PHYSICS IN DAILY LIFE:

FUNNY MICROWAVES

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The introduction of the microwave oven (or just 'microwave', the commonly used *pars pro toto*) has made our daily lives much easier. As physicists we may be a bit misled by the name and think of micrometers. But the standard oven operates at a frequency of 2,45 GHz, which corresponds to a wavelength of some 12 cm. That's not precisely in the middle of the microwave region. This wavelength does explain though that, given the typical oven size, standing wave patterns can cause large intensity differences over our food. We also realize that we need a convenient absorber in our food: water. But the absorption mechanism is not trivial. It is *not* some intramolecular vibration or rotation mode that we are using. Typical rovibrational bands involve much higher energies, such that they are even responsible for the strong absorption in the red part of the visible spectrum in water. Instead, we use the large dipole moment of the water molecule to make it 'wiggle' amidst its neighbours. To be more precise: we absorb radiation by dielectric loss due to dipole relaxation. The microwave region is perfect for that. At much lower radiation frequencies the dipoles would follow the field changes and there would be no absorption. At very high frequency the dipoles have no time to change their orientation, and again nothing much happens. In between, where the dipoles lag behind the field, we expect a broad absorption curve. As already elucidated by Michael Vollmer in Physics Education back in 2004, the microwave frequency employed is not even near the maximum of the absorption curve. If that were the case, the absorption would be so large that only a thin layer of food would be heated. Instead, the frequency used is such that the penetration depth is in the order of a few cm, allowing our food to be heated more evenly.

An interesting consequence of the dipole relaxation mechanism is that ice has very little absorption. The molecules are simply too fixed in their lattice positions to follow the oscillating field. This reduces the absorption by three to four orders of magnitude.

So much for liquid or solid water in our oven: what about metals? Of course, reflection of the microwaves is almost perfect, due to the free electrons which essentially re-radiate the microwaves. Their penetration depth into the metal is in the order of 1 μm only. So our kitchen should be perfectly safe ground as long as we keep the oven closed. And it should be no problem to leave a spoon in our cup of tea. A fork may be risky, though. Its sharp extremities will concentrate the electric field lines just like a lightning conductor does, and may lead to breakdown, with an interesting but possibly harmful light show as a result.

The most spectacular show may be caused by our precious decorated china, especially if the decoration is a thin gold layer. The reason is not trivial. We must remember the extremely small penetration depth of the microwaves in metals. Inside that thin layer a lot of heat will be dissipated. For a solid metal piece like a spoon, this poses no problem. Its thermal conductivity and heat capacity are large, so it can easily absorb the heat and transfer it to the fluid in the cup. Alas, our china cups are poor thermal conductors, and the heat has nowhere to go but to the tiny thermal mass of the metal. So if we absent-mindedly put our beautifully decorated cup of tea in the microwave, we may have to kiss that cup goodbye… ■