schoolphysics

Microwave ovens and resonance in molecules

Like all other objects molecules have a resonant frequency. This means that they vibrate wildly when a certain input frequency is applied to them in just the same way that a child's swing will build up large oscillations if it is pushed at just the right rate.

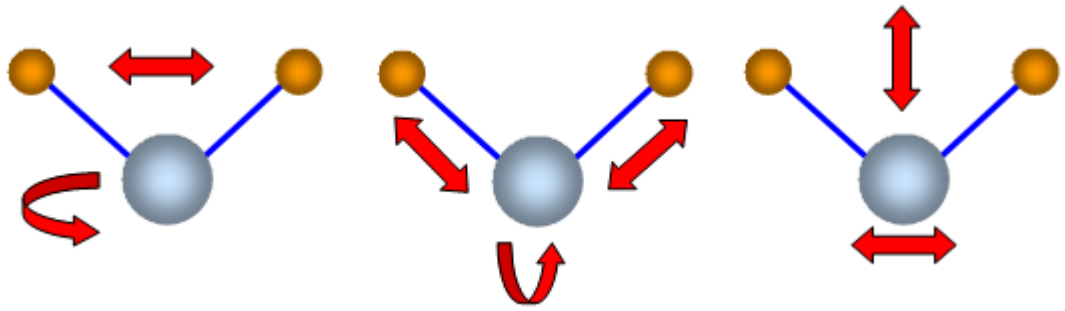
Of course, molecules are complicated things containing two or more atoms and so working out the resonant frequency is tricky. However it is possible to calculate the resonant frequency of diatomic (two atom) molecules and some results are shown below.

Hydrogen chloride 8.66×10^{13} Hz
Carbon monoxide 6.42×10^{13} Hz
Nitrous oxide 5.63×10^{13} Hz

These frequencies lie in the near infra red part of the spectrum, nowhere near the microwave area. The theory behind this calculation is really difficult but of you are interested you can look up theory of how these frequencies worked out in university text books.

Water and microwaves

Water molecules contain three atoms and so can vibrate in a number of different ways. This makes calculating their resonant frequency very difficult. However microwave radiation of any frequency will affect them although they may not resonate.



Some vibrations of a three atom molecules are shown in the diagram. They are not to scale and are only meant to represent possible states of vibration.

When microwaves pass through water the water molecules absorb some of the microwave energy and as a result they twist and turn, writhing around, as the radiation passes by. However after the microwaves have gone the molecules stop moving again, remitting the energy as more microwaves. In free water molecules this does not result in a heating.

In a liquid things are rather different. The water molecules are close to reach other and so there is "friction" between them. It is the rubbing of one molecule against another as in liquid water that

allows the energy to be retained and prevents it being reemitted as microwaves. The "friction" between the writhing water molecules and other molecules in a solid also heats up the solid.

Microwave ovens operate at a frequency of 2.45 GHz (2.45×10^9 Hz) and this is NOT the resonant frequency of a water molecule. This frequency is much lower than the diatomic molecule resonant frequencies mentioned earlier. If 2.45 GHz were the resonant frequency of water molecules the microwaves would all be absorbed in the surface layer of a substance (liquid water or food) and so the interior of the food would not get cooked at all.

The 2.45 GHz is a kind of useful average frequency. If the frequency was much higher then the waves would penetrate less well, lower frequencies would penetrate better but are absorbed only weakly and so once again the food would not absorb enough energy to cook well.

Standing waves set up within the oven. A standing wave is formed whenever two waves travelling in opposite directions meet in a "restricted area". This restricted area could be a metal box (as in a microwave oven) or a stretched string as in a violin.

Microwave ovens cook unevenly because a pattern of standing waves forms inside the oven chamber, and the pattern creates an array of hotspots throughout the oven's volume. An operating frequency of 2.45 GHz will produce a wavelength of around 12.25 cm, and the regions of maximum intensity (hotspots) will be at half-wave points, or every 6.125 cm, but in a complex 3D pattern.

This standing wave pattern explains why microwave ovens only work effectively if the food is rotated through the standing waves and why some ovens actually move the pattern by rotating the transmitter.

Defrost cycle

Microwave ovens have a special cycle to defrost food. This is because while water absorbs the microwaves strongly ice does not. Therefore as the ice melts the water formed gets very hot quickly and so you can have ice and very hot water in the same portion of food. Therefore in the defrost cycle the microwave power is switched on and off so that there is time for the heat to spread out from the melted water.

For further details it is worth looking at a really good site with a moving applet:

Water molecule in a microwave field

This shows the behaviour of a water molecule when subjected to the input of microwave radiation of various frequencies.

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