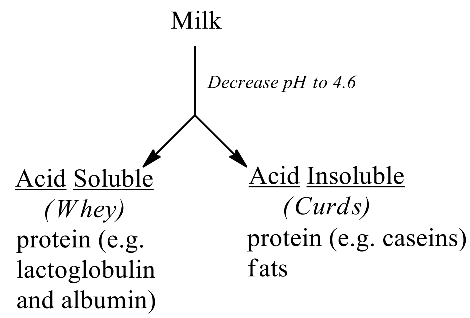

Figure 16.5. Curds versus Whey

Furthermore, *pasteurization* is the process of quickly heating and then cooling the milk to temperatures high enough to kill any contaminating bacteria or other microbes present in the raw milk but not enough heat to destroy the nutritive properties of milk. The heat stable proteins make *pasteurization* effective in sterilizing milk for long-term storage.

Questions:

4. In Figure 16.4, the side chain of a glutamate residue is *protonated*. Circle the hydrogen that was added to glutamate.

5. A recipe for making cottage cheese begins with the following instructions: "*Pour the skim milk into a large saucepan and place over medium heat. Heat to 120°F. Remove from the heat and gently pour in the vinegar. Stir slowly for 1 to 2 minutes. Cover and allow to sit at room temperature for 30 minutes.*"

    a. What chemistry is occurring here with the addition of vinegar?

    b. What should this mixture look like after sitting for 30 minutes?

6. An alternative recipe for *curdling* milk (generating curds and whey) calls for adding lemon juice to warm milk. Why does the addition of lemon juice produce curds and whey?

7. When milk has gone *very bad*, bacteria in the milk generate lactic acid. How does this explain the lumps in sour milk?

8. Raw milk is – by definition – milk that has not been pasteurized or homogenized. The sale of raw milk is regulated by the FDA because it contains bacteria (some from the gut of the cow, but sometimes the milk can be contaminated with bacteria from the…uh…tail area…yuck).
   a. Why do you think the government requires pasteurization?
   b. Is homogenization necessary for health reasons? Why homogenize?

Model 3. *Milk sugar* - Lactose is a *dimer* (or a *di*saccharide) of *glucose* and *galactose* – it is also a *carbohydrate*. As we have seen, Glucose is an important source of energy for the body, while galactose is also an important cellular building block. Galactose is not broken down as a fuel source – rather it is used to make the *cell membrane* (the thin exterior layer of the cell) in animal cells. For the body to be able to use the glucose and galactose from lactose, the bond holding the two sugar molecules together must be broken. An *enzyme* produced in the gut called *lactase* binds lactose and uses a water molecule to break the covalent bond holding the two pieces together. This reaction produces glucose and galactose for the body to absorb and use.

So what happens if a person doesn't produce *lactase* and continues to drink milk and eat ice cream? The *lactose* is not broken down in the gut; water then rushes into the intestines creating a bloated feeling and watery stool. If this wasn't bad enough, the natural bacteria found in human intestines are able to digest the lactose, producing carbon dioxide (CO_2), methane (CH_4) and hydrogen (H_2) gases – resulting in flatulence, cramps, bloating and diarrhea. This syndrome is called *lactose intolerance* and occurs most often in adults.

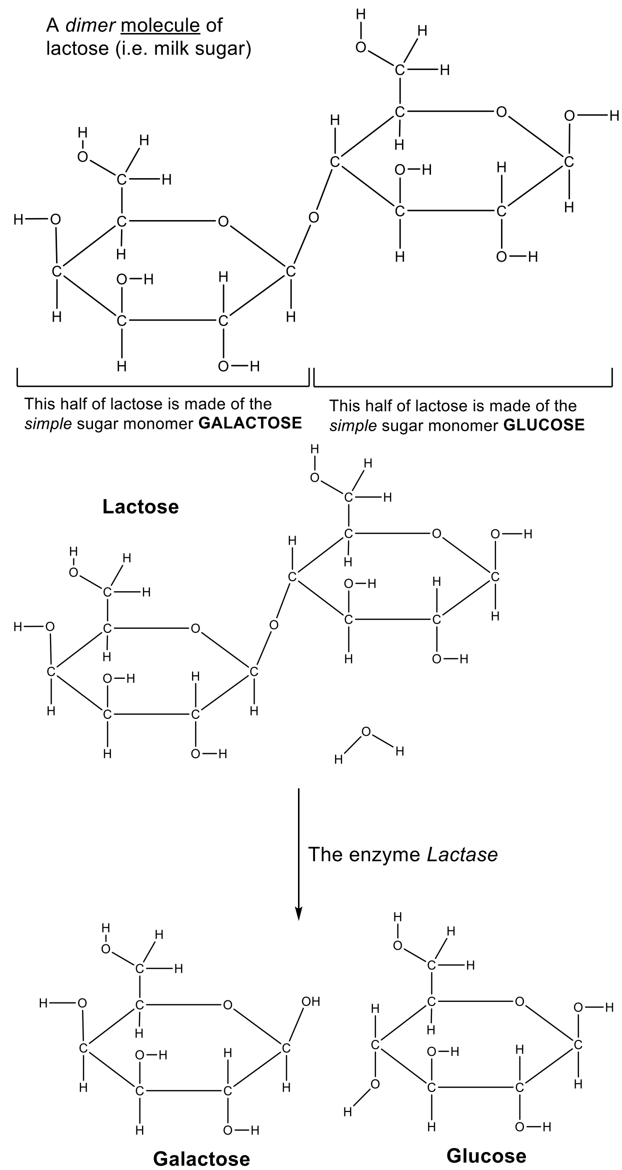

Figure 16.6. Lactose is broken into glucose and galactose by the enzyme lactase.

Questions:

9. Lactaid is a product that you can add to dairy foods before consuming them in order to make the food "lactose-free". The manufacturer's website contains the following description of lactaid: "LACTAID® Dietary Supplements contain the natural enzyme you need to digest dairy, so you can enjoy dairy whenever and wherever you choose." Based on this explanation, explain the chemistry behind how Lactaid helps the lactose intolerant to digest dairy.

10. Lactose intolerance is generally a condition of grown adults (only in rare cases does it affect children). Why did nature ensure lactose *tolerance* in babies and children, while adults can become lactose *intolerant*?