Sugar is sweet…[1]

Model 1. Simple sugars like glucose and fructose are small *monosaccharides*. Table sugar is a *di*mer of fructose and glucose and is therefore called a *disaccharide.* Many sugars joined together in a polymer can make starch or cellulose (depending on the arrangement of bonds), and by analogy, another name for a polymer like starch or cellulose is a *polysaccharide.*

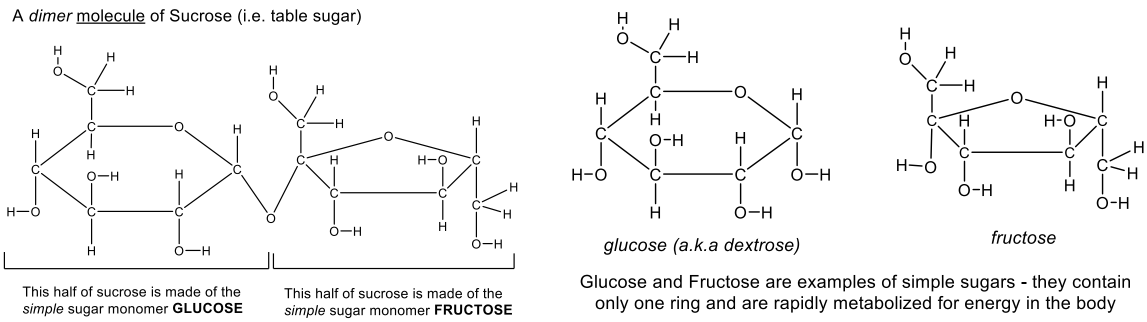


Figure 32.1. Sucrose (i.e. table sugar) is a *dimer* of glucose and fructose.

Table 32.1. The composition and relative sweetness of different sugars and syrups

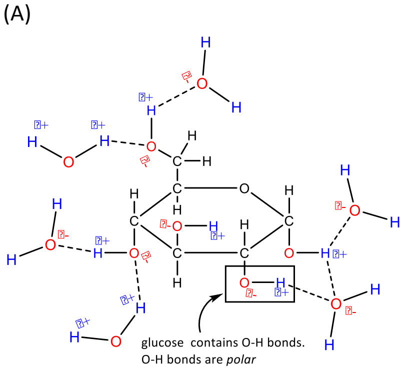
Sugar	Alternative name	Composition of mono- and disaccharides	Relative sweetness
Fructose	Levulose	Pure fructose	120
Glucose	Dextrose	Pure glucose	70
Sucrose	Table sugar	Dimer of glucose and fructose	100[2]
Lactose	Milk sugar	Dimer of galactose and glucose	40
Maltose		Dimer of glucose	45
Corn syrup		Mixture of glucose and maltose, and longer glucose chains	30-50
High fructose corn syrup		Mixture of fructose and maltose, and longer glucose chains. Higher fructose concentration.	80-90
Invert sugar syrup		Mixture of fructose, glucose and sucrose	95
Honey		Mixture of fructose (38%), glucose (31%), sucrose (1.5%), other disaccharides, acids and minerals (~7%)	~97 (similar to sucrose but depends on type
Maple syrup		Mixture of sucrose (62%), glucose and fructose (3%) with trace amino acids, minerals and malic acid	Similar to sucrose, but depends on type

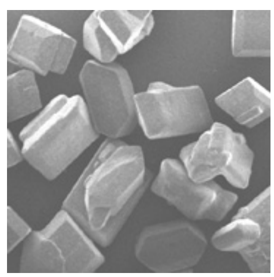
[1] Some of this content can be found in Activity 7_Carbohydrates
[2] Sucrose (table sugar) has been assigned the arbitrary value of 100 – so all the sweetness measurements are simply a comparison to sucrose. For example, maltose is about half as sweet as table sugar, while pure fructose is sweeter than table sugar.

Because we perceive both simple sugars (like glucose and fructose) *and* dimers like sucrose and lactose as *sweet* – all of these *monosaccharides* and *disaccharides* are commonly called *sugar*. Polymers like starch are tastless to humans – only when *acid* or *enzymes* break starch down into its component sugar monomers/*monosaccharides* do we experience the sweet taste.

All sugars are made entirely of carbon, hydrogen and oxygen atoms joined by covalent bonds – this is what makes them examples of *carbohydrate*, $C_n(H_2O)_n$. Because sugars have so many H-O groups, they readily form hydrogen bonds[3] with water – this makes it easy to dissolve sugars in water. Sugars are also small which helps them dissolve readily in water. The hydrogen bonding capacity of sugars allows them to retain moisture in baked goods. It is this "wet sugar" that forms the sticky matrix that holds granola bars together, and gives glazes a glossy appearance.

(A)





Dr. ZoeAnn Holmes, Professor Emeritus, Oregon State University. *Used with Permission*

(B) Sucrose crystals in water

Photo by Bill Keller

(C) The large crystals of rock candy are made from pure sucrose that crystallizes out of a pure sucrose and water syrup.

Figure 32.2. (A) Sugars like glucose can form hydrogen bonds with water. (B) Crystalline sucrose (C) Rock candy

Questions:

1. Explain how glucose, maltose and corn syrup are similar and different. Assign each the label *mixture* or *pure substance*.

2. Explain why honey is a natural source of *invert sugar syrup*.

[3] Remember, a hydrogen bond is a ionic-type non-covalent interaction between a partially positive hydrogen and a partially negative oxygen, it is weaker than a covalent bond

3. Why is high fructose corn syrup is *sweeter* than regular corn syrup?

4. Corn starch is made of amylose and amylopectin – both polymers of glucose. To make corn syrup, manufacturers break down corn starch using acid. Explain how the breakdown of corn starch can make the mixture known as corn syrup (Table 32.1).

5. Sprinkling powered sugar onto a baked dessert can be a nice finishing touch. But on a humid or rainy day, the powdered sugar will often seem to disappear or melt into the cake. What is happening to the sugar, and what is the chemical explanation for why?

6. Chemists call glucose and fructose *isomers*. Using Figure 32.1, can you determine how glucose and fructose are chemically related? (*Hint*: count the number of carbons, hydrogens and oxygens in both molecules).

Model 2. When sugars are dissolved in water, they make a *solution* called a *syrup*. To make a *syrup*, there must be enough water to *dissolve* the sugar. Another way to think of it, is that there must be enough water to separate the sugar molecules from one another. High fructose corn *syrup* is corn syrup in which some of the glucose has been converted to fructose by enzymes. High fructose corn syrup is a common beverage sweetener – for example, in soft drinks. While fructose may be “natural” consuming large amounts of it is not necessarily healthy, but more on this later.

If the dissolved sugar molecules in a syrup get too “crowded” for the water molecules to keep them apart, *and the sugars are all of one kind*, then the sugar molecules will hydrogen bond with each other. When *many molecules of the same kind of sugar* (i.e. a *pure substance*) form a large hydrogen bonded matrix, the sugar has formed a *crystal*.

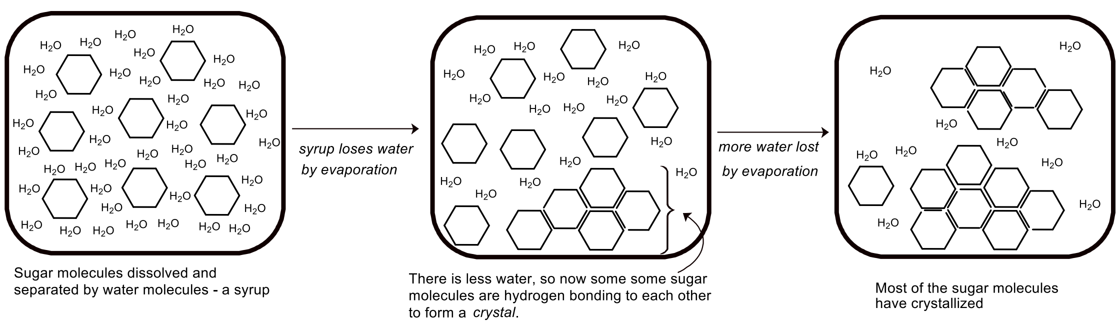


Figure 32.3. Crystallization of a *pure* sugar

The sugar molecules can get closer together (and form crystals) when the temperature of a liquid is very cold (i.e. there is less energy for the molecules to move around), or when water evaporates out of the sugar-water solution (or syrup). In these conditions, the hydrogen bonded sugar molecules form a large enough matrix that they can’t stay dissolved in the water anymore, and the sugars *crystallize* out of solution. If the solution is undisturbed, then the crystals can grow very large. Rock candy is an example of *pure* sucrose that has formed very large crystals of many sucrose molecules packed in an array.

Sometimes, we want a sugary candy like taffy or a smooth icing like fondant or fudge. In these foods, the sugar crystals are very, very small. To get a solid material with small crystals, you want to make crystallization difficult.

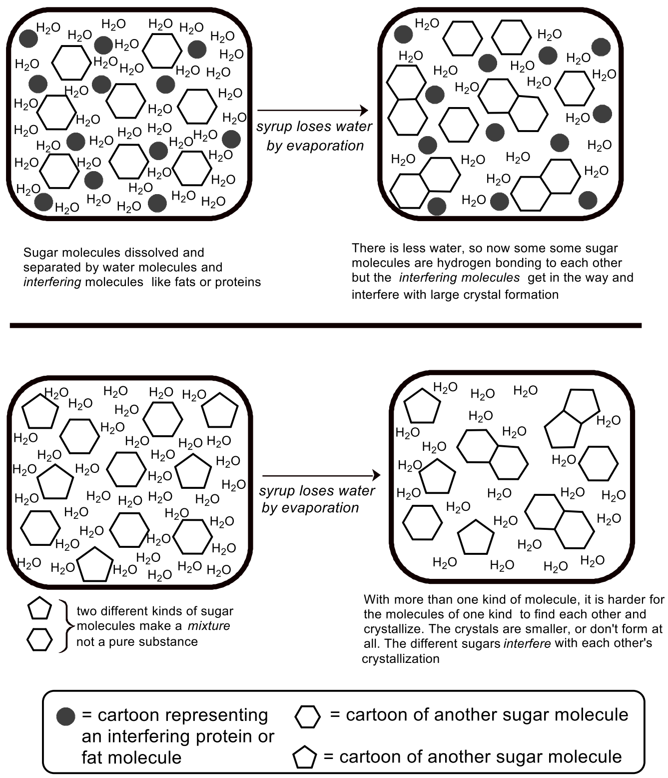


Figure 32.4. *Interfering* with crystallization

Crystals form when a pure molecule can pack up against other molecules of the same type in an extended repeating array. The larger the array, the larger the crystals. But if our solution of sugar is a *mixture* rather than a *pure substance*, forming crystals is more difficult. Crystals only form from *pure substances*. Small amounts of fat, protein, amino acids, other sugars – any other molecule – can get in the way and *interfere* with crystallization. When interfering agents are added, the mixture either forms very small crystals, or cannot form crystals at all.

Questions:

7. High fructose corn syrup is often used to sweeten cold beverages – such as regular soda or juice drinks.
    a. How is HFCS made? Use the words *enzyme* and *isomer* in your answer.

    b. Explain why high fructose corn syrup is good for sweetening a cold beverage – i.e. crystals do not readily form in corn syrup.

8. Another *physical* method of interfering with crystal formation is to agitate, stir or beat the sugar solution. How might this make the crystals smaller?

9. Sucrose is a dimer of glucose and fructose. Add a small amount - like 3 drops - of acid (e.g. lemon juice) to 1 cup of sucrose dissolved in water will break some of the sucrose apart into glucose and fructose – essentially creating *invert sugar syrup* on the spot. This trick of adding lemon juice to sucrose is a strategy for preventing crystallization of sucrose as in the making of caramel candies. Explain how the "lemon juice trick" helps to prevent sucrose crystallization.

Putting it All Together:

10. When you bake a pan of brownies, the temperature is typically 350°F. Water boils (i.e. turns from a liquid into a gas) at 212°F, and yet the brownies are still moist? How can the interactions between water and sugar molecules explain this phenomenon?

11. When making rock candy you are instructed to suspend a string into a solution of table sugar dissolved in water (which can also have some food coloring added!). Then the solution and suspended string must be left undisturbed so the crystals can grow.

Rock candy is characterized by very large crystals. In what ways does this method ensure large sugar crystals?