Microwave Mischief and Madness

Heather Hosack, Nathan Marler, and Dan MacIsaac, Department of Physics & Astronomy, Northern Arizona University, Flagstaff AZ 86011-6010; danmac@nau.edu

Microwave ovens use electromagnetic radiation to heat and cook food. A typical microwave oven uses a magnetron[1] to produce about 1 kW of radiated power at a frequency of 2450 MHz, wavelength of 12.2 cm, electric field strength of 2 kV/m, and power density of approximately 2.8 MW/m^3.[2]

Microwave radiation penetrates foodstuffs and is absorbed by the flexure of polarized water and food molecules, which rub against one another synchronously with and at harmonics of the oscillating electric field component of the radiation. Molecular vibration in the right frequencies is also known as thermal energy or heat; hence, microwave electromagnetic radiation becomes thermal energy for cooking foodstuffs. This effect is sometimes called *dielectric heating*. There is NO notable molecular bond resonance effect in microwave ovens, and some materials with more tightly locked molecules (such as frozen foods) don't flex very well and don't microwave well.

The walls of a microwave are made of metal, which allows electrons to freely move in closed paths and cancel out the electric fields in the oven walls. Thus, microwave radiation cannot penetrate the closed box walls of the oven (or the metal mesh covering the window in the front door) but are reflected back into the oven and through the food until they are absorbed. If the microwave oven is operated without a *load* (material to absorb the microwave energy), microwaves will reflect about until they re-enter the magnetron and eventually damage it; therefore, you should always operate the oven with a load. A small glass of water is sufficient.

Electrically isolated pieces of metal placed in a microwave oven cannot allow electrons to move in closed paths; electrons will "pile up" on the edges of the metal object and may arc over through the air to another part of the metal. For example, small pieces of metal placed in an electric field of 2 kV/m and separated from one another by only 1 cm can experience an electric field difference of:

$$\Delta V = (2 \times 10^3 \frac{V}{m})(1 \times 10^{-2} m) = 20{,}000\ V,$$

which will produce a spark discharge in the microwave between the pieces of metal.[3] Electrons

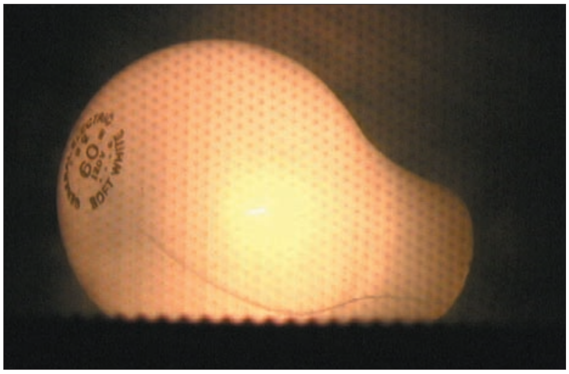

Fig. 1. Lighted bulb.

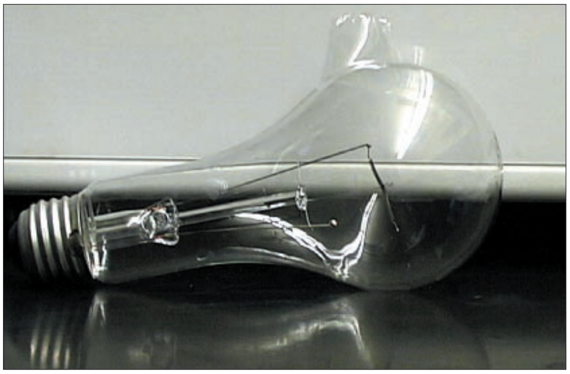

Fig. 2. Broken bulb.

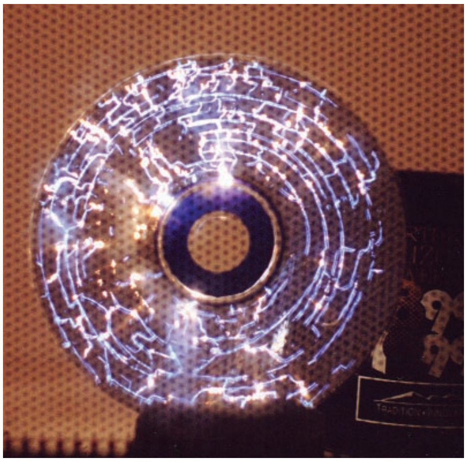

Fig. 3. Lighted CD in microwave.

accelerating though the air will slam into nitrogen molecules in the air, which will emit ultraviolet and blue light via electronic excitation and emission. Hence, microwaving metal objects will produce extremely hot, bluish sparks.

Some Microwave Oven Experiments

Prepare the oven by taping a paper file card over the light in order to darken the interior. Darken the room for your audience. Consider using an old glass plate that you won't miss underneath objects in the oven. Times vary with each experiment; always use high power, but note the duration in parentheses.

Small spark discharges *(relatively safe)*

- *CDs* (6–8 s). Electrons arc across thin foil tracks and destroy the CD by vaporizing the thin metal, constantly changing the discharge paths. Do not breathe the smoke or melt the plastic (see Fig. 3).
- *Small Christmas tree ornaments.* See CDs.
- *Frozen or fresh-diced carrots*. Arcs between the corners. Electrons collect on corners (points of most curvature) and edges, causing arcing.
- *Bar of soap*. Ivory or Irish Spring (with whipped-in air bubbles for flotation) works well; wet the topside. Microwave until it bubbles with steam and re-sculpts itself (because of water's dielectric properties).
- *Grape races*. Prick one end of several seedless grapes with a toothpick and place on a glass plate. Also demonstrates water's dielectric properties. Try a grape cut in half with a knife, leaving a thin flap of connective tissue (electrons try to move through highly resistive grape-skin, and plasmoids may form).

Microwave Demonstration Safety Issues & Guidelines

When performing these microwave demonstrations please follow and provide these safety guidelines to the audience:[4]

Protect Yourself and Others — Don't microwave yourself. Never try to defeat the safety interlock and run the microwave oven with the door open; severe tissue damage can occur. Perform experiments in a fume hood or well-ventilated area. Don't burn yourself — most hot items (especially glass trays and bulbs) look just like cold items, except they will burn you. Sealed items (like eggs) and containers can explode when heated. Use gloves or oven mitts. Have bystanders maintain a distance of three feet, or use a shield. When demonstrating for a class or a crowd, consider using a video camera on manual focus.

Beware of being scalded by hot fluids — In a ceramic container it is possible to superheat water; some pockets can be hotter than 100°C. Superheated water will *flash boil* or geyser out of the container if boiling is suddenly triggered by vibration, for example, from an object (like a spoon) or a powder or your upper lip. If you are superheating fluids, protect yourself with appropriate eye protection or a face shield and long sleeves.

Protect the oven — Especially if it belongs to Mom or the department secretary! Use a small container of water in a back corner to absorb excess microwave energy and avoid magnetron damage. Run these experiments for a maximum of 30–60 seconds and allow cool-down time.

Fluorescent lightbulbs – Dramatic, but breaking or melting these will cause release of toxic mercury vapor. Don't microwave these until they melt. Incandescents are fair game (see Fig. 1).

Plasma and vaporized metal are extraordinarily hot — Some scientists refer to plasma as the fourth state of matter. If making plasma in the microwave oven, watch for molten glass and plastic, and turn off the oven if plasmoids lodge against the walls of the oven. (Have a fire extinguisher on hand just in case.) Vaporized metal and plasma can melt through the oven walls, set fire to plastic liners and paint, and crack and melt glass (see Fig. 2). Careless experiments with plasma in a microwave oven will result in you buying a new one (and maybe unwanted attention from the fire department).

Hot objects and larger discharges *(less safe)*

Remember to put a glass of water in the oven for a load.

- *Lightbulbs.* Put incandescent lightbulbs (burned-out or working) into a microwave, either in a glass of water, or just standing in an empty glass. Additional microwaving of vaporized tungsten will melt through the bulb (Fig. 2); standing the bulb in water eliminates this. Rapid electron motion excites the atoms of the very thin and resistive filament.
- *Small fluorescent tubes or neon bulbs* (3–4 s). Twist the neon bulb leads together and place them in a small ball of tinfoil. Disposable camera flash units (xenon strobe bulbs) and fluorescent tubes work well. Watch the heat — additional microwaving can melt the bulbs.
- *Kitchen scour pads* (Cu, steel wool). Ignites if enough time is given. Electrons will collect on irregularly shaped edges of tightest curvature and arc.
- *Aluminum-foil rings* (10-cm diameter, twist a constriction at one point) *or copper coils*. These arc, create plasma, and generate ultraviolet light (this heavily loads the magnetron, so keep it under 10 seconds and allow cool-down time). The aluminum will melt glass, so use old glass beneath it. Be sure to leave a gap in the ring; electrons will collect on irregularly shaped edges and arc.
- *Copper wiring*. These create arcs between the wiring. Most thin metal wiring will work well for this. Electrons will collect on irregularly shaped edges and arc.
- *Superheated water.* Wear goggles and oven mitts. Boil and cool to remove air bubbles; heat in a smooth ceramic container. Water will superheat (exceed its boiling point) and flash-boil after a nucleation seed, such as instant coffee, is introduced. An infamous accident for people microwaving coffee.
- *Ball lightning (plasma)*. Place wooden kitchen matches in putty, then in the oven. Ignite the matches, then blow them out after a short time. Microwave the smoke, which ignites and moves about as plasmoids.[5] Wooden toothpicks placed alongside candlewicks also work. One current theory for the little-understood phenomenon of ball lightning involves excited carbon microparticles. Be careful not to set fire to the interior of the oven.

Acknowledgments

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References

1. Magnetron and microwave ovens are explained at http://www.gallawa.com/microtech/how_work.html and http://rabi.phys.virginia.edu/HTW/microwave_ovens.html. Other explanations of how microwave ovens work can be found in Craig Bohren's letter "How does the microwave oven really work?" *Am. J. Phys*. **65**, 12 (1997), as well as in Eugene Hecht, *Physics: Algebra/Trig.* (Brooks-Cole, Pacific Grove, 1998).
2. A description of basic calculations for the microwave is available at http://www.pueschner.com/engl/basics/calculations_en.html.
3. Metal arcing in microwave ovens and a discussion of why it happens can be found at http://www.gallawa.com/microtech/metal_arc.html.
4. For good safety reference in regard to microwave oven experiments followed by similar activities, see http://www.everist.org/special/mw_oven/index.htm.
5. There is a wealth of scientific literature on microwave-driven plasma, ball lightning, and speculative links between the two phenomena. Bibliographies can be found at http://www.sciam.com/askexpert/physics/physics30.html and http://www.eskimo.com/~billb/tesla/ballgtn.html.