Superheating and microwave ovens

There have been many reports of injury to people using microwave ovens to heat water to make hot drinks. Water heated in a microwave oven may be superheated and when objects (e.g. a spoon) or granulated materials (e.g. instant coffee) are put into it, the water may boil very vigorously or even appear to explode out of the container. The vigorously ejected boiling water can cause serious burns. Sometimes even the act of taking the container out of the oven and or putting it on the bench can cause the boiling.

- When does superheating happen?
- How to avoid it
- What is superheating?
- Why is it dangerous?
- Why does it occur to a greater degree in microwave ovens than in saucepans or kettles?
- Why is it possible to heat water above its boiling temperature?
- Some quantitative details
- More about boiling and freezing temperatures
- Other potential dangers associated with microwave ovens

When does it happen?

The following conditions promote these potentially dangerous events:

- Using a container with a very smooth surface, such as an unscratched glass or glazed container.
- Heating for too long.
- Quickly adding a powder, such as instant coffee (or sometimes even an object to stir it).
- Standing with one's face above the container makes injury more likely.

How it could be dangerous: You put water in a new mug (one that has no cracks in the internal glazing and which has never been scoured). You put it in the oven with a setting that is a little too long for the amount of water. While it is heating the phone rings. You return some time later, decide to reheat it, so you restart the oven. You take out the cup and immediately add a spoonful of instant coffee. The water boils vigorously, throwing boiling water over your arm and face.

How to avoid it

- Before putting the water into the oven, insert a non-metal object with a surface that is not smooth. (e.g. a wooden stirrer. A wooden skewer or icecream stick will do.)
- Use a container whose surface is at least a little scratched.
- Do not heat for longer than the recommended time for the quantity of water used.
- Tap the outside of the container a few times with a solid object while it is still in the oven. Use a long object so that your hand remains outside the oven. Alternatively, and still keeping your hand outside the oven, insert a stirrer while the container is still in the oven. (Thus, if vigorous boiling occurs, most of the boiling water will strike the inside of the oven.)
- Keep your face well away from the open oven door and from the container.

All these precautions should reduce the chance or extent of superheating and resultant injury. Nevertheless, very hot water is always dangerous and one should always treat it with caution.

What is superheating?

In this context superheating means the heating of a liquid to a temperature above its normal boiling point. The superheated state is unstable, and it can very rapidly turn into liquid at the boiling point, plus a substantial quantity of vapour.

Why is it dangerous?

If one litre of water is superheated by only 1 °C (i.e. if it is heated to 101 °C without boiling at normal pressure), it is in an unstable state, and it can suddenly produce about 3 litres of steam. The rapid production of a substantial quantity of steam ***within*** the bulk of the water will cause it to boil vigorously and possibly to appear to explode. The result is boiling water flying at speed out of the container.

Why does it occur to a greater degree in microwave ovens than in saucepans or kettles?

In a microwave oven, the water is usually hotter than the container, whereas parts of the kettle or saucepan are usually hotter than the water. Further, the surfaces of some containers used in microwave ovens may be very smooth, almost at a molecular scale, whereas this is not true for kettles or saucepans.

Microwave ovens heat the water directly: the microwaves pass through the container and the water, and the water itself absorbs energy from them. The container absorbs little energy directly. In a kettle or saucepan, the container itself (saucepan) or a heating element (some kettles) is hotter than the water. The hottest points cause a small amount of local superheating, boiling is initiated here, and this then stirs the water.

Why is it possible to heat water above its boiling temperature?

Let's talk only about pure water, and only water at or close to atmospheric pressure.

At the surface between air and water, or between steam and water, water boils at 100 °C. Water boils at 100 °C if there is already a bubble of steam (or air) present. But ***in the absence of bubbles, water can be heated above 100 °C***. There are two reasons. First, to make a stable bubble, a lot of water molecules in the same small area must form steam. This is improbable. Second, it takes extra energy to form the bubble itself: energy to push the water out of the way, and energy to make the surface between water and steam. Once a bubble forms (a process called *nucleation*), it is easy to increase its size. So the superheated water nearby evaporates very quickly, producing a large volume of steam.

Smooth containers do not have bubbles of air clinging to their sides. Rough walled or scratched containers may hold microscopic bubbles in their cracks. These become *nuclei* for boiling. Even a crack that is fully filled with water can be a boiling nucleus because it reduces the required area of the water-vapour surface.

Some quantitative details

The **latent heat** of vapourisation of water is L = 2.23 MJ/kg. This means that it takes 2,230,000 Joules of heat to evaporate 1 kg of water at 100 °C and at normal atmospheric pressure. (One kilogramme of water is about one litre.)

The **specific heat** capacity of water is c = 4.2 kJ/kg. This means that it takes 4,200 Joules of heat to raise the temperature of 1 kg of water by 1 °C.

Suppose that we heat one kilogram of water from 100 °C (its normal boiling temperature) to 101 °C, i.e. it is now superheated by 1 °C. When it begins to boil, it will very quickly cool to 100 °C, and the heat liberated turns water into steam. Cooling this kg of water by 1 °C gives 4.2 kJ, which is enough to evaporate c/L = 4200/2230000 kg of water. This is only 1.9 millilitres of water, which does not sound very much, but it turns into 3 litres of steam. Those three litres of steam are created *inside* the hot water, quite suddenly, so the water is ejected violently from the container.

More about boiling and freezing temperatures

The temperature for *equilibrium* boiling and freezing (ie boiling and freezing in the absence of superheating or supercooling) is affected by pressure and composition. Add a solute to the liquid phase, and you usually depress the freezing point and raise the boiling point. Increase the pressure and the boiling temperature rises, while the freezing temperature changes by a small amount: downwards for water and upwards for almost everything else. A non-technical explanation is given on Boiling and freezing: the effects of solutes and of pressure.

Other potential dangers associated with microwave ovens

Sparks and fires

Electrical conductors, such as aluminium foil, cutlery, even gold leaf on plates, should not be used in microwave ovens. These conductors concentrate the electric field and so can produce sparks. The sparks in turn may cause a fire.

- Don't put metals in the microwave oven

Uneven heating

Partly because the electromagnetic field in a loaded oven is not uniform, and partly because they heat quickly, microwave ovens can give rise to uneven heating. When we take food out of a normal oven, we expect the outside to be at least as hot as the inside. With a microwave oven, the reverse is often true: the liquid inside is hotter than its container. Users may underestimate the temperature and thus cause burns.

- Be aware that high temperatures may be present, even if the container is only warm.

Steam in sealed continers

A gram of steam at 100°C contains more heat than a gram of boiling water, and so may produce more severe burns. If food is heated in a sealed container, this can produce steam inside the container. When released, the steam, perhaps under a small pressure excess, may burn the user.

- Don't heat things in sealed containers
- If the instructions say 'leave to cool', do so.

Microwave leakage

Microwave ovens are usually made of metal, and there is a metal screen in the door. An automatic switch turns the oven off when the door is opened. Thus, when microwaves are radiated into the oven, the volume is almost completely surrounded by electrical conductor, which means that the microwaves are reflected rather than being transmitted to thespace outside. ('Almost' is there because the screen in the door usually has small holes to allow the user to look in. These holes are much smaller in size than the wavelengths used and so very little energy is radiated through these holes.)

If it were possible to turn the oven on with the door open, a beam of microwaves would radiate through the open door. This beam would be dangerous: it would rapidly heat up human tissue (just like cooking meat) and could have other health effects as well.

- Never disconnect the automatic safety switch
- If the door or the case of the oven are damaged, either discard the device or have it checked for microwave leakage.

Opinions expressed in these notes are mine and do not necessarily reflect the policy of the University of New South Wales or of the School of Physics.

Some sites with related material

- Mpemba effect: can hotter samples freeze faster than cold?
- What is 'unfreezable water'? Supercooling, rather than superheating, is sometimes involved.
- Despite its ubiquity, water is a remarkable and unusual chemical. See Martin Chaplin's page: Water structure and behaviour.
- Boiling and freezing: the effects of solutes and of pressure.

- A list of other educational pages in physics by Joe Wolfe.
- Resource site for high school physics from the School of Physics, UNSW
- A FAQ in high school physics. Originally set up for teachers and students using the New South Wales syllabus.

Source:http://www.animations.physics.unsw.edu.au/jw/superheating.htm#when