The Secret of Popcorn Popping: Water Power at the Cellular Level

by
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On a Friday night in October in a dimly lit family room, Kate, home for a fall break from college, has just finished watching a movie with her sister, Lisa, to celebrate National Popcorn Popping Month. Lisa loves spending time with her sister. However, Kate is lying on the couch catching up on the sleep she had missed during the past week because of the never-ending exams and term papers.

Lisa: Hey, Kate, wake up. The movie's over!

Kate: Oh, I must have dozed off. How was the movie?

Lisa: It was great. Too bad you missed it.

Kate: Glad to hear you liked it. Let's clean up this place… there is leftover popcorn. Do you want to finish it?

Lisa: The good ones are all gone, and the rest of them haven't popped.

Kate: Oh, I didn't see those 'old maids'… I wonder why they didn't pop.

Lisa: It may be that they weren't heated enough, but I did follow the instructions, and it worked perfectly before!

Kate (now fully awake): The amount of heat is only a part of the explanation. The real drive for popping popcorn is water power.

Lisa: Huh, how come?

Kate: If the hull (the protective coat) is damaged, the water leaks out. Then, the kernel will not pop; no matter how much you heat it. More heat can only dry it up.

Lisa: I still don't understand why water is found inside the corn kernel. It looks dry to me.

Kate: Come on! Water is there even though you can't see it. Where there's life, there's water. Life on earth simply cannot exist without water. Don't you get it? Water is present in all living organisms.

Lisa: Okay, smarty pants, just tell me exactly how water causes the corn to pop.

Kate: When you heat the corn, the water inside each kernel boils and becomes a vapor. As a vapor, water occupies more volume and can generate enough pressure from within to burst open each kernel and the previously condensed starch expands to form a puff ball.

Lisa: Ah, now I get it. It's the steam that does the trick. Those damaged corn kernels dry up; without water there is not enough steam to build up the pressure. So the old maids don't pop and remain intact. What happens if the corn is loaded with water?

Kate: Too much water interferes with the expansion of the starch and you'll have chewy popcorn.

Lisa: Gross. Then the secret to perfect popcorn is having the right amount of water!

Kate: You got it! The ideal amount of water is 14 to15 percent.

Lisa: What does all that water do inside that corn kernel?

Kate: I just told you that water is in all living things including us. The average adult body contains about 42 liters of fluids, located on the inside (intracellular fluid) and the outside (extracellular fluid) of all cells.

Lisa: Chill out. I just wonder what is so special about water that makes it essential for life.

Kate (takes a deep breath): Though the individual water molecule is small and simple, water molecules can form a large powerful network via hydrogen bonding. Water is known as the solvent of life because it can dissolve many inorganic and organic compounds, such as minerals and our body's building blocks, including glycerol, monosaccharides, amino acids, etc. This feature enables water to carry nutrients to—and wastes away—from cells and tissues.

Lisa: The network of water acts like a transport vehicle! Do all biological molecules dissolve in water?

Kate: Of course not! That would be a disaster! Solubility in water is very selective. Cell membranes, for example, do not dissolve in water.

Lisa: Really, why not?

Kate: Cell membranes are made in part from glycerophospholipids, a kind of fat.

Lisa: So cell membranes are made of fat? I know fat and water don't mix, right?

Kate: Yes, fats are a part of the cell membrane, mainly glycerophospholipids (and cholesterol). A glycerophospholipid is a four-part molecule that consists of a glycerol, a trialcohol. Two of the alcohols are bonded to two long-chain fatty acids and the third alcohol is bonded to a phosphate-modified carbon moiety. When mixed with water, the phospholipids form two-layered membrane envelopes—and water can be found on both the inside and outside of those envelopes. Without water cell membranes could not form.

Lisa: It makes sense that the cell membrane serves as a fatty barrier to enclose the contents of a cell. But why is the enveloping membrane two layered? Is it because water is on both sides of the cell?

Kate: Yeah, now you're thinking. The two parts of a glycerophospholipid behave differently around water. In the presence of water, the phosphate-containing moieties (polar heads) orient themselves at the surfaces to contact with the water, while the fatty acid portions (the two non-polar tails) are sequestered to the interior of the membrane, away from water, to interact with each other.

Lisa: What makes the polar heads face the water while the non-polar tails bury themselves inside the membrane?

Kate: Water power! The water is a polar molecule (its two ends have opposing charges); the polar heads of the lipid are hydrophilic (i.e., water-loving) and therefore are attracted to water; and the non-polar tails of the lipids are hydrophobic (i.e., water-fearing). The general solubility rule is obeyed, and "like dissolves like." Therefore polar substances attract water; and non-polar substances repel water.

Lisa: Interesting! Water serves as an usher to direct who goes where, making sure its favorites are nearby. Quite a powerful director! You mentioned awhile ago that water acts as a transport vehicle to carry wastes, nutrients, and building blocks around cells. Here water is an enabler for the formation of cell membranes. Water is not only powerful, but also very flexible. Tell me more about the functions of cellular water.

Kate: Using the same tricks, water directs protein folding in accordance with the polarities of the amino acid building blocks. Generally, charged and polar amino acids stay at the surface of the protein in contact with the water. Non-polar amino acids pull the protein chain in the opposite directions in order to stay together and away from

the water. That is why many proteins, for example, enzymes, have a globular shape in an aqueous environment. The driving force is to form a hydrophobic core within a hydrophilic shell. However, in the absence of water, proteins fail to fold into these native structures and hence do not function properly.

Lisa: I see, both protein folding and cell membrane formation obey the "like dissolves like" rule. Since water is in contact with these biomolecules, does water have a role in their chemical reactions?

Kate: Sure it does. Most biochemical reactions happen in aqueous solutions. Water not only provides the environment or medium mentioned previously, it is also actively involved in reactions.

Lisa: Give me some examples.

Kate: One example is called photosynthesis in which CO_2 combines with water to form glucose and oxygen. Next many glucose molecules are connected together by dehydration reactions, in which water is removed, forming a chain-like macromolecule called a polysaccharide. That's how plants like corn make starch.

Lisa: Okay, everyone knows that plants can make foods from ground water and CO_2 in the air. Can you come up with some more interesting reactions involving water?

Kate: Certainly! In the process of hydrolysis, macromolecules are disassembled by the addition of water to release building blocks. For example, after you eat popcorn, the starch is broken down by your digestive system. During digestion, the starch is hydrolyzed by water with the help of enzymatic proteins (properly folded due to water) to release glucose for use by the body's cells.

Lisa: So water is involved in both the formation and breakdown of starch. The former is called dehydration reaction and the latter is hydrolysis. Isn't glucose the same as blood sugar?

Kate: Right on.

Lisa: What happens to glucose afterwards—besides being burned up as a fuel?

Kate: After glucose is absorbed by a cell, it can be stored as a glycogen in your liver or muscles for later use; and any excess of glucose is converted to fat.

Lisa: Wow, glucose has four different pathways to choose from: (1) as a fuel, (2) as a blood sugar, (3) as a raw material to make fat, or (4) as glycogen. It's quite complicated. What's glycogen then?

Kate: Glycogen is a molecule used to store energy for animals. Like starches in general it is made of many glucose molecules linked together by glycosidic bonds. Its degradation maintains the blood sugar concentration between meals and provides the quick energy.

Lisa: Since glycogen is similar to starch, water must also be involved in the formation and the breakdown of glycogen, right?

Kate: Yep. The synthesis of glycogen, glycogenesis, is also a dehydration process, and the breakdown of glycogen, glycogenolysis, is a hydrolysis reaction, the reversal of the dehydration reaction.

Lisa: Here we go again with another reaction reversal that needs water. I'm really getting the hang of it. When glucose is burned up as a fuel, does it have anything to do with water?

Kate: Of course; water is one of the byproducts. The overall reaction is called cellular respiration (a combustion reaction), in which glucose reacts with O_2 to generate CO_2, H_2O, and energy.

Lisa: I see. Cellular respiration is just the reverse of photosynthesis, and both get involved with water. Water is not only a flexible and forceful medium to transport nutrients and wastes, direct membrane formation, and affect protein folding, it's also a ubiquitous and multifunctional "stuff" that's actively involved in living chemistry.

Kate: Good summation, Sis!

Questions

1. According to Kate, what is the secret of perfect popcorn popping?
2. After 1.00 ml of water is completely vaporized to gas, how many milliliters of vapor are produced at standard temperature and pressure? (Density of water is 1.00 g/mL; molar volume of any gas at STP is 22.4 L/mol.)
3. Write the equation for the formation of maltose, a disaccharide, which consists of two glucose units. Classify the reaction.
4. How many water molecules are needed to break down an oligosaccharide that contains 10 glucose units? Classify the reaction.
5. Write and balance the cellular respiration equation of glucose ($C_6H_{12}O_6$). Compare it with the photosynthesis reaction in terms of reactants, products, energy flow, and the significance of each.
6. Glycerol, a part of glycerophospholipid, is highly attracted to water and often used in skin care products such as lotions and cosmetics. Draw the structure of glycerol. Explain its attraction to water and describe the interaction of glycerol with water.

References

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Resources

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