July 26, 2019

Maths, Physics & Chemistry

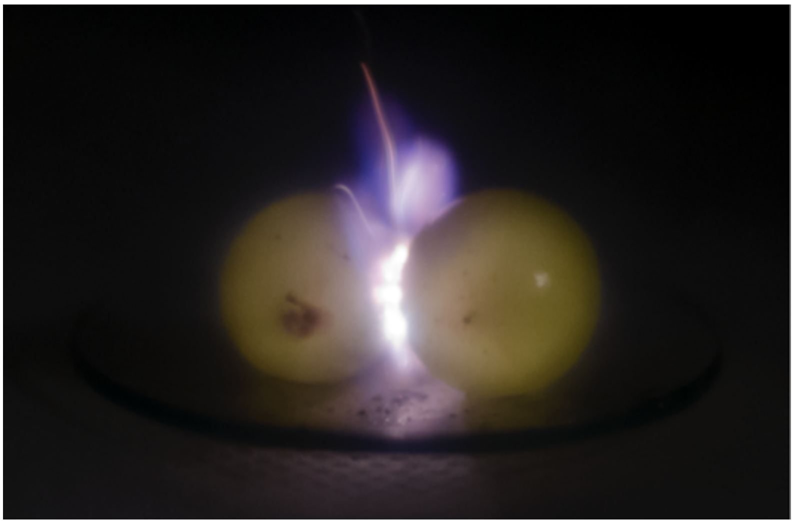
Grape expectations: how balls of water can mimic metallic objects in the microwave oven

by Aaron Slepkov[1] | Professor

[1]: Department of Physics & Astronomy, Trent University, Peterborough, Ontario, Canada

This Break was edited by Max Caine, *Editor-in-chief* - TheScienceBreaker

ABSTRACT
Our study into the sparking of grapes in microwave ovens reveals that the phenomenon has less to do with the electrical conductivity of grapes and everything to do with the unique optical properties of water at microwave frequencies.



A pair of grapes sparking in a household microwave oven.
Image credits: Aaron Slepkov and Hamza Khattak ©

When you see sparks in your microwave oven, it usually means you accidentally left a metallic object inside. So, imagine the surprise of millions of people who have observed in-person or online that under the right conditions grapes, cherry tomatoes, ground cherries (physalis), and olives can spark in the microwave oven as well. Does this mean that the fruit is acting as a metal? We used to think so, but now we know that the answer is far more interesting…and possibly more useful as well.

We have been studying the underlying physical mechanism behind this fascinating manifestation of the wrath of grapes and have arrived at a surprising conclusion: To a microwave oven, a grape is really just a ball of water. We now know this because we can demonstrate the effect with skinless "water-beads"—couscous-sized polymer grains that hydrate to become grape-sized hydrogel spheres that are over 98% pure water.

Our everyday experience of interacting optically with water is unremarkable. At visible wavelengths, water is mostly transparent and has an unimpressive index of refraction of ~1.3. The index of refraction mediates the interaction of light with a material and, in particular, with interfaces between materials. Air has an index of refraction of ~1, so when light hits an air/water boundary it bends towards the higher-index material. That's why your legs appear to bend at unhealthy angles when you dangle them in the pool. Microwave radiation is also a type of light, just with longer wavelengths than we can see with our eyes. While unremarkable optically at visible wavelengths, at microwave frequencies water has a huge index of refraction of ~9. It is also not entirely transparent to microwaves but is instead somewhat absorptive. Indeed, this absorption is the microwave oven's '*raisin' d'être*; it is how the oven heats your water-laden food! A key finding of our study is that the large index of refraction of water acts to trap light in the object, making the grape a resonant cavity of sorts. Another key finding is that the absorption isn't simply parasitic—removing energy and reducing the intensity of light in the grapes—but acts to broaden the range of conditions for which grape sizes are resonant with the microwave radiation. In essence, the absorption is responsible for our being able to observe the "grape plasma" phenomenon with a range of fruit sizes.

The sparking of fruit in the microwave is impressive and memorable. However, to best investigate how light packs inside of grapes, we were most interested in observing how grapes heat up in the absence of plasma. Using a combination of thermal cameras, thermally-activated paper, and sophisticated computer simulations, we were able to study the optical intensity of microwaves inside of the water-beads. We found that isolated water beads act as resonators that trap microwave light with the highest intensity at their centres. However, when two beads are brought ever closer together, the isolated modes from each bead can begin to "sense" the other resonator and the intensity moves closer to the point of contact. Once the beads come in contact, the light concentrates almost entirely between the two objects, with high enough electromagnetic field intensities to rip electrons off of any available sodium or potassium, creating a spark of ionized plasma. Wrapping the beads in thermal paper allowed us to see that isolated beads heat up uniformly around their surface, but when two beads are brought together they only heat up at the point of contact. This finding confirms dozens of online videos: an isolated grape never sparks, instead heating from the inside out. Only a contacted group of grape (hemi)spheres will spark. Thus, rather than acting as metallic mirrors that reflect light off their surfaces, the grapes are super-lenses for microwave radiation.

Beyond the fun aspects of providing a new explanation for a popular-science phenomenon, our study provides new insights to the emerging field of nanocluster plasmonics. Nano-plasmonic applications rely on the ability of tiny metallic objects to concentrate visible light to minuscule subwavelength regions. This approach is already revolutionizing fields such as super-resolution microscopy, photodynamic drug therapy, and single-molecule spectroscopy. Our work confirms recent theoretical ideas that non-metallic objects with extremely high indexes of refraction and a small amount of absorption can mimic the photonic behaviour of similarly-sized metallic objects. Thus, microwave photonics with absorptive dielectrics may become a useful modelling sandbox for nanophotonics, guiding the design and discovery of suitable optical counterparts at visible wavelengths.