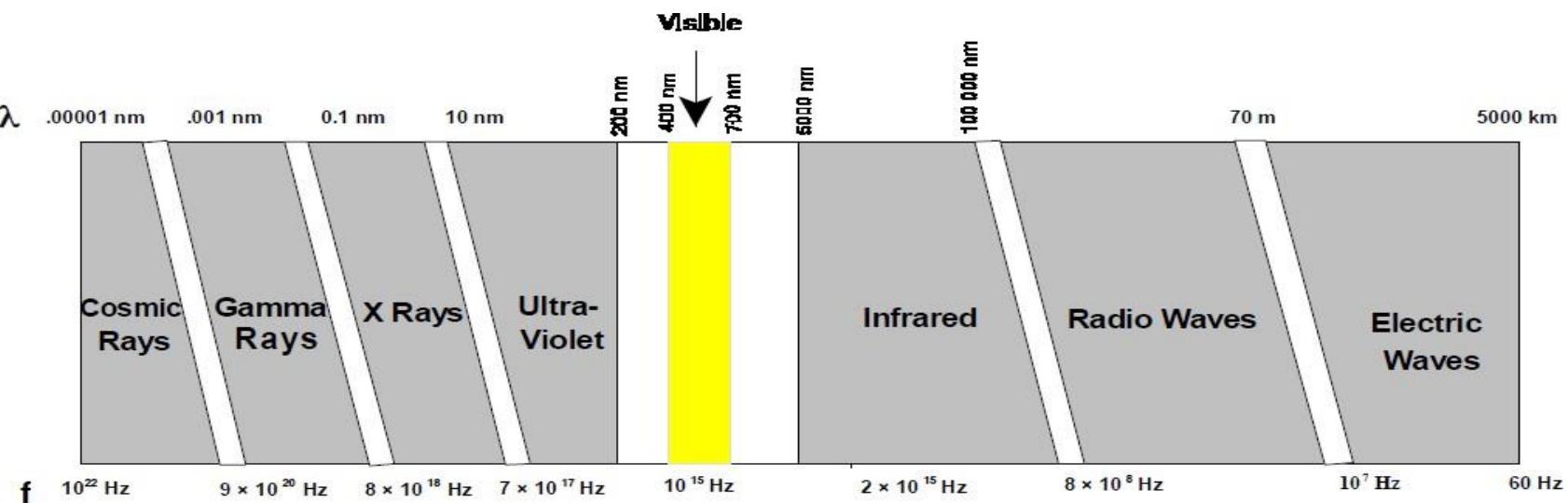


DIELECTRIC PROPERTIES

Electromagnetic radiation encompasses a wide variety of phenomena as represented by the various regions along its broad spectrum.

Utilizing selective parts of the electromagnetic spectrum is the basis for our modern electrical power distribution system and the many forms of transmitted communication including radar, radio, television, and satellite.

Short wavelength energy is used for medical purposes including X-rays and radiography. The intermediate range includes the infrared, visible, and ultraviolet portions of the spectrum. Only a few specialized, narrow regions are utilized in food applications. These include light, infrared, and microwave frequencies.



$$\begin{aligned}\lambda &= \text{wavelength} & f &= \text{frequency} \\ f \times \lambda &= c & (\text{speed of light} = 3.00 \times 10^8 \text{ m/s})\end{aligned}$$

Electromagnetic spectrum

| Frequency | Wave length | Designation | | | Use |
|-----------|--------------------|-------------|----------------------|------------------|--|
| 100 | 10pm | *1 | Gamma ray | | Medical, Material Inspection |
| 10 | 100 | | X ray | | Medical, Material Inspection |
| 1GHz | 1nm | *2 | Ultraviolet ray | | Bactericidal lamp* Electronic device Manufacturing equipment |
| 100 | 10 | | Visible ray | | |
| 10 | 100 | *2 | Infrared ray | | Infrared heating appliance |
| 1GHz | 1 μ m | | Far infrared ray | | |
| 100 | 10 | *3 | Decimillimetric wave | | |
| 10 | 100 | | EHF | Millimetric wave | Radar system |
| 1GHz | 1mm | *3 | SHF | Centimetric wave | Satelite broadcasting |
| 100 | 10 | | UHF | Decimetric wave | Television, Cell-phone, Microwave oven |
| 10 | 100 | *3 | VHF | Meter wave | FM radio, Television |
| 1GHz | 1m | | HF | Decametric wave | Shortwave radio |
| 100 | 10 | *3 | MF | Hectometric wave | Middle-wave radio |
| 10 | 100 | | LF | Kilometric wave | Ship, Aircraft Communication, Induction heating cooking device |
| 1MHz | 1km | *3 | VLF | Myriametric wave | |
| 100 | 10 | | ELF | | 50/60Hz High-voltage transmission line |
| 10 | 100 | *3 | | | Electric home appliances |
| 1kHz | 10 ³ km | | | | Biological electric phenomena, such as brain wave |
| 100 | 10 ⁴ km | *4 | | | Radio wave, radiation around earthquake source |
| 10 | 10 ⁵ km | | | | |
| 1Hz | 10 ⁶ km | ULF | | | |

*1 Ionizing radiation

*2 Light

*3 Nonionizing radiation

*4 Radio wave

APPLICATION OF DIELECTRIC PROPERTIES OF FOODS

Electromagnetic heating such as microwave and radiofrequency (RF) heating are used in many processes such as reheating, precooking, tempering, baking, drying, pasteurization, and sterilization in industry and at home, including electromagnetic heating processes related to dielectric properties of the material.

Since microwave heating is common in many food processes, determination of dielectric properties becomes significant to understand the heating profiles of foods in a microwave oven, and to develop equipment and microwaveable foods.

Dielectric properties can be **used for quality control of foods** such as to

- ✓ determine the state of fish and meat freshness,
- ✓ evaluate frying oil quality,
- ✓ determine moisture content , water activity
- ✓ determine acid value, density, and viscosity

Basic Principles of Microwave Heating

Microwaves, which are electromagnetic waves, cover a spectrum of frequencies ranging from 300 MHz to 300 GHz.

Microwaves, like light waves, are

- ✓ reflected by metallic objects,
- ✓ absorbed by dielectric materials, or
- ✓ transmitted from glass.

Microwave heating is to heat dielectric materials through mainly their molecular motion and their ionic conduction by the action of electromagnetic waves of 300MHz to 300GHz. 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**.

A **dielectric** is an electrical **insulator** that can be **polarized** by an applied **electric field**. When a dielectric is placed in an electric field, electric charges do not flow through the material as they do in a **conductor**, but only slightly shift from their average equilibrium positions causing **dielectric polarization**. Because of dielectric polarization, positive charges are displaced toward the field and negative charges shift in the opposite direction. This creates an internal electric field which reduces the overall field within the dielectric itself. A material is classified as “**dielectric**” if it has the ability to store energy when an external electric field is applied.

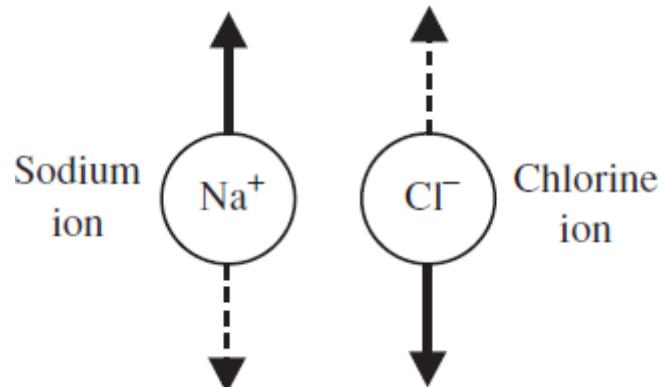
At the microscopic level, several dielectric mechanisms can contribute to dielectric behavior. **Dipole orientation** and **ionic conduction** interact strongly at microwave frequencies. Water molecules, for example, are permanent dipoles, which rotate to follow an alternating electric field. These mechanisms are quite lossy—which explains why food heats in a microwave oven.

Ionic Interaction (Ionic Conduction)

Figure illustrates 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 neighbours and transfer agitation or heat to them. This heat is then transferred to the other parts of the material.

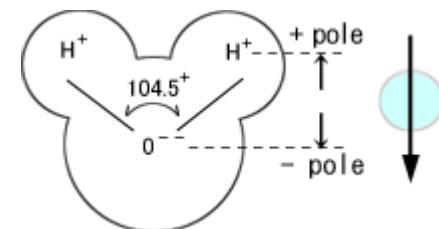
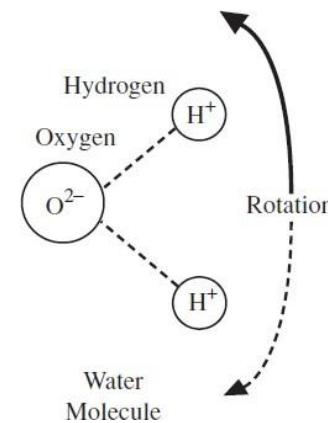
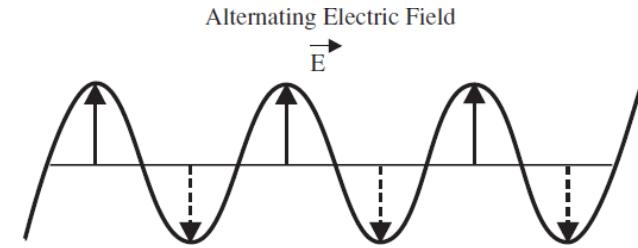


Dipolar Rotation

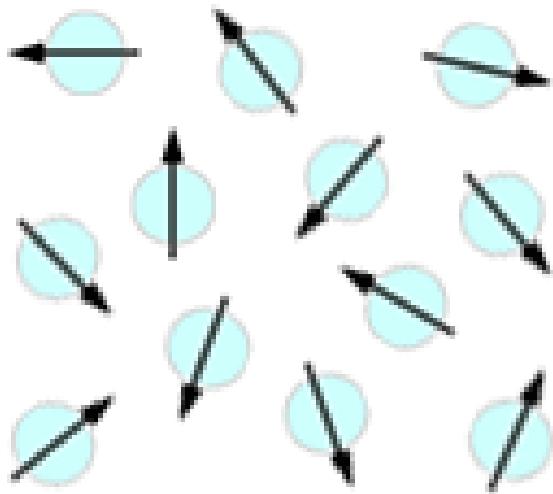
The physically separated charges are called dipoles. Molecules with such separated charges are known as polar molecules. Molecules such as water or gelatin are polar. Water in food is the primary component responsible for dipolar rotation.

If the water molecules are placed in an alternating electric field, they will experience a rotational force attempting to orient them in the direction of the field.

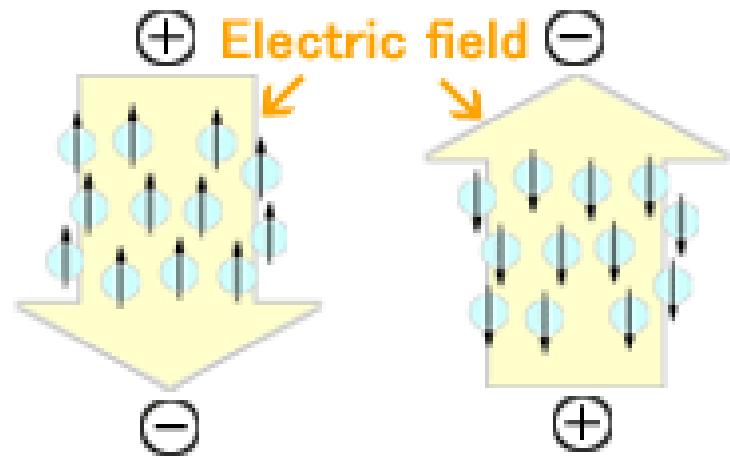
As molecules attempt to orient themselves in the field direction, they collide randomly with their neighbors. When the field reverses its direction, they try to line up with the reversed direction and further collisions occur. This causes thermal agitation and heating takes place.



The structure of water molecules (left) and Image of permanent dipole (right)



1) When there is no external electric field



2) When there is an external electric field

Direction of dipoles influenced by external electric field

Definition of Dielectric Properties

Dielectric properties can be categorized into two:

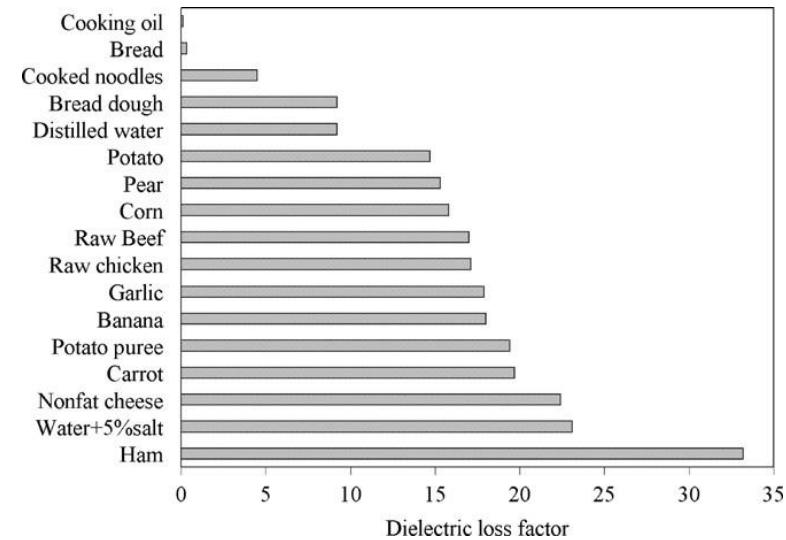
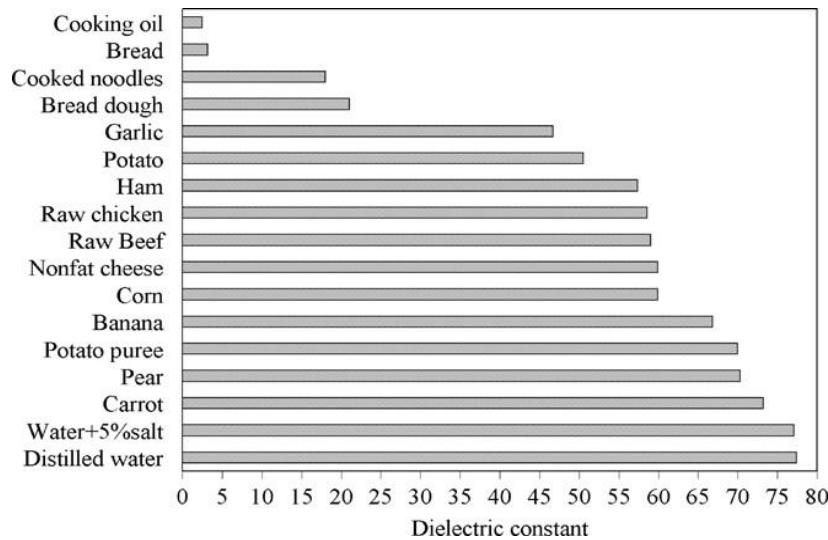
1. Dielectric constant (ϵ) is the ability of a material to store microwave energy
2. Dielectric loss factor (ϵ') is the ability of a material to dissipate microwave energy into heat. The parameter that measures microwave absorptivity is the loss factor.

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 :

$$Q = 2 \pi f \epsilon_0 \epsilon' E^2$$

f is the frequency, ϵ_0 is the dielectric constant of free space ($8.854 \times 10^{-12} F/m$), ϵ' is the dielectric loss factor, and E is the electric field (v/m or Newton/coulomb).



Dielectric constant of various food materials at 25°C.

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

Dielectric properties of cooking oil are very low because of its nonpolar characteristic. Dielectric properties of water and high-moisture-containing foods such as fruits, vegetables, and meat are high because of dipolar rotation. The highest loss factor is observed in the case of salt-containing foods such as ham.

As microwaves move through the slab at any point, the rate of 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 penetrate 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 (δ_p), which is defined as the depth at which power density (level) 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
(for 2450 MHz, $\lambda_0 = 122$ mm).

Wavelength, frequency and velocity of electromagnetic waves are related by $\lambda = v / f$, where, λ is wavelength, m; f is frequency in Hz; v is velocity of light, 3×10^8 m/s.

$$\lambda_{915} = 3 \times 10^8 \text{ (m/s)} / 915 \times 10^6 \text{ (1/s)} = 0.328 \text{ m}$$

$$\lambda_{2450} = 3 \times 10^8 \text{ (m/s)} / 2450 \times 10^6 \text{ (1/s)} = 0.122 \text{ m}$$

The microwave power absorbed by the dielectric

In the applicator, a vessel with liquid 'w' [g] (at initial temperature T_1 , [$^{\circ}\text{C}$]) is irradiated at microwave power P_A [W] for t [s]. Then, the liquid becomes T_2 [$^{\circ}\text{C}$]. And, the specific heat of the liquid is C [J / $\text{kg} \cdot \text{K}$]. Then, microwave power [W] absorbed by the liquid is given by P_B . And, the heating efficiency is given in %.

For example, when the liquid is water, by using the specific heat of water 4180 [J / $\text{kg} \cdot \text{K}$], absorbed microwave power of water can be calculated.

$$P_B = \frac{w \cdot C \cdot (T_2 - T_1)}{t} \quad \eta = 100 \cdot (P_B / P_A) \quad [\%]$$

When complex permittivity is drawn as a simple vector diagram, the real and imaginary components are 90° out of phase. The vector sum forms an angle ' δ ' with the real axis (ϵ). The relative "lossiness" of a material is the ratio of the energy lost to the energy stored. The loss tangent or $\tan \delta$ is defined as the ratio of the imaginary part of the dielectric constant to the real part. **D denotes dissipation factor and Q is quality factor.** The loss tangent $\tan \delta$ is called, **tangent loss or dissipation factor.** Sometimes the term "quality factor or Q-factor" is used with respect to an electronic microwave material, which is the reciprocal of the loss tangent. For very low loss materials, since $\tan \delta \approx \delta$, the loss tangent can be expressed in angle units, milliradians or microradians.

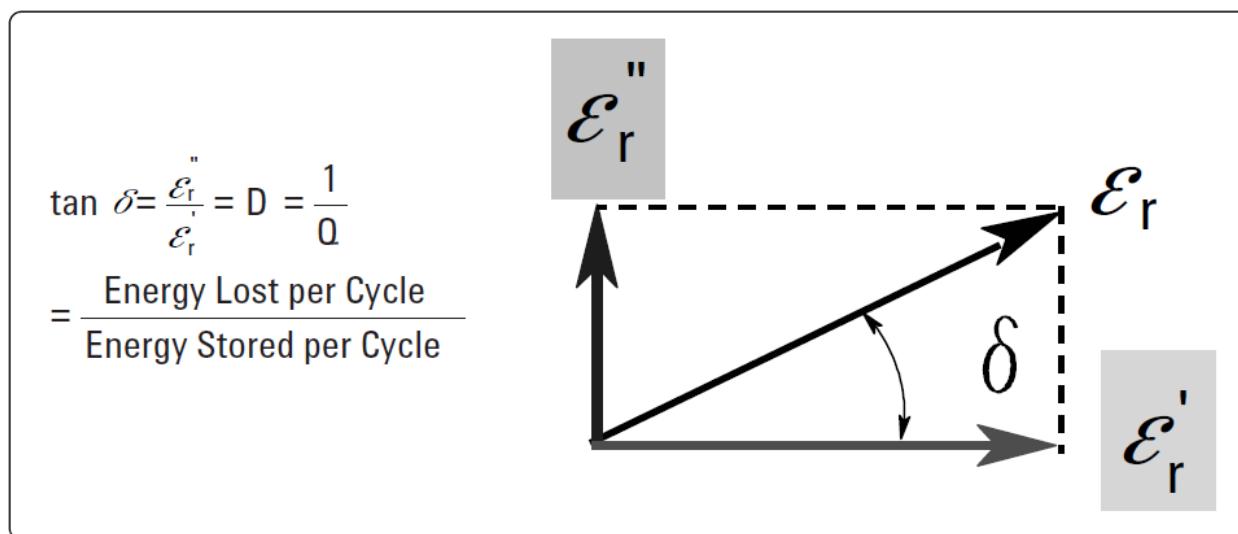


Figure 3. Loss tangent vector diagram

Factors affecting Dielectric Properties

1. Moisture Content: 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. There is a critical moisture content below which loss factor is not affected significantly with moisture content . Dielectric properties of foods decrease during drying, since free moisture content in the system decreases. The rate of variation of dielectric properties depends on the ratio of bound to free moisture content.

2. Temperature: Since dielectric loss and dielectric constant are temperature dependent, thus the dissipation factor (loss parameters of microwave applications) will increase with temperature.

3. Composition of Foods:

*Salt Solutions,
Carbohydrate,
fat,
protein*

THANK YOU