Myths Chemistry Tells the Truth

By Brian Rohrig

To describe how things work, people sometimes use simple explanations that are easy to remember. But some of these explanations are not based on any scientific evidence. Many such explanations become part of our culture because people keep repeating them, but these explanations are more myths than actual truths. One way to reveal the truth behind some of these myths is by using chemistry. Let's examine two such myths and see if they hold up under serious scientific scrutiny.

Myth I Microwaves heat food from the inside out.

The birth of microwave ovens

The year was 1946. World War II had just ended. The Raytheon Corporation needed to shift its efforts from fulfilling military contracts to the civilian front. They had already done a lot of experimenting with magnetrons—radar tubes that generate microwave radiation.

A magnetron releases pulses of microwaves that bounce off any object in their path. The object returns a tiny part of the wave's energy to a dish or antenna, which is usually located at the same site as the magnetron. During World War II, U.S. submarines began using these tubes, which helped them detect enemy ships more quickly.

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One day, engineer Percy Spencer happened to walk by a row of these tubes that were in operation. He also happened to have a candy bar in his pocket. When he took out the candy bar, he noticed that it was soft and gooey. He then placed some popcorn kernels near

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these tubes. Amazingly, the kernels popped! Upon exposing a raw egg to these waves, it exploded, showering unsuspecting onlookers with egg on their faces. From these humble experiments, the idea of cooking food with microwaves was born.

The first microwave oven weighed 750 pounds and was more than 5 feet tall. An early commercial model was introduced in 1954 and cost up to $3,000—the equivalent of around $30,000 in today's money! Today, microwave ovens are much smaller and are more affordable and are present in more than 90% of U.S. homes.

What are microwaves?

There is nothing mysterious about microwaves. They are a type of electromagnetic radiation, just like visible light, radio waves, and X-rays. All types of electromagnetic radiation travel about 300,000 kilometers per second in a vacuum. This value is typically referred to as the speed of light. What distinguishes one type of radiation from the next is its wavelength—the distance between two successive crests in the wave. The microwaves used to cook food have a wavelength of 12.24 centimeters.

Many types of electromagnetic radiation can pass through objects unobstructed, so people think that microwaves heat food from the inside out. Because microwaves can pass through plastic, paper, and glass, can they can also penetrate food and cook the inside first?

What happens inside a microwave oven?

To understand how microwaves cook food, let's consider this little experiment: Fill a beaker half-full with water and place it in a microwave oven. Place an empty beaker next to the first one. Turn on the microwave oven. After a minute or so, the hotter beaker will be the one containing water. This shows that microwaves heat food by heating the water within the food.

Water is a very effective absorber of microwave energy due to its polar nature. In a water molecule, the electrons are more strongly attracted to the oxygen end than to the two hydrogen ends. So, the oxygen end has a slightly negative charge and each hydrogen end has a slightly positive charge (Fig. 1).

Inside a microwave oven, microwaves produce constantly changing electric fields in the food. The water molecules in the food react to the electric field by rotating in order to minimize the repulsive force on both the positive and negative ends of the molecule (Fig. 2). When the electric field changes from positive to negative, as it does with an electromagnetic wave, the water molecules rotate again and orient themselves in the opposite direction.

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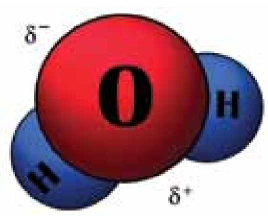

Figure 1. Water is a polar molecule. The oxygen end is an electrically negative region (shown as delta⁻), while the hydrogen end is electric ally positive (shown as delta⁺). These electric regions compensate, keeping the molecule neutral.

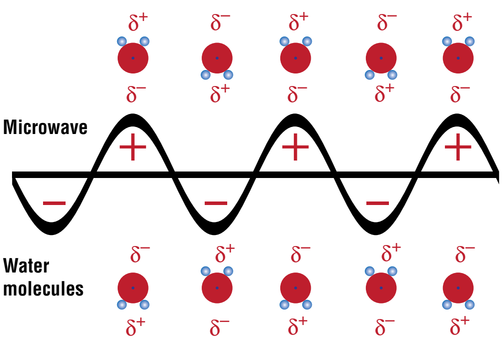

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Figure 2. Water molecules in a microwave are flipped back and forth. As the crest of the microwave passes by the water molecule, the molecule moves toward the wave. Then, as the oppositely charged trough of the microwave passes by, the water molecule is flipped in the opposite direction.

The microwaves that cook food have a frequency of 2.45 gigahertz, or 2.45 billion hertz. In other words, every second the wave vibrates back and forth 2.45 billion times. These waves flip back and forth, and as a result, the water molecules are flipped back and forth 2.45 billion times each second!

As the water molecules rotate, they bump other molecules causing them to move randomly. As all these water molecules move, they generate heat. As a result, microwave energy is converted to thermal energy, which heats food.

Water is the answer

So, do microwaves heat food from the inside out? "This depends on where water is located within the food," says Kit Keith Yam, professor in the Department of Food Science at Rutgers University, New Brunswick, N.J. "In popcorn, water content is higher inside than outside, so heat flows from the inside to the outside."

Water content is the key. Since microwave ovens primarily heat food by heating water within the food, if there is no water, there will be little heating. For instance, you are trying to heat up some leftover lasagna that has been in the refrigerator for a couple of days. Chances are, the surface will tend to be a bit dry due to the evaporation of water on the surface of the lasagna. But the inside of the lasagna will have most of its moisture intact.

So, after heating the lasagna in the microwave oven, the inside may end up hotter than the outside. This may have led to the misperception that microwaves heat from the inside out—but this would only be true if the inside of a food contains more water than the outside.

Often, the water content of food is relatively uniform, and the food heats evenly throughout. In the case of a frozen piece of meat, we often observe that the outside can thaw completely while the inside remains frozen. Here's why. In ice, the molecules cannot rotate as easily as in liquid water, so microwaves do not heat ice as effectively as they heat liquid water. As the frozen piece of meat thaws, the heated liquid water gradually heats the frozen water by normal conduction, so the frozen piece of meat heats unevenly.

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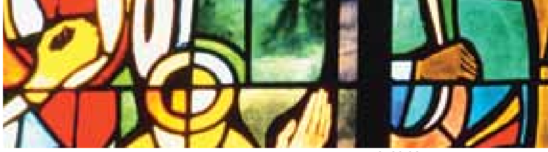
In a microwave oven, a frozen piece of meat thaws unevenly because microwaves do not heat a frozen solid as effectively as a liquid.



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Is the myth busted?

We can safely say that the myth of microwave ovens heating food from the inside out is clearly busted, with one exception: If the inside of a piece of food contains more water than the outside, then the inside will indeed heat faster than the outside.

Myth 2

The bottoms of old windows are thicker because glass, being a liquid, flows over time.

If you visit a 12th century medieval cathedral in Europe, you will be thoroughly impressed not only with the architecture but also with the gorgeous stained glass windows. If you were allowed to remove one of these stained glass panes, you would notice that unlike today's glass, the windowpane would be uneven. If you examined several different panes, you would probably notice a pattern. In most cases, the bottom of the windowpane would be thicker than the top.

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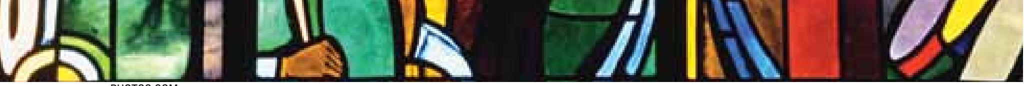
Some people have created a myth about these windowpanes: Because glass is a liquid, over a period of several hundred years, it flows. In the United States, windowpanes from the colonial period show a similar unevenness.

A likely reason this myth has developed is that many people assumed that glass was liquid, while it is actually solid. Why would people assume that glass is liquid? That's because, on a molecular level, glass looks more like a liquid.

Molecular structure of glass

A liquid is a substance that takes the shape of its container; a solid maintains its shape. Most solids are crystalline in nature, meaning the molecules are arranged in a repeating pattern, contributing to its rigid structure.



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In sodium chloride, for instance, the orderly arrangement of sodium and chloride ions takes the shape of a cube. Whether you examine a large piece of rock salt or a tiny granule of table salt, the ions are always arranged in the same basic cubic structure.

Window glass, on the other hand, is not crystalline but amorphous. An amorphous substance has no discernible crystal structure. Its molecules are not arranged periodically, much like a liquid (Fig. 3). Besides window glass, other examples of amorphous substances are volcanic glass, pumice, and glass rocks formed as a result of a meteor impact.

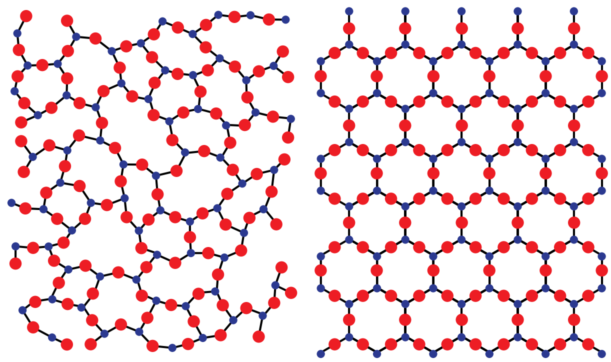

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Figure 3. Atomic structure of glass (left) and crystal (right). Red, oxygen; blue, silicon.

All liquids are viscous, meaning that they resist flow. An object that flows slowly, such as honey or syrup, is more viscous than a substance that flows more quickly, such as water or alcohol. Viscosity is sometimes referred to as thickness. Thicker (more viscous) substances flow more slowly than thinner (less viscous) substances.

It is usually easy to distinguish a solid from a liquid. You can be fairly confident that the chair you are sitting on will pretty much have the same shape a hundred years from now. The same goes for the desk you may be using or the paper that this article is written on. Conversely, if you are sipping a Coke or a cafe latte, there is little doubt they are liquids, as they require a container to, well, contain them.

But consider the Silly Putty toy. If shaped into a ball and placed on a table, it looks like a solid. But over a period of several minutes, it begins to flatten out a little on the bottom. If you come back and observe it the next day, it will have flowed into a puddle! What looks like a solid is actually a viscous liquid.

These observations about viscous liquids have led some to assume that because glass is amorphous, it is a viscous liquid masquerading as a solid. But intense scientific study has shown that the glass used to make windowpanes, which is a mixture of soda ash, limestone, and sand, exhibits no flow at all. One scientist has calculated that it would take 10^{32} years for glass to produce any noticeable flow! The study of much older Egyptian and Roman glass up to 2,500 years old has shown no deformation at all. And very old samples of volcanic glass also show no flow after they have solidified.

"A glass is a solid with a structure *resembling* that of a liquid, but a glass is a solid—pure and simple," says Peter Harrowell, professor of chemistry at the University of Sydney in Australia.

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From molten glass to windowpane

So, what has caused the unevenness in old samples of glass? It has to do with how glass windows were made. "Back in the day, glass windows were made by hand, using a blob of molten glass that was gathered on the end of a pipe and spun to create a relatively flat, round plate," says Richard Brow, Curator's professor of ceramic engineering at the Missouri University of Science and Technology, Rolla, Mo. **"**After cooling, sections were sliced from the plate to form windowpanes. Often, these panes were not uniform in thickness, and architects would put the thicker edges at the bottom."

If you were placing a pane of glass in a window frame, and you noticed that one end of the glass was thicker than the other, it would make sense to place the thicker side toward the bottom. This placement would increase the stability of the window, since the center of gravity of the pane would be lower. If the thicker side of the pane was placed at the top of the window, it would be less stable. This is the most likely reason why old glass windowpanes are often thicker on the bottom.

Is the myth busted?

It is safe to say that the glass-flowing myth is clearly busted, along with the myth that glass is a liquid. An amorphous solid is still a solid. And solids just don't flow.

Now, it's your turn to bust some myths. If you know of a myth or folk tale that can be explained with chemistry or science, don't hesitate to contact us at chemmatters@acs.org, and your story may end up on the Web page of *ChemMatters* (www.acs.org/chemmatters)!

"Check out the video podcast on busting the myth "Microwaves heat food from the inside out" at: www.acs.org/chemmatters !

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