Electromagnetic Properties of Foods

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Content:
-Microwave heating
-Dielectric properties of foods

Microwave

- Microwave is a form of electromagnetic radiation with wavelengths ranging from about one meter to one millimeter in lenght corresponding to frequencies between 300 MHz and 30 GHz respectively.

- Microwave heating takes place in dielectric materials such as foods due to the polarization effect of electromagnetic radiation at frequencies between 300 MHz and 300 GHz.

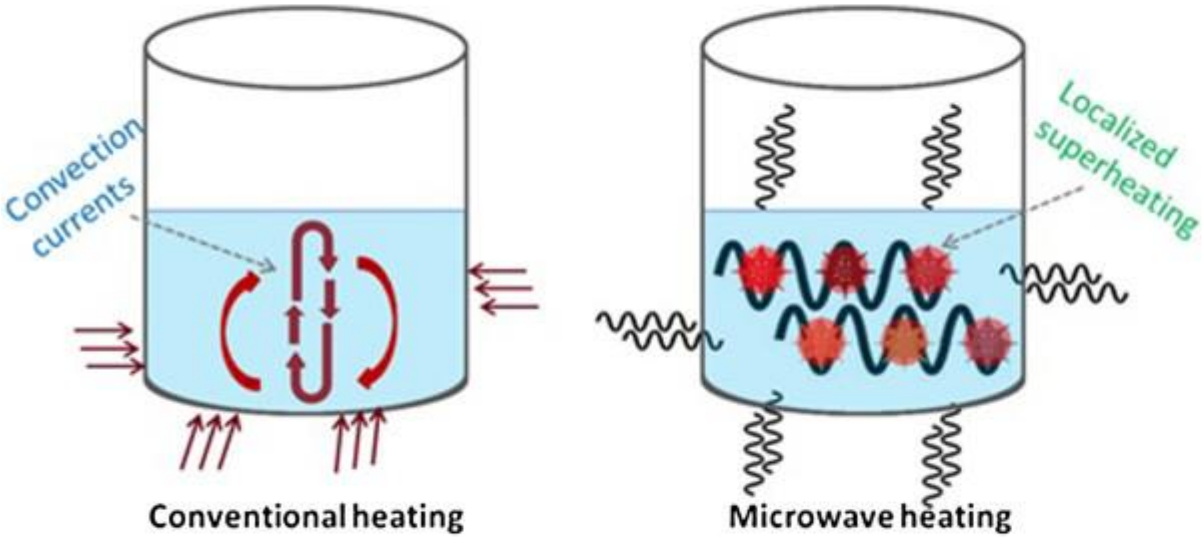
Mega**H**ert**Z** means one million cycles per second

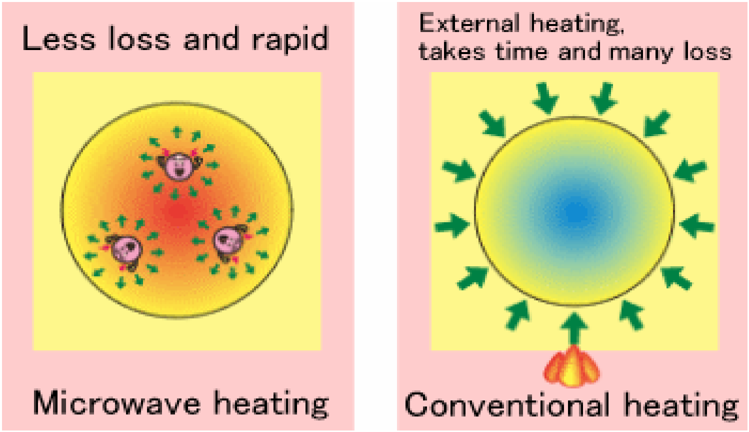
Microwave heating in food processing

The applications of microwave heating in food processing include;

- Reheating
- Precooking
- drying,
- pasteurization,
- sterilization,
- thawing,
- tempering,
- baking of food materials etc.

Microwave heating versus conventional heating





Basic principles of microwave heating

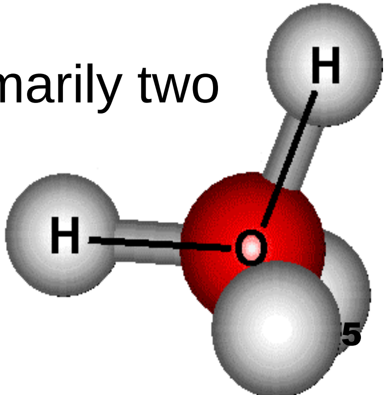
- Microwaves are electromagnetic waves that cover a spectrum of frequencies ranging from 300 MHz to 30 GHz.
- Microwaves, like light waves, are reflected by metallic objects, absorbed by dielectric materials, or transmitted from glass.
- Although microwaves cover a wide range of frequencies, their use is restricted to some frequencies owing to the possibility of interference of microwaves with radar or other communication devices.

The typical frequencies used in microwaves are:

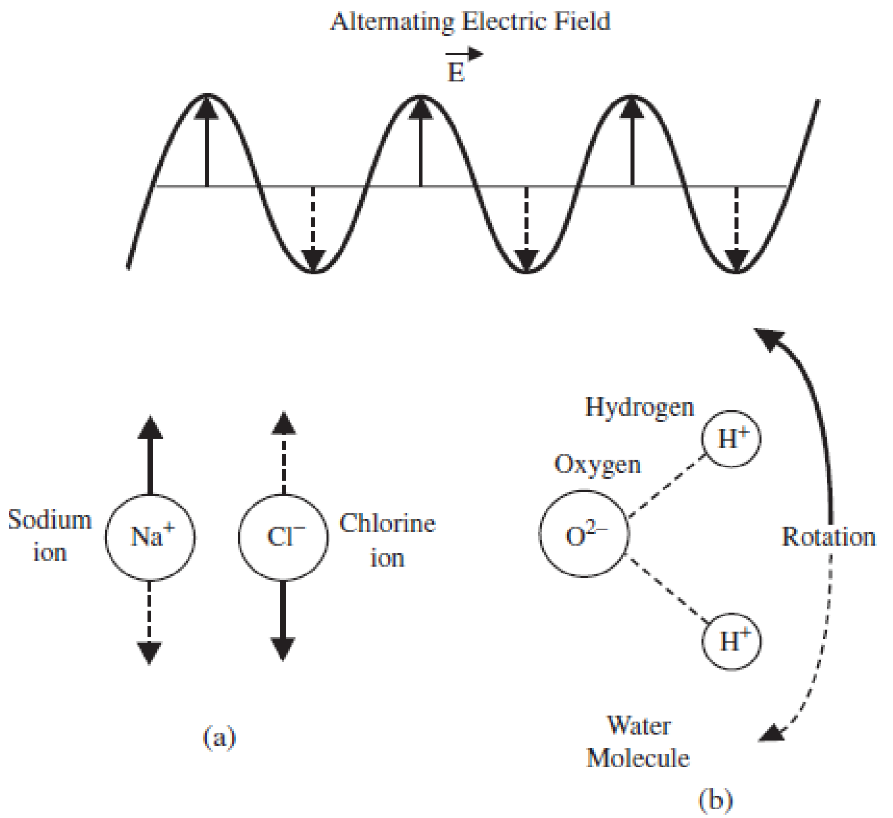
- 2450 MHz for home type ovens and
- 915 MHz for industrial use.

Absorption of microwave energy in the food involves primarily two mechanisms:

- ionic interaction
- and dipolar rotation



Ionic interaction (ionic conduction)

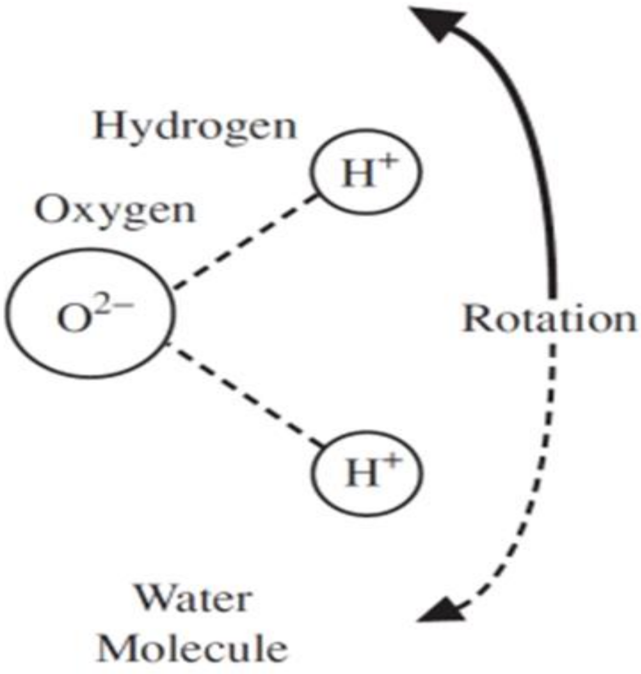


Mechanisms of microwave interaction with food: (a) ionic, (b) dipolar

Ionic interaction

- 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.
- As the concentration of ions (e.g. dissolved salts) increase, the rate of heating also increases because of the ionic interaction with microwaves.

Dipolar rotation



Definition of Dielectric Properties

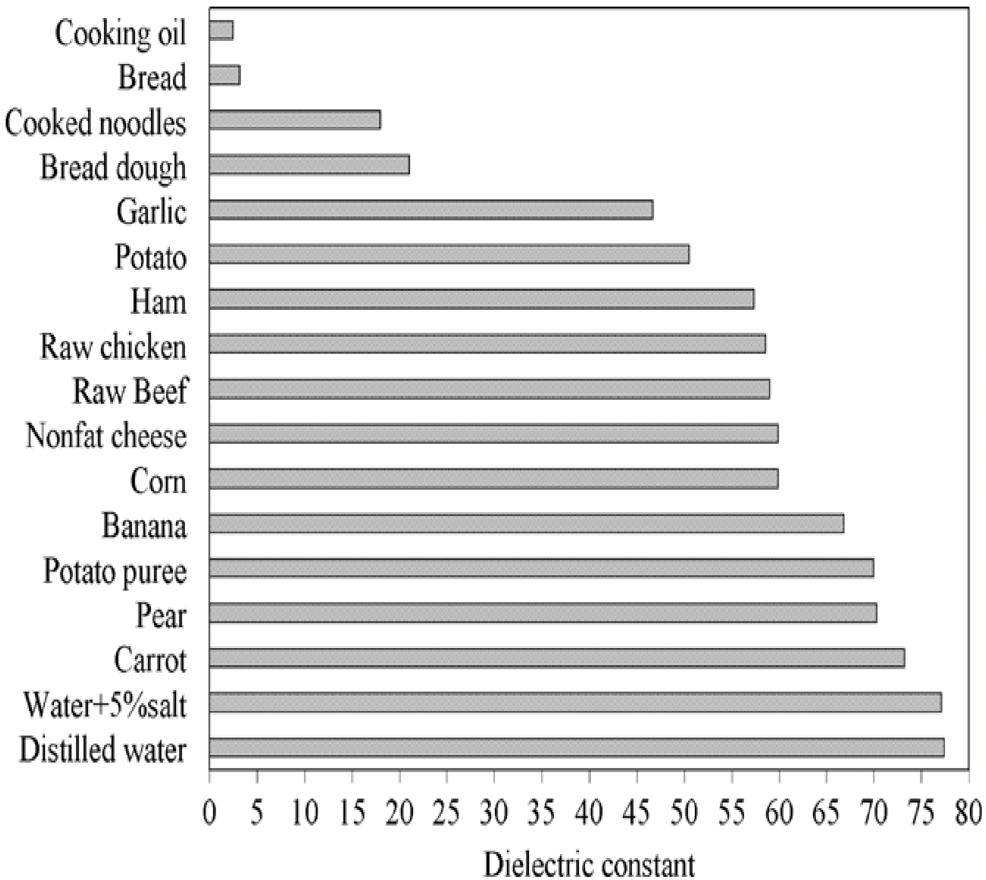
Dielectric properties can be categorized into two:

- Dielectric constant
- Dielectric loss factor

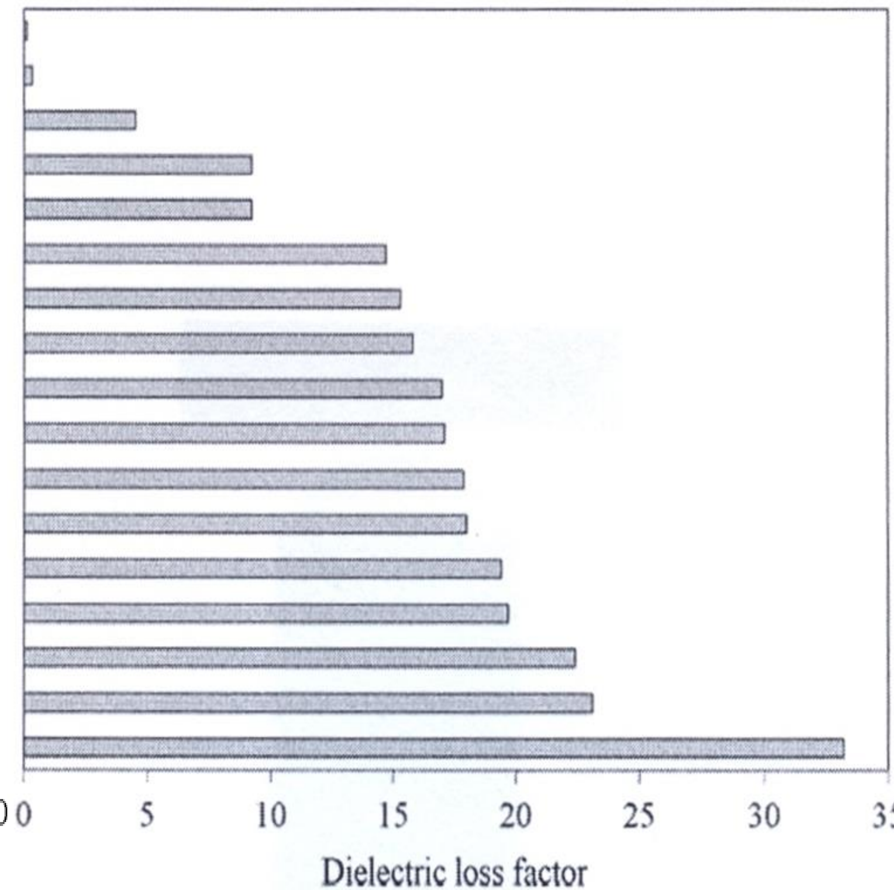
Dielectric constant (ε'): the ability of a material to store microwave energy.

Dielectric loss factor (ε''): 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.

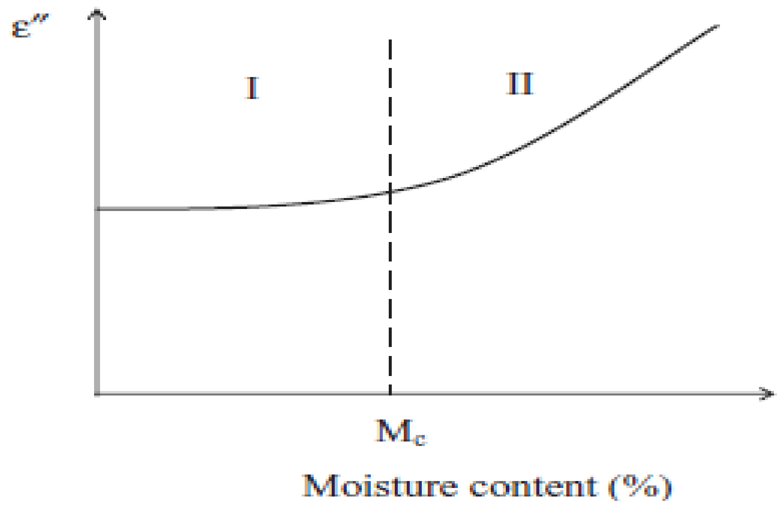


Dielectric constant of various food materials at 25◦C.



Dielectric loss factor of various food materials at 25◦C.

Effects of Moisture Content on Dielectric Properties

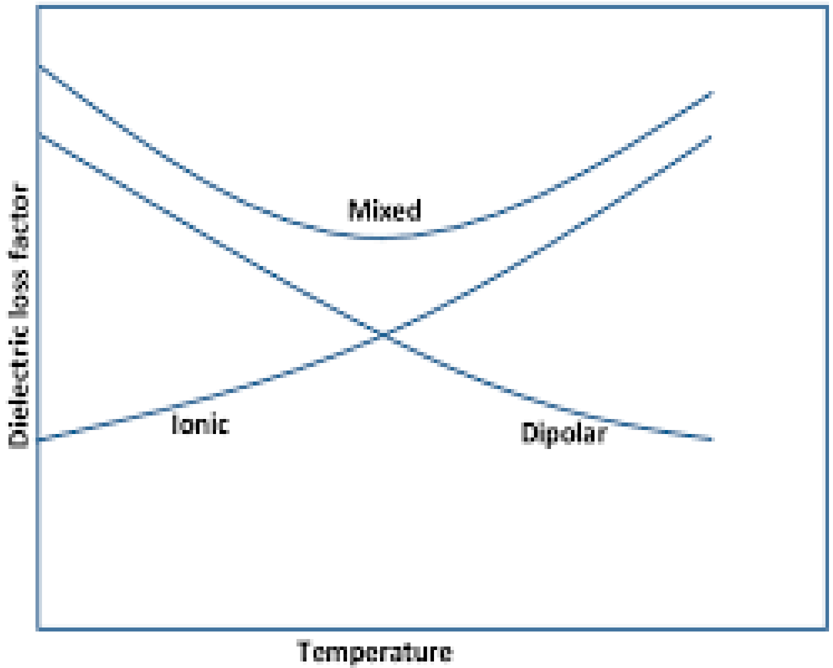


Variation of loss factor with moisture content

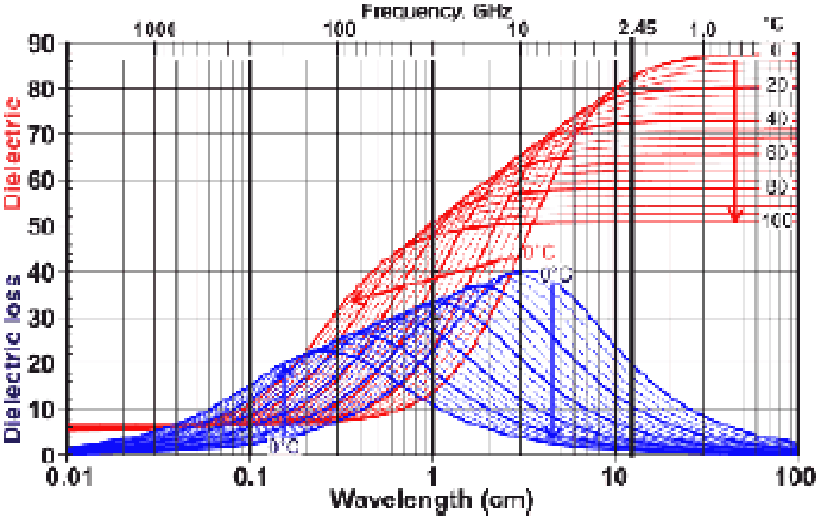
- Dielectric properties of foods decrease during drying, since free moisture content in the system decreases.
- Feng, Tang, and Cavalieri (2002) showed that both dielectric constant and loss factor of apples decreased during drying owing to the reduced moisture content in the food.

Effects 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 (ham).
- The loss factor of ham shows a continuous increase during heating.
- 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.



11: Variation of loss factor components with temperature, redrawn wit



Dielectric loss water

Effects of Temperature on Dielectric Properties

- 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 become more mobile and not tightly bound to water, and thus the loss factor from ionic loss component increases with temperature.

Effects of Composition of Foods on Dielectric Properties

- Dielectric properties of food products depend on composition. Carbohydrate, fat, moisture, protein, and salt contents

Dielectric Properties of Salt Solutions

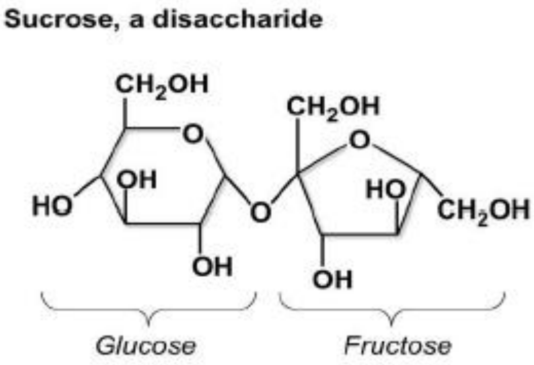
- Salt is one of the major components in food systems, which is responsible for ionic conduction.
- addition of salt to food decreased dielectric constant but increased loss factor.
- The decrease in dielectric constant with the addition of salt is due to binding of water in the system which reduces the available water for polarization.
- On the other hand, addition of salt increases the loss factor since more charged particles are added to the system and charge migration is increased.

Dielectric Properties of Carbohydrates

- 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.

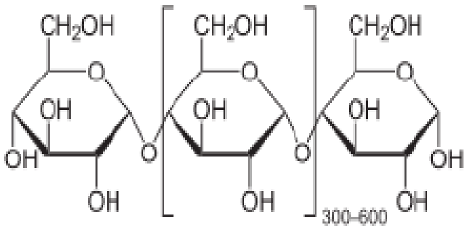
- Hydrogen bonds and hydroxyl–water interactions also play a significant role in dielectric properties of high sugar, maltodextrin, starch hydrolysate, and lactose such as disaccharide-based foods.



(a) Starch

- Starch molecule is $(C6H10O5)n$. Starch is a polysaccharide comprising glucose monomers joined in α 1,4 linkages. The simplest form of starch is the linear polymer amylose;

amylose



(b) Sugar

- Sugar is an important microwave absorbing food ingredient as compared to other hydrocolloids.
- Sugars modify the dielectric behavior of water.
- The hydroxyl water interactions stabilize liquid water by hydrogen bonds and affect the dielectric properties of sugar solutions.
- The degree of microwave interaction depends on the extent of hydrogen bonding.

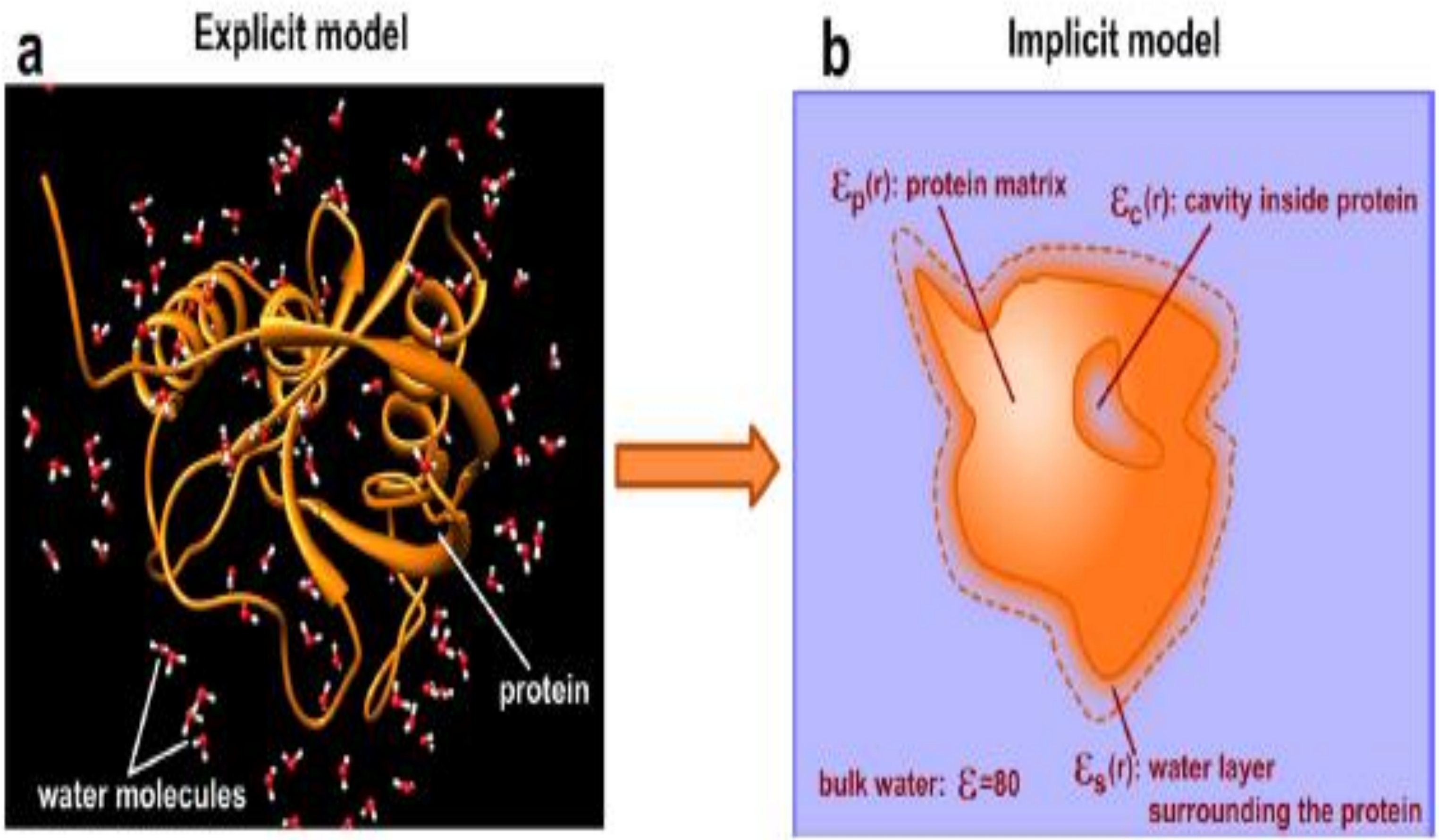
- Hydroxyl groups of glucose are more accessible for hydrogen bonding as compared to starches.
- In starches, less hydroxyl groups are exposed to water and fewer stable hydrogen bonds are formed.
- Therefore, the loss factors of the starch solutions were reported to be lower than that of the sugar solutions.

(c) Gum

- Gums have the ability to bind high amounts of free water in the system.
- Therefore, 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.

Dielectric properties of proteins

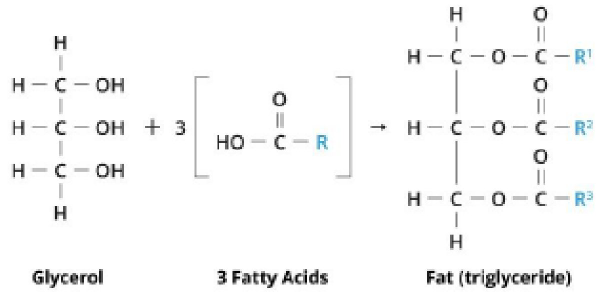
- The primary structure of a protein refers to the sequence of amino acids in the polypeptide chain. The primary structure is held together by peptide bonds that are made during the process of protein biosynthesis.
- Free amino acids are dielectrically reactive.
- Free amino acids and polypeptides contribute to the increase in dielectric loss factor.
- Since protein dipole moments are a function of their amino acids and pH of the medium, the dielectric properties and microwave reactivity of cereal, legume, milk, meat, and fish proteins are expected to be different.



a
Explicit model
protein
water molecules
b
Implicit model
$\varepsilon_p(r)$: protein matrix
$\varepsilon_c(r)$: cavity inside protein
bulk water: ε=80
$\varepsilon_s(r)$: water layer surrounding the protein

Dielectric properties of fats

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



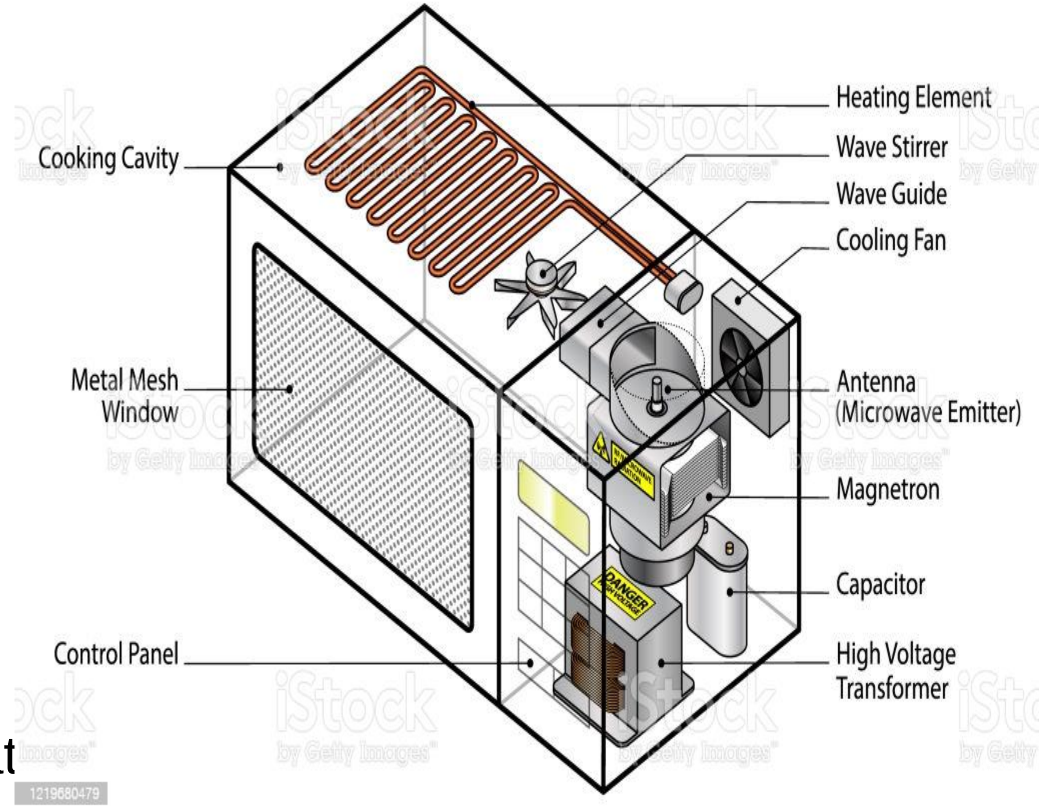
- Since lipids are hydrophobic except for ionizable carboxyl groups of fatty acids, they do not interact much with microwaves.
- Therefore, dielectric properties of fats and oils are very low.
- The effect of fat on dielectric properties of food systems is mainly the result of their dilution effect in the system.
- The increase in fat content reduces the free water content in the system, which reduces the dielectric properties.

Microwave heating system

- 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.

Microwave oven

- Contains high voltage
- It is used to produce microwaves.
- A component called the magnetron generates microwaves from electricity inside the microwave oven.
- To power the magnetron, a transformer converts the standard household electricity from a wall socket of 120 (or 230) volts to about 4,000 volts or higher.
- The voltage heats a filament at the center of the magnetron, boiling off electrons.



Microwave oven

- The microwaves are transmitted into the cooking compartment by an antenna where they are bounced around eventually penetrating the food.
- The microwave door contains a metal mesh that reflects the microwaves like a mirror and keeps them from leaking out.
- The mesh holes are too small for microwaves to escape through but large enough that visible light can, so we can see what's cooking inside.