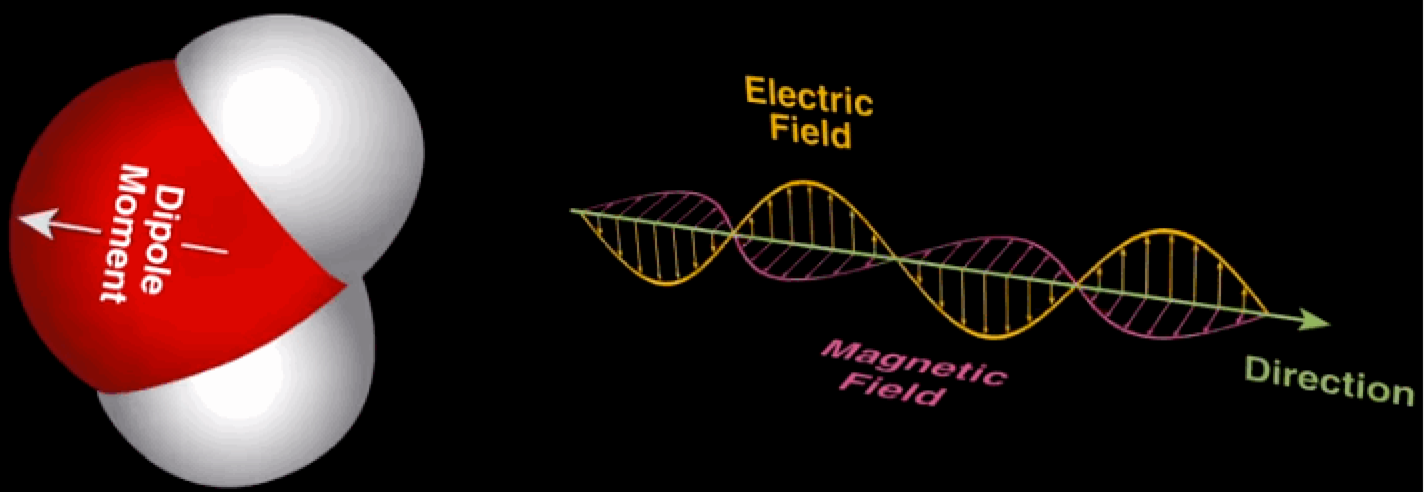
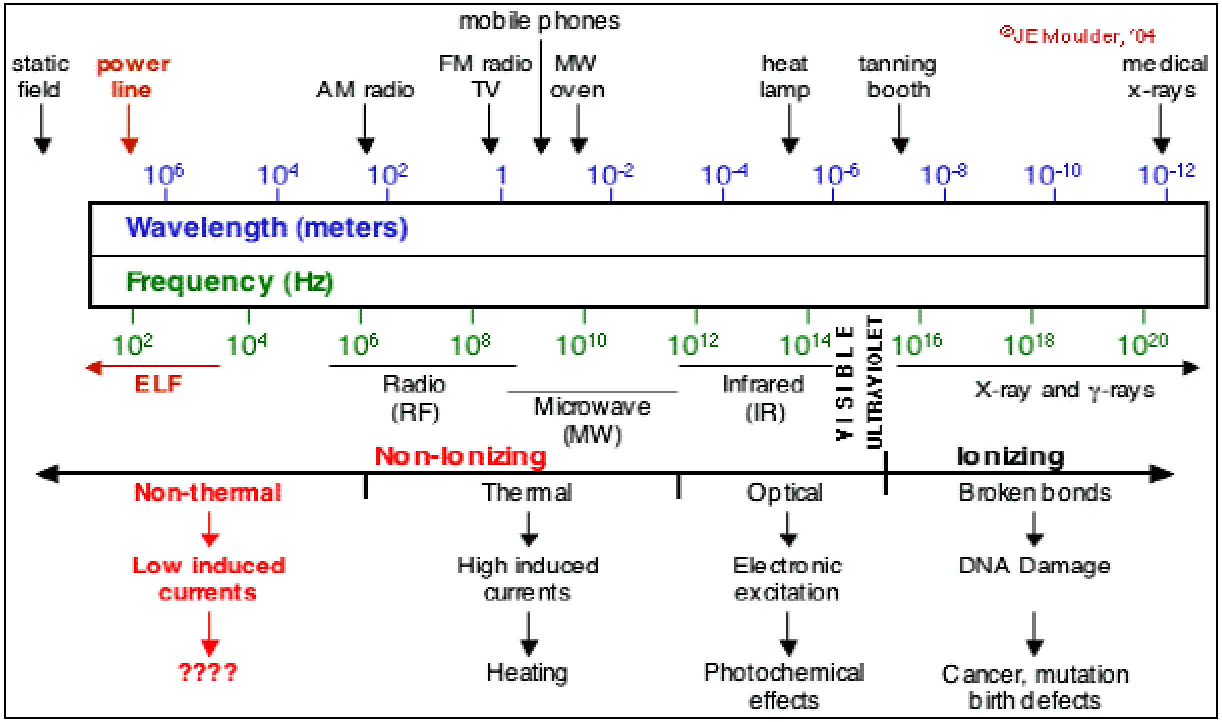
KERONE in Food Technology



Microwave Interaction with Polar Materials

Electromagnetic Spectrum



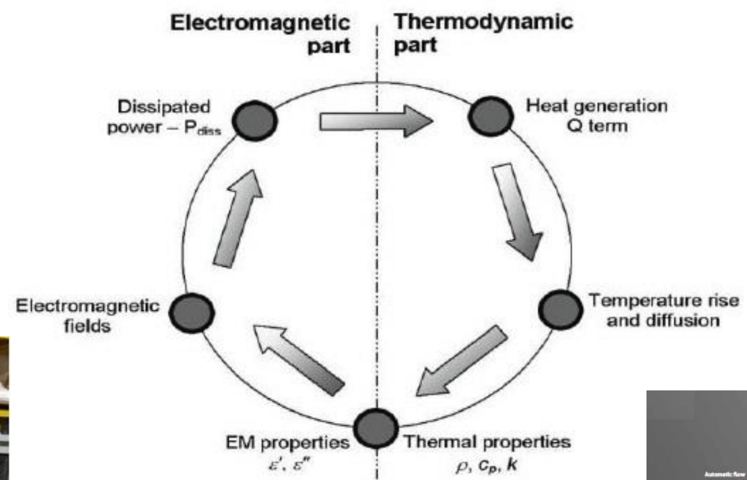
Courtesy: University of Virginia, Charlottesville

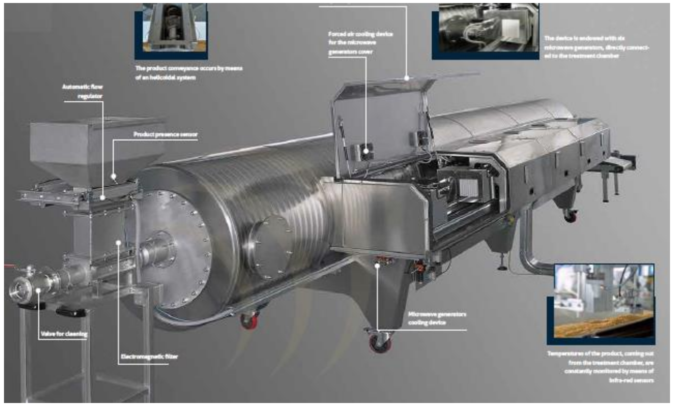
Basic principles of Microwave Heating

- Microwaves are electromagnetic waves that cover spectrum of frequencies ranging 300 MHz to 300 GHz
- It likes light waves, are **reflected by metallic objects, absorbed by dielectric materials, or transmitted from glass**
- The typical frequencies used in microwaves are **2450 MHz** for home type ovens and **915 MHz for industrial use**.
- Absorption of microwave energy in the food involves primarily two **mechanisms- ionic interaction and dipolar rotation**
- Electromagnetic heating such as microwave (MW) and radiofrequency (RF) heating are used in many processes like reheating, precooking, baking, drying, pasteurization , disinfestation and sterilization in industries

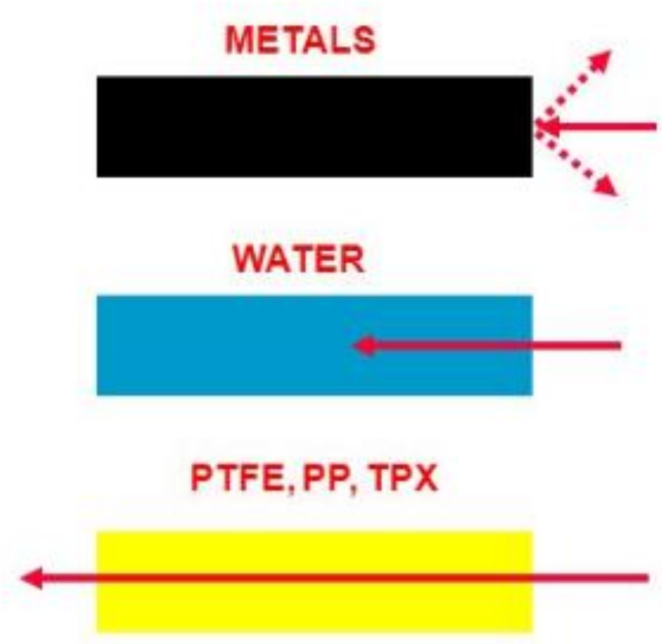
Microwave Heating Systems

- Electrical energy is transformed from the outlet to the microwave
- The microwave heating system transforms electric energy into radiant energy
- Radiant energy is turned in to thermal energy as the food kernels absorb the microwaves. This causes the kernels to become hot and cooked





Interaction of materials with microwaves



Reflective

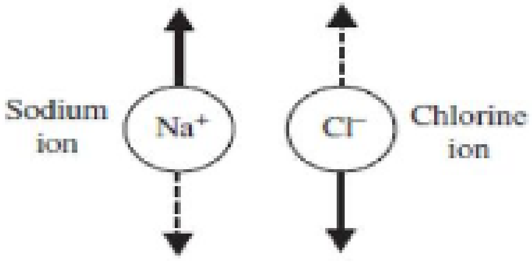
Absorptive

Transparent to Microwaves

Ionic Interaction (Ionic Conduction)

The mechanism of ionic conduction, salt, a common molecule in foods, is composed of positive sodium and negative chloride ions in dissociated form. The net electric field in the oven will accelerate the particle in one direction and the oppositely charged particle in the other direction.

If the accelerating particle collides with an adjacent particle, it will impart kinetic energy to it and set it into more **agitated** motion. As a result of agitation, the temperature of the particle increases. More agitated particles interact with their neighbors and transfer agitation or heat to them. This heat is then transferred to the other parts of the material.



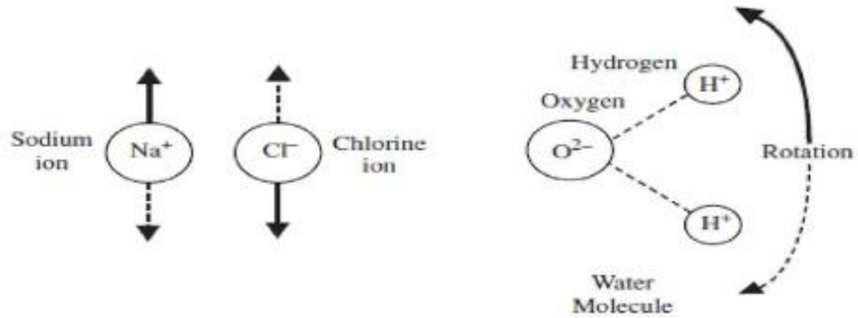
Dipolar Rotation

The physically separated charges are called dipoles. Molecules with such separated charges are known as polar molecules.

Molecules having a center of symmetry such as **methane (CH4)** are nonpolar and exhibit zero dipole moment. Molecules such as **water** or gelatin are polar because they have no charge symmetry and exhibit strong dipole moments.

Water in food is the primary component responsible for dipolar rotation. If the water molecules are placed in an alternating electric field, they will experience a rotation force attempting to orient them in the direction of the field.

As molecules attempt to orient themselves in the field direction, they collide randomly with their neighbors. When the field reverses its direction, they try to line up with the reversed direction and further collisions occur. This causes **thermal agitation and heating** takes place.

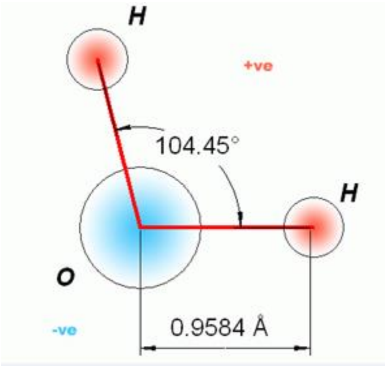


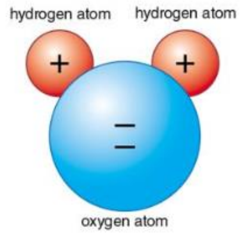
Ionic

Dipolar

Interaction of water molecules with microwaves

Water molecules are polar

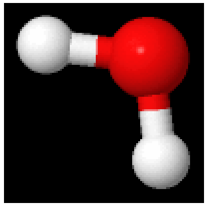




Food containing water can be heated up by microwaves **effectively**

The oscillating **E-field** of the microwave makes the water molecules **vibrate**

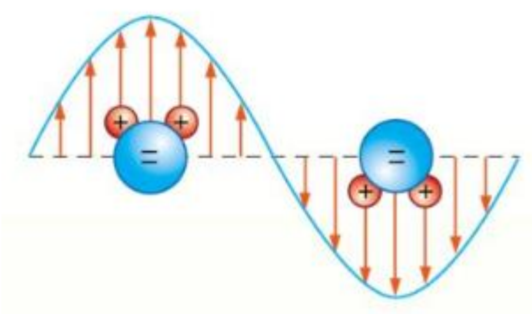
Microwave spectra have provided a very precise value for O-H bond length, 95.84 ± 0.05 pm and H-O-H bond angle, 104.5 ± 0.3 degree



Rotational spectrum

KE of the molecules ↑

Food temperature ↑

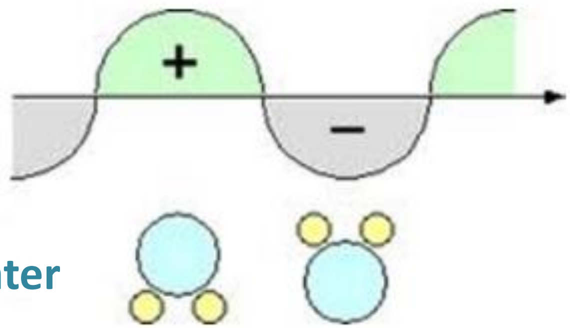


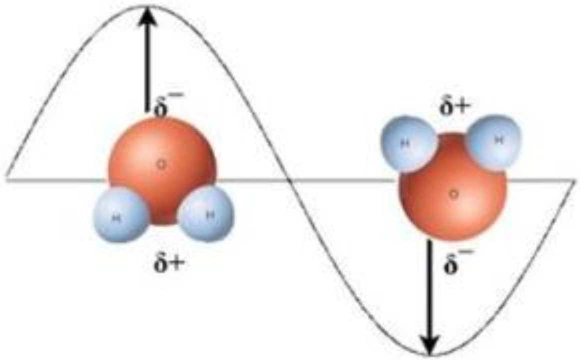
Mechanisms of microwave interaction with food

One side of the molecule is more negatively charged and the other side is more positively charged, even though the molecule itself is neutral

Microwaves

Orientation of water molecules

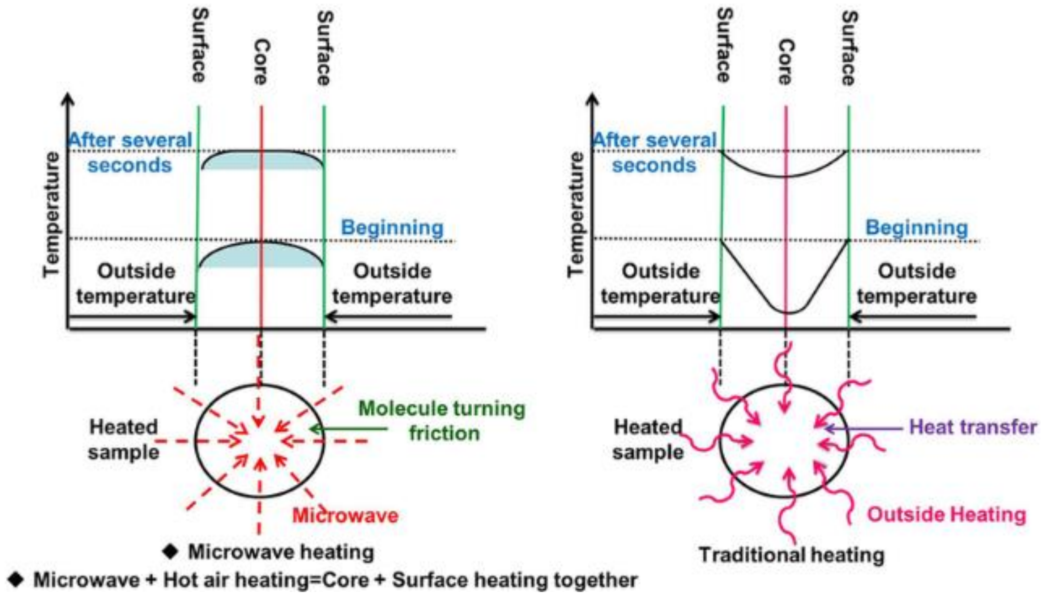


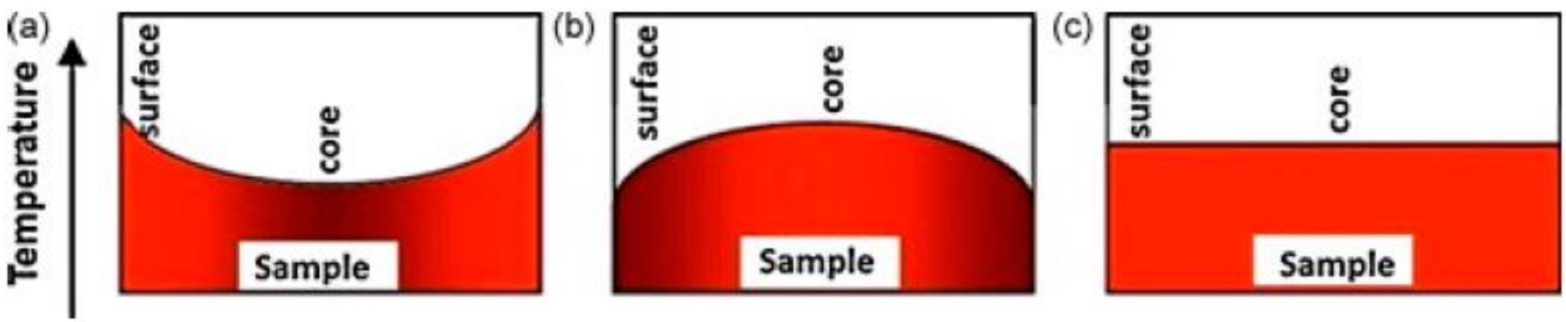


The water molecules in food will rotate due to the microwaves + ve or –ve amplitude

They vibrate rapidly at the antinode and do not vibrate at the nodes

Temperature Profile





Temperature profile within the sample in: (a) conventional heating; (b) microwave heating; and (c) microwave hybrid heating

Definition of Dielectric Properties

- Dielectric properties can be categorized into two: dielectric constant and dielectric loss factor.
- **Dielectric constant (ϵ')** is the ability of a material to store microwave energy and **dielectric loss factor (ϵ'')** is the ability of a material to dissipate microwave energy into heat.
- The parameter that measures **microwave absorptivity** is the **loss factor**. The values of dielectric constant and loss factor will play important roles in determining the interaction of microwaves with food.
- The rate of heat generation per unit volume (Q) at a location inside the food during microwave heating can be characterized by

$$Q = 2\pi f \varepsilon_0 \varepsilon'' E^2$$

Where f is the frequency, ϵo is the dielectric constant of free space (8.854 x 10 $^{-12}$ F/m), ϵ'' is the dielectric loss factor, and E is the electric field.

As microwaves move through the slab at any point, the rate is heat generated per unit volume decreases

For materials having a high loss factor, the rate of heat generated decreases rapidly and microwave energy does not penetrated deeply.

A parameter is necessary to indicate the distance that microwaves will penetrate into the material before it is reduced to a certain fraction of its initial value.

This parameter is called **power penetration depth (dp),** which is defined as the depth at which power decreases to 1/e or (36.8%) of its original value. It depends on both **dielectric constant and loss factor of food.**

$$\delta_p = \frac{\lambda_0}{2\pi\sqrt{2\varepsilon'}}\left(\sqrt{1+(\varepsilon''/\varepsilon')^2}-1\right)^{-\frac{1}{2}}$$

Where λ_0 is wavelength of the microwave in free space

Dielectric properties of cooking oil are very low because of its nonpolar characteristics. Dielectric properties of water and high-moisture-containing foods such as fruits, vegetables and meat are high because of dipolar rotation

Effects on Moisture Content on Dielectric Properties

- Liquid water is very polar and can easily absorb microwave energy based on the mechanism of dipolar rotation. The dielectric constant and loss factor of free water are predicted by Debye models.

- Debye models are expressed in terms of wavelength and temperature-dependent parameters.

$$\varepsilon' = \frac{\varepsilon_s - \varepsilon_0}{1 + \left(\lambda_s/\lambda\right)^2} + \varepsilon_0$$

$$\varepsilon'' = \frac{(\varepsilon_s - \varepsilon_0)\left(\lambda_s/\lambda\right)}{1 + \left(\lambda_s/\lambda\right)^2}$$

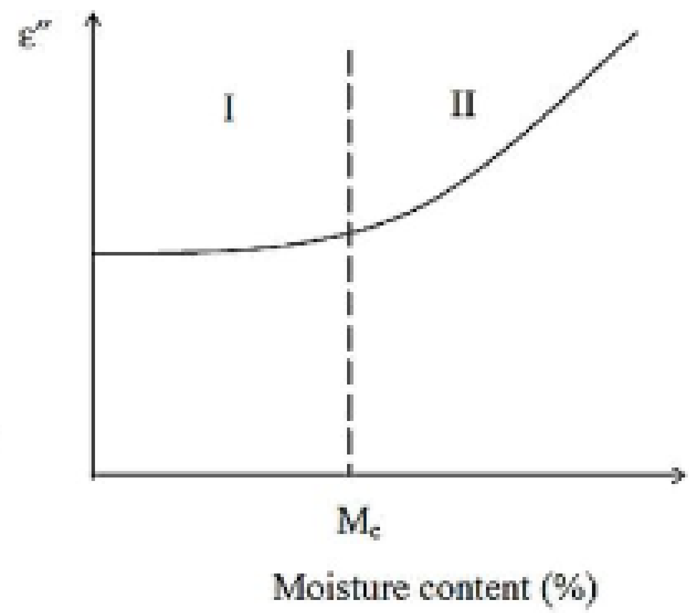
Where εs is static dielectric constant, ε_0 is optical dielectric constant, λ is wavelength of water, and λ_s is critical wavelength of polar solvent

▪ Water can exist in either the free or bound state in food systems

▪ Free water is found in capillaries but bound water is physically adsorbed to the surface of dry material.

▪ The dielectric loss factor is affected by the losses in free and bound water but since relaxation of bound water takes place below microwave frequencies, its effects are small in microwave processing.

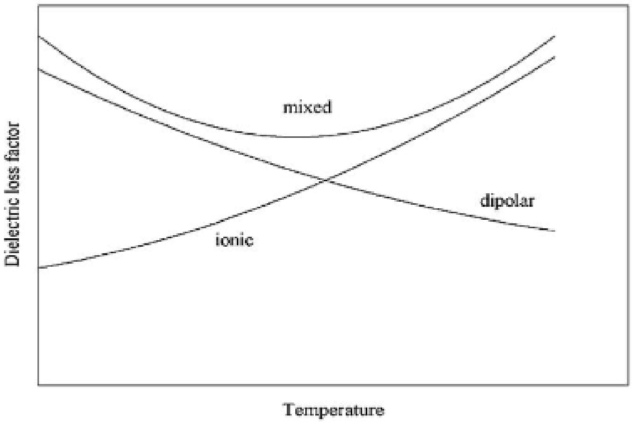
The variation of dielectric loss factor with moisture content. From the figure, loss factor is constant in the bound region (**region I)** up to a critical moisture content (Mc) but then increases sharply for high moisture contents. Therefore, the effect of bound water on dielectric properties is negligible



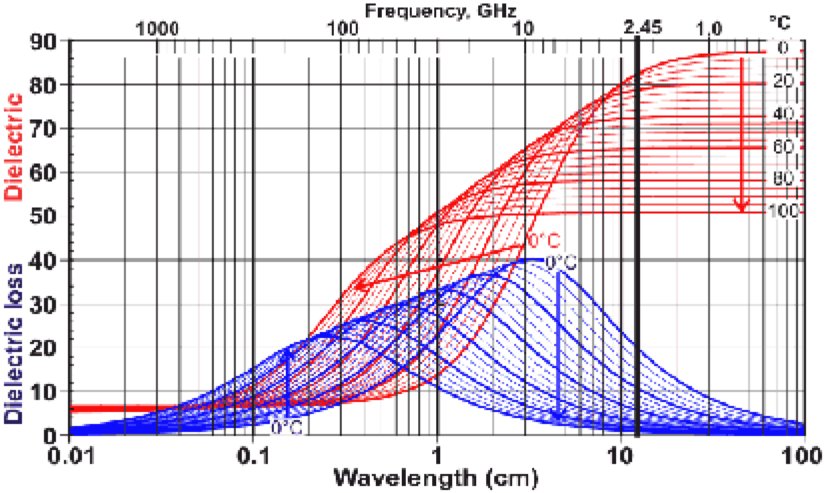
- The interaction of food components with water is a significant factor in affecting their dielectric properties
- **The stronger the binding forces** between protein or carbohydrates and water, the **smaller the value of the dielectric constant and loss factor** since free water in the system decrease
- Therefore, adjusting the moisture content is the key factor in formulating microwaveable foods.
- The increase in water increases the polarization, which increases both dielectric constant and loss factor. At low moisture contents, variation of dielectric properties with moisture content is small.
- For food materials having high moisture contents, bound water does not play a significant role and the dielectric properties are affected by dissolved constituents as well as water content.
- Dielectric properties of **foods decrease during drying, since free moisture content in the system decreases.**

Effect of Temperature on Dielectric Properties

- Free and bound moisture content and ionic conductivity affect the rate of change of dielectric constant and loss factor with temperature
- If the water is in **bound form**, **the increase in temperature increases the dielectric properties**. However, in the presence of **free water, dielectric properties of free water decrease as temperature increases**.
- Therefore, the rate of variation of dielectric properties depends on the ratio of bound to free moisture content.
- During thawing, both dielectric constant and loss factor show large increases with temperature. After the material thaws, dielectric properties decrease with increasing temperature for different food materials except for a salted food.
- The variation of dielectric loss factor of a salt solution or a salty material with respect to temperature is different because the loss factor of a salt solution is composed of two components **: dipolar loss and ionic loss**.



Variation of loss factor components with temperature



Dielectric loss water

- **Dipolar loss decreases with temperature** at frequencies used in microwave processing. In contrast to dipolar loss, loss factor from **ionic conduction increases with temperature** owing to the decreased viscosity of the liquid and increased mobility of the ions.

- At higher temperatures,, ions becomes more mobile and not tightly bound to water, and thus the loss factor from ionic loss component increases with temperature.

- On the other hand, microwave heating of water molecules or food containing free moisture decreases with increasing temperature. The reasons are the **rare hydrogen bonds** and **more intense movements**, which require less energy to overcome intermolecular bond at higher temperatures.

- For materials containing both dipolar and ionic components, it is possible to observe first a decrease and then an increase in loss factor with temperature.

Effects on Composition of Foods on Dielectric properties

- Dielectric properties of food products depend on composition such as
  - **Carbohydrate**
  - **Fat**
  - **Moisture**
  - **Protein**
  - **Salt**

- The presence of free and bound water, surface charges, electrolytes, non-electrolytes, and hydrogen bonding in the food product play important roles in dielectric properties

- The investigation of dielectric behavior of major food components and the effects of processing on dielectric properties are important for food technologies and engineers to improve the quality of microwave foods, to design microwaveable foods, and to develop new microwave processes.

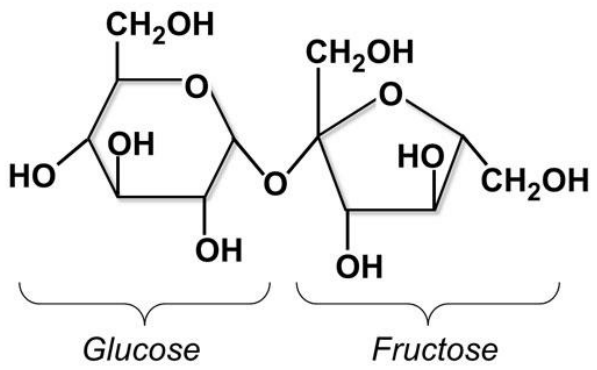
Dielectric properties of Carbohydrates and Interaction with MW

- Starches, sugars and gums are the major carbohydrates in food systems

- For carbohydrate solutions, the effect of free water on dielectric properties becomes significant since carbohydrates themselves have small dielectric activities at microwave frequencies

- Hydrogen bonds and hydroxyl-water interactions also play a significant role in dielectric properties of high sugar, maltodextrin, starch hydrolysate and lactose such as disaccharide- based foods.

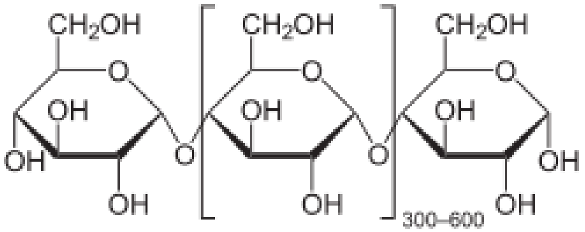
Sucrose, a disaccharide



Starch : Definition and chemical characteristics with MW

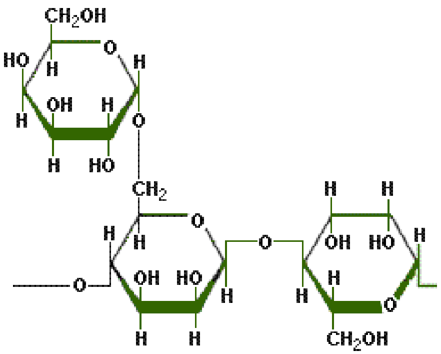
Starch molecule is $(C_6H_{10}O_5)_n$. **Starch** is a polysaccharide comprising glucose monomers joined in α 1,4 linkages. The simplest form of **starch** is the linear polymer **amylose**; amylopectin is the branched form

amylose



- Variation of dielectric properties of starch with temperature depends on whether starch is in solid state or in suspension form.
- When the dielectric properties of different starches in powder form were measured at 2450 MHz both the dielectric constant and the loss factor increased with temperature.
- For starch suspensions, the effect of free water on dielectric properties becomes significant. Dielectric constant and loss factor of different starch suspensions were shown to decrease as temperature and starch concentration increased.
- The increase in starch concentration decreases both the dielectric constant and loss factor since **starch molecules bind water and reduce the amount of free water** in the system

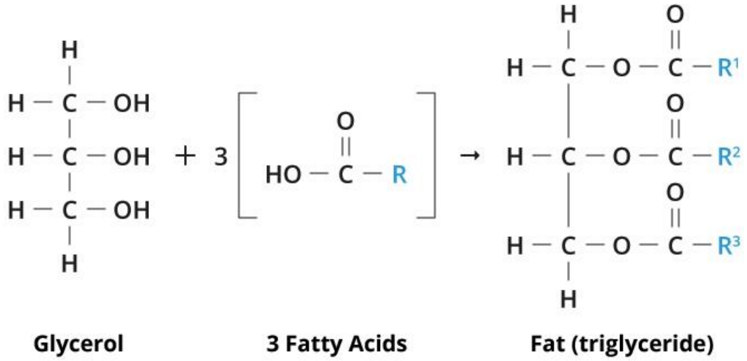
Gum: Dielectric Properties and Microwave



- Gums have the ability to bind high amounts of free water in the system.
- Depending on the amount of moisture bound to the gums, dielectric constant and loss factor of the system change.
- Charge of the gum is a significant factor in affecting its dielectric properties. As the charge increases, the amount of moisture bound to the charged groups increases, which lowers the dielectric constant and loss factor.
- In the absence of water, the effect of charge disappears. The effect of charge on dielectric values may be due to the fact that water associated with highly hydrophilic charged groups may not be free to interact with microwaves
- For microwaveable food formulations, it is important to know water binding capacity of the gums and viscosity of the solution to have an idea about the dielectric properties and microwave heat ability of these formulations.

Fat: Dielectric Properties and MW interaction

Fat molecules are made up of four **parts**: a **molecule** of glycerol (on the right) and three **molecules** of fatty acids.



- Since lipids are hydrophobic except for ionizable carboxyl groups of fatty acids, they do not interact much with microwaves.

- Therefore, dielectric properties of fats and oils are very low. The effect of fat on dielectric properties of food systems is mainly the result of their dilution effect in the system.

- The increase in fat content reduces the free water content in the system, which reduces the dielectric properties.

Proteins: Dielectric Properties and Microwave

The primary **structure** of a **protein** refers to the sequence of amino acids in the polypeptide chain. The primary **structure** is held together by peptide bonds that are made during the process of **protein** biosynthesis.

- Free amino acids are dielectrically reactive. Free amino acids and polypeptides contribute to the increase in dielectric loss factor
- The water adsorbed on the protein also affects their dielectric properties
- Dielectric properties of proteins change during denaturation. Protein denaturation is defined as the physical change of the protein molecule due to heat, UV, or agitation, which results in a reduction in protein solubility and increase in solution viscosity.
- During denaturation of proteins, since the structure of protein is disturbed, the asymmetry of the charge distribution will increase. This will result in large dipole moment and polarization, which will affect the dielectric properties.
- Moreover, moisture is either bound by the protein molecule or released to the system during denaturation, which shows a decrease or increase in dielectric properties, respectively

Feature	Benefit	Economic Value
Higher Power Densities	More efficient energy usage	Increased production speeds
	Selective heating - "product not plant"	Decreased production costs
	Heat not expended to heating air, walls of the oven, conveyor and other parts	Since energy source is not hot there is a plant cooling savings: HVAC Savings
More Uniform Temperature Profiles	Energy is selectively absorbed by areas of greater moisture	Minimizes over-processing; no scorching, overheating or case hardening
	Enhanced product performance	Improved yields

Feature	Benefit	Economic Value
No-Contact Drying Technology	Reduces production run times	Reduces both cleaning times and chemical costs
	Lack of high temperature heating surfaces	Reduces material finish marring
No Greenhouse Gas Emissions From Heating Source	May Eliminate the need for environmental permits	Cost savings
	Improves working conditions	Employee retention
Increased Plant Throughput	Less handling, floor traffic, fork trucks, pallets, transfer points and congestion	Better employee ergonomics, safety and product damage More productivity
	Less floor space requirements, contamination, product damage	

Feature	Benefit	Economic Value
Decreased Process Time	Decreased energy usage on basis of batch processed/continuous runs	Energy savings due to shorter batch times
	Ability to pulse the power for precise control	Reduced production
More Compact	Requires a smaller equipment space or footprint	Reduced fixed cost savings
	Can be remotely located in a dry, safe area	More usable plant floor space for increased production

Feature	Benefit	Economic Value
Safety	Chokes, mesh screens, and safety interlocks for complete operator safety	Prevent employee injuries and liability claims
	Safer than steam and hot oil heating	Prevents injury & worker discomfort
Precision Energy Control	Can be turned on and off instantly	Eliminates the need for warm up and cool down
	Product heating occurs from top down	Reduces product fouling

Accreditations

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CRISIL Verified

Member of A.M.P.E.R.E. (Europe)

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ISO 9001:2008 | ISO 9001:2015 | OHSAS 18001 | EMS 14001

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