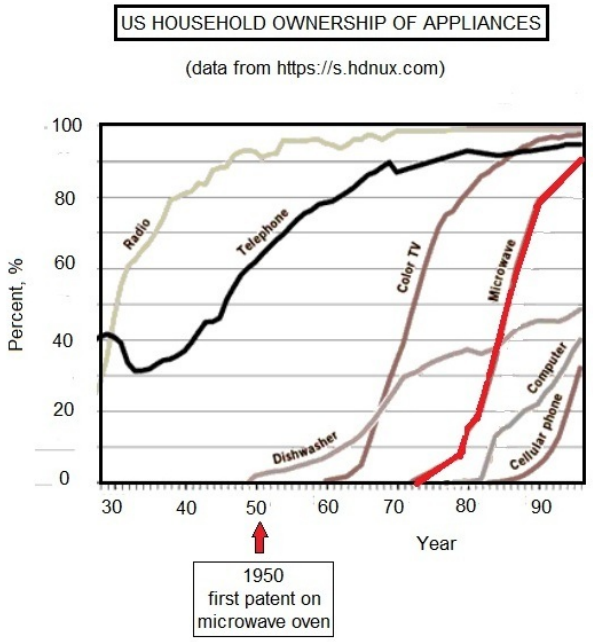
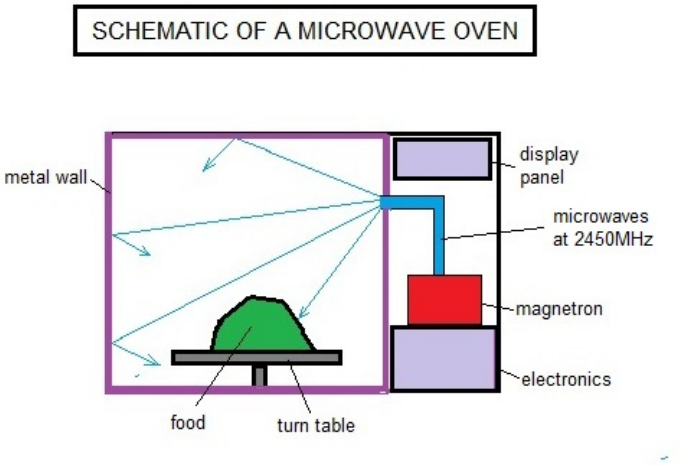
WHAT MAKES A MICROWAVE OVEN WORK?

If one looks at the various household appliances available to US consumers over the last one hundred years, among the fastest in acceptance has been the microwave oven as shown in the following graph-



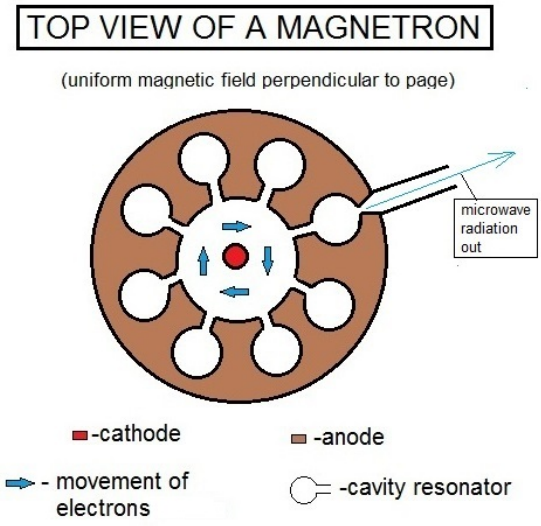
It started from essentially zero household units sold in 1972 to over 90% saturation by 1996. Despite of this unprecedented acceptance, even today very few consumers understand how these ovens work. We want in this article to give a brief description of microwave ovens and how the water molecules contained in food placed in them are heated by microwaves generated by a magnetron.

We begin with a simple schematic of a typical microwave oven. It is of the type I can buy today for less than $100 at any Wall Mart. The components are as shown-



The right side contains the power generating magnetron plus display and control electronics. The left represents a container which metal walls into which (when on) are pumped 2450 MHz microwaves which reflect continually off of the metal walls except for those penetrating the food sitting on top of a rotating plate. The front door is transparent to visible light so the food can be seen from the outside, however, a metal screen built into the glass wall of the front door makes it opaque to microwaves. Microwaves hitting the food typically can penetrate about one inch into the food before they have converted all their energy into heat. Fortunately, most food placed into these ovens have small enough dimension so that uniform heating will result, especially when aided by the rotating table. Plastic and ceramic containers plus paper plates used for holding food , soup, or drink are unaffected by these microwaves, so such ovens are ideal for heating or reheating cups of coffee or heating soup. A large turkey will not cook properly in a microwave oven because of the short penetration distances of the waves.

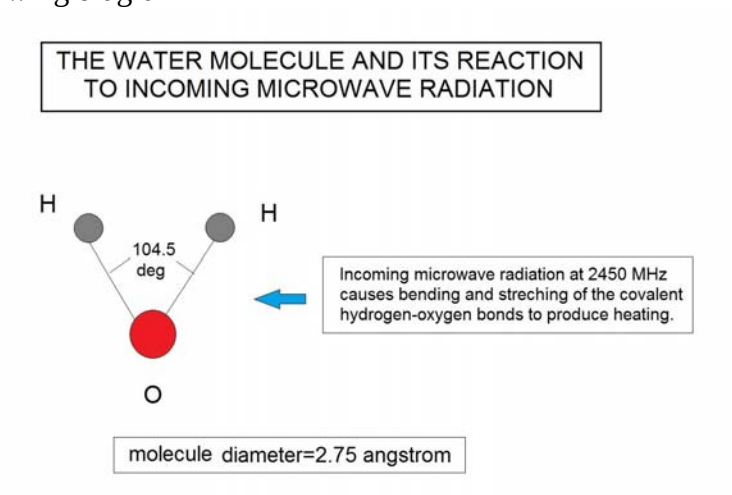
We next consider the power source for microwave ovens. This is the magnetron. The magnetron is a device which generates short wavelength electromagnetic waves to frequencies into the gigaherz range using a resonant cavity principle not unlike what happens when you blow over a pipe at one of its ends. Here is a schematic of a typical magnetron as found in microwave ovens-



The device is essentially a diode tube with a central cathode from which electrons flow toward the anode shown in brown. A vertical magnetic field causes the electrons to circle in the evacuated space as shown by the blue arrows. On passing the resonant cavities microwaves are generated in them which can then pass out along a wave-guide. The dimension of the cavities determine the frequency of the EM waves. Most magnetrons sold today for microwave heating generate 2450 MHz waves, Recalling that EM waves are governed by the simple equation $c=\lambda f$, where $c=3x10^8$m/s and f=2.45GHZ for the present case, we find that the wavelength of the microwaves is $\lambda=0.3/245=0.122m=12.2cm$. An interesting point to note is that the proposed 5G cell phone technology deals with comparable wavelength microwaves but at much lower energy densities. So internal heating of the brain by holding a cell phone near ones ear and talking for extended periods should be miniscule. The magnetron was first developed in England just prior to WWII. The device was licensed to the US and was a major contributor to the war effort in the area of improved radar. My own contact with magnetrons , sold in the medical field at that time as diathermy units , first came in the middle 1950s when I was working part-time as a student trainee at the National Bureau of Standards. We were studying afterglows in various oxygen-nitrogen mixtures and used diathermy units working at 2450MHz to excite the gas mixtures at low pressures. Needless to say I took precautions by always using metal screen protection.

We next look at what precisely causes the heating of food in microwave ovens. It is well known that microwaves are generally heavily absorbed by liquid water penetrating no more than a few centimeter before converting all their energy into heat. Since most foods have high water content it stands to reason that food will also be heated by incoming radiation. Although this fact is clear today, it was not back in the late 1940s when Percy Spencer(1894-1970) , an employee at Raytheon, supposedly observed that the chocolate bar he was carrying in his shirt pocket melted as he was fiddling in front of one of the Raytheon radars .This observation gave him the idea of heating food and led to his 1950 patent for a microwave oven. I sometimes wonder if that story is true, for if the microwave pulses were strong enough to melt chocolate in his pocket they would also cause painful body heating.

To see what is happening in microwave heating of water molecules in food we look at the following diagram-



We see here a ball-stick model of the water molecule whose diameter is a little less than 3 Angstrom. The two hydrogen atoms are connected to the larger oxygen atom by covalent bonds. The molecule has a dipole moment causing it to interact with incoming microwaves. Typically the microwaves can cause a periodic stretching and bending of the bonds without breaking them. This will be felt as heat as the movements equilibrate with neighboring molecules. Although the molecules other than water will not directly be affected by the 2450MHz waves, collision of the heated water molecules will transmit this heat directly to non-exited neighboring molecules. The amount of heating food containing H2O will experience will depend on the time of microwave exposure. The reason one is usually advised to let heated food sit a few minutes after heating is that it takes time to transmit this heat throughout the food by conduction. Note that the 2450MHz microwaves have photon energies orders of magnitude less than needed for ionization. Therefore they are non-ionizing, unlike x-rays. The main health hazard of direct exposure to these microwaves is believed to be local overheating of the fluid in the eye lens as these cells are poorly supplied by cooling blood flow. Cataracts may be a possible consequence of longer term exposure.

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