

Nutrition & Food

Spicy Foods and Milk vs. Water



Food and Agriculture
Center for
Science Education

Description of Event:

Human eating spicy peppers and the ensuing sensations they experience.

Depending on scope of a potential unit/transfer task/engineering problem: may or may not include the sensation being magnified with water and relieved when drinking milk.

Essential Question(s):

- Why does a spicy pepper cause a burning sensation?
- Why does water not provide relief, but milk does? Or, why does milk provide some relief to the burning sensation?

Stimuli: How will students experience and/or observe the phenomenon/problem?

Experience with tasting a spicy pepper and trying different liquids (or solids) to ease the burning sensation. *Specifically, a picture of the table from a Hot Ones episode showing the water and milk on the table.*

Related Phenomena/Problems:

- Some foods create different sensations (not related to flavor-based sensations)
- Some chemicals, including some in foods, can create similar sensations on different types of tissue (i.e. mucous membranes, the lens of the eye)
- Mint creates a cold sensation
- Squirrels stay away from a bird feeder after the seeds were mixed with ground chili pepper
- Dish soap, hand soap, and laundry soap remove stains using the properties of detergents
- A person uses a wet washcloth to clean up drips (oil-based paint) on the hardwood floor while painting. When they start with a new color on the cabinets, the washcloth just smears the paint and makes a mess.
- While using her grandpa's wrench to remove the engine from the lawn mower, the wrench gets covered in grease. Mia tries to clean the wrench with wet paper towels, but the grease just spreads (on the wrench, onto the paper towels, and onto her hands. Her grandpa pulls out a can of liquid and rises the wrench in it. The wrench, and his greasy hands, wipe clean.
- While approaching their parked car, the owner notices someone stealing something out of it. The car owner pulls out pepper-spray from their bag and aims it at the burglar. The burglar places their hands on their face and lays on the ground in paint.
- Comparing the difference in sensations when eating tissue of a spicy pepper vs a seed, vs whole biting into a seed vs chewing on a seed.

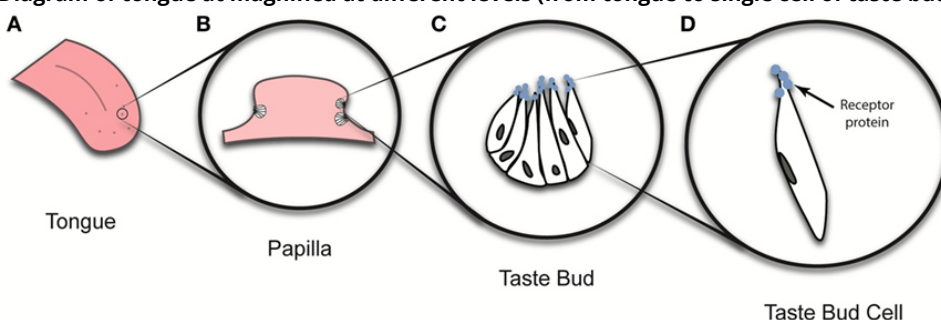
Considerations for Instructional Design:

- Could be incorporated into a lesson on polar molecules/nonpolar molecules
- Could serve as a contextualized example demonstrating the concepts of Brown's motion and London dispersion forces
- Could serve as a contextualized example of a physical interaction between molecules requiring no extra energy or chemical changes to the structures
- Could serve as an investigative phenomenon related to the function of the trigeminal nerve
- Can serve as a contextualized example of feedback loops involving nerve receptors, stimuli, and response
- Could serve as an investigative phenomenon related to prolonged exposure to a stimulus and desensitize of the receptors and increasing a person's tolerance to capsaicin

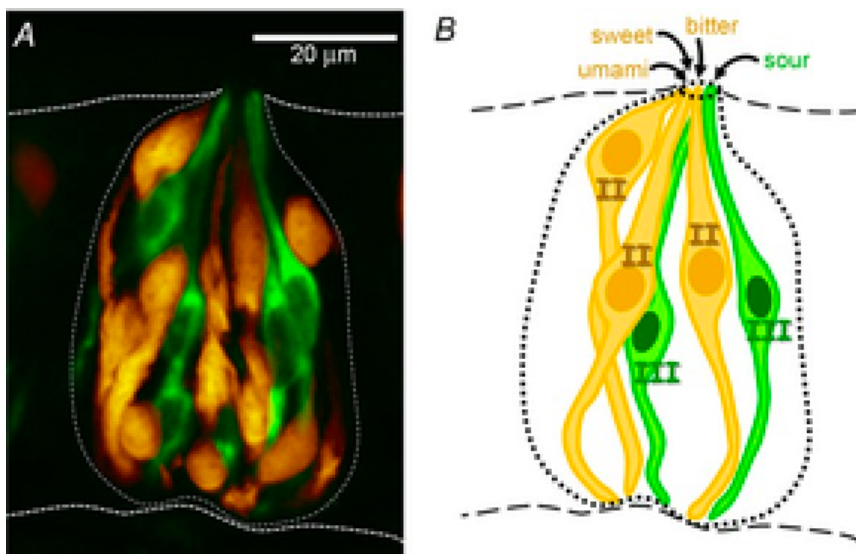
Explanation:

A student observes a teacher, a peer, or someone on video, eating a chili pepper. The student notices the person's facial expressions indicating pain and saying, "Hot! Hot!" while reaching for water. Even as the person drinks the water, they still appear to be in pain. The student may even notice the person's eyes water and sweat beading up on their brow. Optional: The student may notice the person grab a glass of milk off the table. After a few gulps of milk, the student notices the person experience some relief.

Unlike sweet, sour, salty, and bitter, spicy is not a flavor. The spicy or hot sensation is due to a substance present in spicy peppers, called capsaicin. Instead of acting on the receptors on our taste buds, it reacts on a pain receptor called transient receptor potential vanilloid 1 (TRPV-1). TRPV-1 is typically involved in sensing heat and helping to regulate our body temperature. Capsaicin activates the receptors, which open ion channels in the nerve endings of the tongue. With the ion channels open, positively charged ions can flow into the nerve endings. These ions depolarize the nerve, which sends a signal to the brain, which then causes the heat/burning sensation.

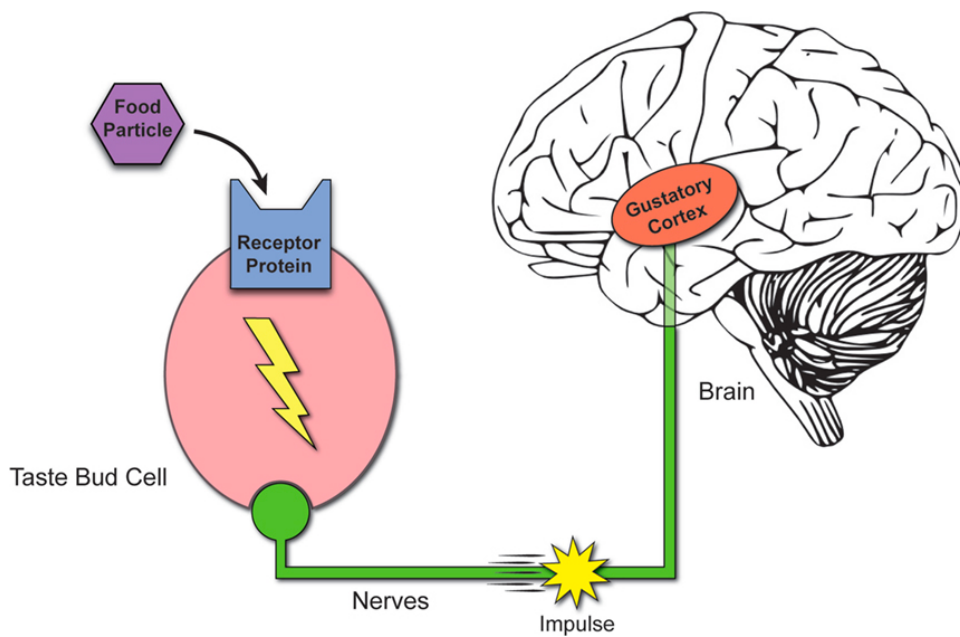
Diagram of tongue at magnified at different levels (from tongue to single cell of taste bud with receptor)**Taste bud receptor:**

- A) Imaging (enhanced with color) of taste bud with the 4 receptors*
- B) Diagram of taste bud with the 4 receptors

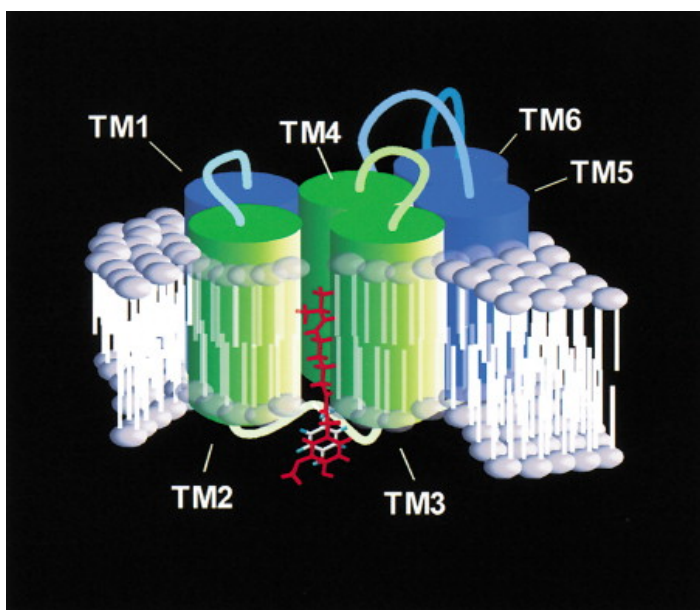


*Receptor (type II) cells express GFP (but here, are pseudo-colored yellow) while presynaptic (type III) cells, immunostained for aromatic amino acid decarboxylase, a 5-HT-synthesizing enzyme, appear green. The dark spaces between the labelled cells are occupied by glial-like (type I) cells that ensheath all the other cells but are not visualized here. The taste bud resides in oral epithelium (dashed lines). Adapted with permission from J Neurosci (DeFazio, Dvoryanchikov et al. [2006](#)). (Chaudhari, 2014)

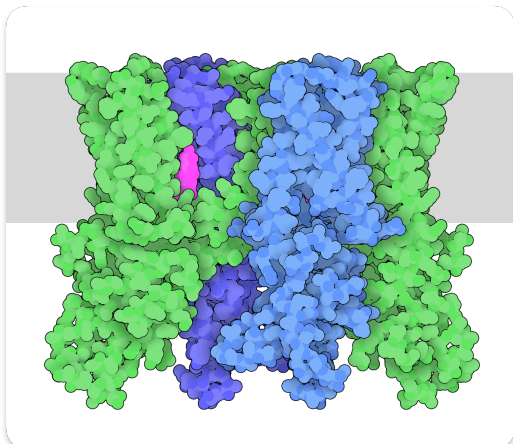
Diagram of taste bud receptor feedback loop (Vera, 2017)



Structural Model of Capsaicin Bound to TRPV-1 Receptor (Jort and Julius 2002)



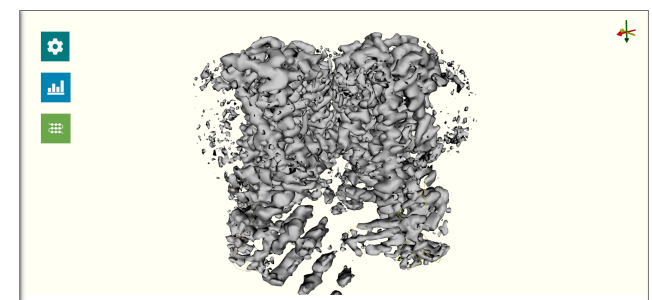
Model of the molecular structure of a TRPV-1/Capsaicin Receptor



PBD-101 Molecular explorations through biology and medicine. Molecule of the Month: Capsaicin Receptor TRPV-1

Electromagnetic image of Capsaicin Molecule

Structure of TRPV1 in complex with capsazepine, determined in lipid nanodisc



October 2020, David Goodsell Electron Microscopy Data Bank

Because it is sensed as a pain response, it is given special attention. TRPV-1 warns the brain: "This is something that can cause harm, I better pay attention." The sensation felt in the mouth is pain/hot; the same response as if your mouth encountered a hot liquid. Other responses to heat in the body can occur, as well:

- Sweat to cool the skin
- Red cheeks as capillaries dilate to dissipate heat
- Runny nose due to mucus membranes being irritated/activated to flush out any irritants
- Tears in eyes as they try to flush out any irritants

Capsaicin lowers your mouth's temperature pain threshold by about 50 degrees F. Normal pain threshold would be about 109 degrees F. This is the reason that cold water may initially provide temporary relief because it lowers the physical temperature momentarily.

Capsaicin is a nonpolarized molecule with a long hydrocarbon tail. Nonpolar molecules do not have an electrical charge. In contrast, polar molecules have distinct regions of positive and negative charges. This is because some atoms have a greater ability to attract electrons. In a polar molecule, the electrons of one atom are either entirely donated to another atom (ionic bond) or shared (covalent bond) in an uneven manner where the electron(s) are closer in proximity to one atom than the other.

Polar molecules are attracted to other polar molecules because the negative and positive poles on other molecules attract each other. Nonpolar molecules can be pushed out the way by polar molecules because they repel each other.

Nonpolar molecules are also attracted to other nonpolar molecules. While they don't have any permanently charged poles, the electrons are always in motion and therefore may be unevenly distributed between atoms at any given point in time. This creates temporary charges that can attract one another. These charges and the movement they create are known as London dispersion forces. Polar molecules being attracted to polar molecules and nonpolar molecules being attracted to other nonpolar molecules are the basis for the "like dissolves like" principle.

Because capsaicin is a nonpolar molecule, it requires another nonpolar molecule to grab it and wash it/pull it from the binding site on the TRPV-1 receptor. The polar molecules in water are not attracted to the capsaicin, and the water continues to move around the mouth attracting other polar molecules.

Milk has a protein/molecule in it called casein, which happens to be a nonpolar molecule. Casein is a protein found in milk and dairy products. It accounts for roughly 80% of the protein in milk, cheese, and yogurt. (Yes, other dairy products also have the potential to provide relief.) The nonpolar casein molecules are attracted to the nonpolar Capsaicin molecules. The casein molecules surround the capsaicin and "wash it away" from the heat receptors. This mechanism is similar to how laundry and dish detergents work on grease. With the Capsaicin molecule no longer attached, the TRPV-1 receptor returns to its original shape and the ion channel closes. With the ion channel closed, the activity at the synaptic cleft to the nerve ceases, the brain stops sending pain signals, and the effects such as sweat and runny nose dissipate.

Scientists hypothesize that capsaicin in peppers further developed to discourage mammals from eating the peppers and encourage birds. Why? Because mammals have molars, which grind and damage the seeds, and the peppers cannot proliferate. Birds generally eat the seeds whole. Birds do have TRPV-1 receptors, though they seem to be resistant to capsaicin stimuli.

Student questions about this phenomenon/problem that could be instructionally productive (hypothesized):

- Do peppers increase the temperature in your mouth?
- Why do spicy peppers cause pain in the mouth?
- Why do spicy peppers make a person's face sweat?
- Why do spicy peppers make a person's nose run?
- Why do spicy peppers cause tears?
- Do spicy things damage taste buds?
- Does the temperature of the water make a difference?
- Does the milk have to be cold?
- Would whole milk work better than non-fat/skim milk?
- Would any dairy product work?
- Is there a chemical reaction between the liquid and the tastebud?
- How do we taste things?

Explaining the phenomenon/problem or related phenomena could lead students toward developing the following DCIs:

PS1.A: Structures and Properties of Matter

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1) *This is critical to understanding the interactions of the molecules.*
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3) *(secondary to HS-PS2-6) This works toward the "like dissolves like" principle and why a nonpolar lipid molecule can surround capsaicin and mitigate its spiciness.*

PS1.B: Chemical Reactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (HS-PS2-6) *(secondary to HS-PS1-1) (secondary to HS-PS1-3)*

- Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects. (MS-PS2-3)

PS2.B: Types of Interactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (secondary to HS-PS-1) (secondary to HS-PS1-3) This builds toward the “like dissolves like” principle.

PS3.C: Relationship Between Energy and Forces

- When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)

LS1.A: Structure and Function

- All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out much of the work of cells. (HS-LS1-1)

LS1.B: Growth and Development of Organisms

- In multicellular organisms, individual cells grow and then divide via a process called mitosis, thereby allowing the organism to grow. The organism begins as a single cell (fertilized egg) that divides successively to produce many cells, with each parent cell passing identical genetic material (two variants of each chromosome pair) to both daughter cells. Cellular division and differentiation produce and maintain a complex organism, composed of systems of tissues and organs that work together to meet the needs of the whole organism. (HS-LS1-4)

LS1.C: Organization for Matter and Energy Flow in Organisms

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5)
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6)
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6) (HS-LS1-7)
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another and release energy to the surrounding environment and to maintain body temperature. Cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. (HS-LS1-7)

LS4.B: Natural Selection

- Natural selection leads to the predominance of certain traits in a population, and the suppression of others. (MS-LS4-4) This builds toward understanding why birds have resistance to capsaicin pain reaction.
- In artificial selection, humans have the capacity to influence certain characteristics of organisms by selective breeding. One can choose desired parental traits determined by genes, which are then passed on to offspring. (MS-LS4-5)

Notes about relevance and authenticity (funds of knowledge, interests, identity) Why might students be engaged?

- Students can experience or have experienced the sensation of eating a spicy pepper.
- Different people have different thresholds for the amount of spice they can comfortably tolerate.
- Student can experiment or have experimented with different food/drink to dissipate the burning sensation due to spicy peppers.
- The global salsa and hot sauce market was reported to be \$5 billion in 2022 and is expected to grow by a steady 5% through 2028. (Impactful Insights, 2022)

Resources/References

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