dissolved in water, the fluoride ions are free to move. Fluoride ions prevent tooth decay by strengthening the enamel. The primary component found in tooth enamel is a strong, insoluble mineral called hydroxyapatite (Ca$_5$(PO$_4$)$_3$(OH)). Hydroxyapatite contains positive ions (Ca$^{2+}$) and negative ions (PO$_4^{3-}$ and OH$^-$), which are attracted to each other to form the crystalline structure of hydroxyapatite.

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

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

A certain amount of demineralization is normal. But it is also normal for the reverse process, remineralization, to occur:

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

If too much bacterial acid is produced, demineralization can outstrip remineralization, leading to a cavity. How does this happen? When acids are present in a solution, they dissolve to produce hydrogen ions ($H^+$). In the mouth, as bacteria produce acids, the amount of hydrogen ions builds up. These ions combine with the hydroxide ions produced during demineralization to form water:

$$H^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$$

But hydroxide ions are essential to remineralization, so their neutralization by hydrogen ions causes remineralization to slow down. The hydroxyapatite on the surface of the teeth keeps ultimately leading to tooth decay. Fluoride ions present in mouthwashes help the enamel to remineralize. They accumulate on the surface of the enamel, thus creating a barrier that prevents bacterial acids from reaching the enamel. Also, the fluoride ions attract calcium ions, ultimately changing hydroxyapatite into fluorapatite (Ca$_5$(PO$_4$)$_3$(F)), which is stronger than the original hydroxyapatite.

Bad breath can be caused by many different gases, but two of the most common are hydrogen sulfide (H$_2$S) and methyl mercaptan (CH$_3$SH)—both sulfur-containing compounds. Other gases that lead to bad breath are isole (C$_3$H$_6$N) and skatole (C$_9$H$_9$N), the two gases primarily responsible for the smell of feces.

**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 farts. “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). Bacteria belong 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 flatulence. Some indigestible sugars can have the same effect. For instance, lactose in milk, which is a carbohydrate molecule (Fig. B) formed from glucose and galactose,
Sweet aminos
Not all artificial sweeteners look like sugar.
Aspartame, known by the brand names NutraSweet and Equal, is the primary sweetener in most diet sodas. It is a combination of amino acids, the building blocks of proteins, organic compounds found in meat, eggs, milk, and legumes. A protein is a molecule made of a chain of repeating units of amino acids.

The structures of two amino acids, aspartic acid and phenylalanine, are shown in Fig. 2. Aspartame (Fig. 3) consists of a combination of these two amino acids. While aspartame 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 sweeter than sugar, so it can be used in small amounts. Sucralose (brand name: Splenda). Its chemical structure is similar to that of sucrose (Fig. 4), but unlike saccharin, sucralose has no calories. It is washed out of the body without being digested. Sucralose is 600 times as sweet as sucrose, about three times as sweet as aspartame, and twice as sweet as saccharin.

Table 1 summarizes the relative sweetness of common artificial sweeteners compared to sucrose.

Table 1. Relative sweetness of artificial sweeteners compared to sucrose

<table>
<thead>
<tr>
<th>Sweet Substance</th>
<th>Brand name</th>
<th>Relative Sweetness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>none</td>
<td>1</td>
</tr>
<tr>
<td>Glucose</td>
<td>none</td>
<td>0.7</td>
</tr>
<tr>
<td>Fructose</td>
<td>none</td>
<td>1.8</td>
</tr>
<tr>
<td>Aspartame</td>
<td>NutraSweet</td>
<td>200</td>
</tr>
<tr>
<td>Saccharin</td>
<td>Sweet’N Low, SugarTwin</td>
<td>300</td>
</tr>
<tr>
<td>Sucralose</td>
<td>Splenda</td>
<td>600</td>
</tr>
</tbody>
</table>

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 rats, 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.

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

Selected references