Ca$_5$(PO$_4$)$_3$(OH) $\rightarrow$ 5 Ca$^{2+}$ + 3 PO$_4^{3-}$ + OH$^-$

A certain amount of demineralization is normal. But it is also normal for the reverse process, remineralization, to occur. 5 Ca$^{2+}$ + 3 PO$_4^{3-}$ + OH$^-$ $\rightarrow$ Ca$_5$(PO$_4$)$_3$(OH)

If too much bacterial acid is produced, demineralization can outstrip mineralization, leading to a cavity. How does this happen? When acids are present in a solution, they combine with the hydroxide ions produced during demineralization to form water: 

H$^+$ + OH$^-$ $\rightarrow$ H$_2$O

But hydroxide ions are essential to remineralization, so their neutralization by hydrogen ions causes remineralization to slow down. The hydroxide ion on the surface of the teeth helps dissolve, ultimately leading to tooth decay. Fluoride ions present in mouthwashes help remineralize the enamel. They accumulate on the surface of the enamel, thus creating a barrier that prevents bacterial acids from reaching the enamel. This is why fluoride toothpastes are so effective. Fluoride ions attract calcium ions, ultimately changing hydroxyapatite into fluorapatite (Ca$_5$(PO$_4$)$_3$(OH) and F$^-$), which are attracted to each other to form the crystalline structure of hydroxyapatite.

The bacteria present on your teeth produce acids that cause hydroxyapatite to break apart—a process called demineralization:

Ca$_5$(PO$_4$)$_3$(OH) $\rightarrow$ 5 Ca$^{2+}$ + 3 PO$_4^{3-}$ + OH$^-$

The bacteria break down cellulose, so if undigested food enters the colon, there is more for the bacteria to feed on. And when you have a lot of bacteria, you have a lot of their waste products in the form of gas. Foods high in fiber—such as fruits, vegetables, and beans—tend to produce a lot of flatus. Some indigestible sugars can have the same effect. For instance, lactose in milk, which is a carbohydrate molecule (Fig. 8), forms from glucose and galactose.

**Passing gas**

Eating a lot of fiber can have an undesirable side effect: the production of large amounts of intestinal gas. When this gas is released, it is known as flatulence. The gas itself is known as flatus. "Passing gas" is actually a good way to describe this process. People pass gas 14 times per day, on average. This gas is produced by bacteria in the colon. Fiber is made of a substance called cellulose (Fig. 7). Cellulose belongs to a group of materials called carbohydrates that are composed of carbon, hydrogen, and oxygen and are made of a series of repeating small molecules. In the case of cellulose, the repeating small molecule is glucose (C$_6$H$_12$O$_6$) (Fig. 8).

In the colon, bacteria break down cellulose, so if undigested food enters the colon, there is more for the bacteria to feed on. And when you have a lot of bacteria, you have a lot of their waste products in the form of gas. Foods high in fiber—such as fruits, vegetables, and beans—tend to produce a lot of flatus. Some indigestible sugars can have the same effect. For instance, lactose in milk, which is a carbohydrate molecule (Fig. 8), forms from glucose and galactose.

**People pass gas 14 times per day on average.**

As the gas forms, it rises to the surface of the colon. When too much gas accumulates, it is released as flatus. But it is normal to release some flatus during the day. People pass gas 14 times per day, on average. Or is it? "A lot of bacteria, you have a lot of their waste products in the form of gas. Foods high in fiber—such as fruits, vegetables, and beans—tend to produce a lot of flatus. Some indigestible sugars can have the same effect. For instance, lactose in milk, which is a carbohydrate molecule (Fig. 8), forms from glucose and galactose.

**Better than sugar?**

According to the U.S. Department of Agriculture, Americans consume an average of 156 pounds of sugar each year. That’s a little more than 31 of the five-pound bags you might see in the baking goods aisle in the grocery store! We all know that eating too much sugar can cause tooth decay, weight gain, and type-2 diabetes, but is there a way to indulge your sweet tooth and still avoid sugar? Yes. Food and beverages labeled “diet” taste sweet yet don’t contain sugar—thanks to artificial sweeteners.

Why do artificial sweeteners have no calories? Could they be bad for your health? Let’s compare the chemistry of sugar and artificial sweeteners to find out.

**Figures**

- Figure 1: Chemical structure of saccharin, an artificial sweetener.
- Figure 6: Enamel is the hard white substance that covers a tooth.
- Figure 7: Chemical structure of cellulose.
- Figure 8: Chemical structure of glucose.
**Sweet aminos**

Not all artificial sweeteners look like saccharin. Aspartame, known by the brand names NutraSweet and Equal, is the primary sweetener in most diet sodas. It is a combination of two amino acids, aspartic acid and phenylalanine, as shown in Fig. 2. Aspartame (Fig. 3) consists of two of these amino acids.

While saccharin tastes sweet, it also has a lingering bitter and metallic taste that some people can detect. That makes it a good choice for sweetening tea and coffee, which have their own bitter taste, but not necessarily a good one for candies and soft drinks, which are known to be sweet. Aspartame does not have a bitter taste, which makes it a better choice for a wide variety of sweet foods and drinks.

Unlike other artificial sweeteners, aspartame is metabolized in the body, so aspartame is higher in calories. But aspartame is 180 times sweeter than sugar, so it can be used in small quantities and, as a result, does not generate as many calories as sucrose.

Another popular artificial sweetener is sucralose (brand name: Splenda). Its chemical structure is similar to that of sucrose (Fig. 4).

![Figure 4. The chemical structure of sucralose is similar to the structure of sucrose.](image)

**Any risks to human health?**

Over the years, concerns have been raised that several artificial sweeteners may cause health problems. In theory, artificial sweeteners should be safe because they pass easily through the digestive system without being processed. But scientific tests were needed to confirm that artificial sweeteners were indeed safe.

In 1977, rats that were fed saccharin developed bladder cancer. The rat, however, had to eat an amount of saccharin comparable to a human drinking hundreds of cans of soda each day. As a result, Congress required that all food containing saccharin display the following label: “Use of this product may be hazardous to your health. This product contains saccharin, which has been determined to cause cancer in laboratory animals.” Subsequent studies could not find evidence that saccharin causes cancer in humans. It is now used in food and drinks all over the world.

In 1996, studies suggested that aspartame may cause brain tumors because the number of people with brain tumors had increased over the years after aspartame was introduced on the market. Further studies, however, revealed that brain cancer had started to rise 8 years before aspartame was made publicly available. No other studies have since shown a correlation between aspartame use and cancer.

Many other artificial sweeteners have been tested. None of these tests has provided clear evidence of an association with cancer in humans. So, avoiding how to make sugar or artificial sweeteners might be beneficial to health and be just what the doctor ordered!

![Figure 2. Examples of two amino acids: (a) aspartic acid and (b) phenylalanine. Like all other amino acids, aspartic acid and phenylalanine consist of three parts: a head (blue), a central carbon: and an amino group (–NH2), a carboxyl group (–COOH), and a side chain (middle) that varies depending on the amino acid.](image)

![Figure 3. Chemical structure of the artificial sweetener aspartame](image)

---

**SELECTED REFERENCES**


