Heat Treatment

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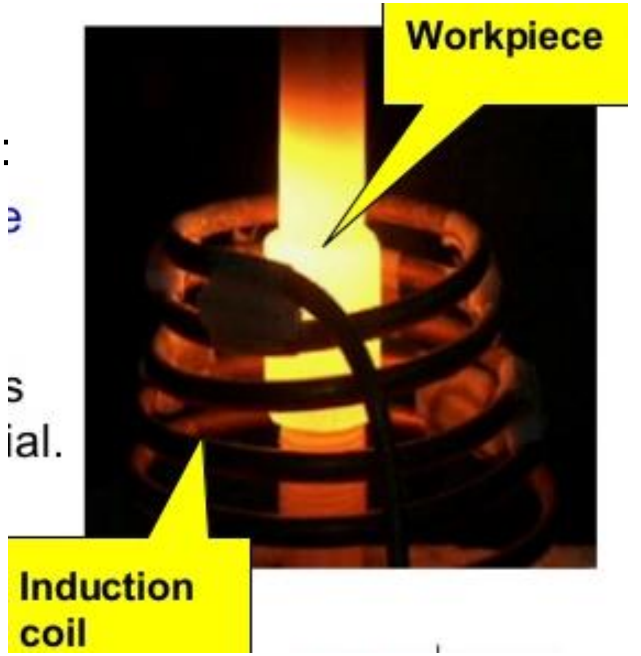
Lecture Contents

1. **What is heat?**
2. **What is the measuring unit of heat?**
3. **What is Heat Transfer?**
4. **What is Electric Heating?**
5. **Power frequency heating**
6. **High frequency heating**
7. **Dielectric heating (Dipole rotation)**
8. **Comparison between Conventional and Microwave Heating**
9. **Industrial Heat treatment**

6. High Frequency Heating

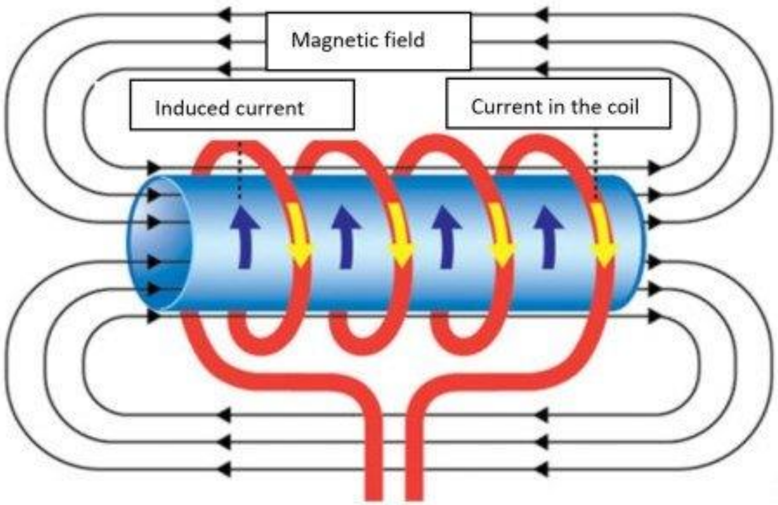
High frequency heating can be classified into two types: induction heating and dielectric heating .

(1) Induction Heating: Induction heating can be classified into two types: direct induction heating and indirect induction heating.



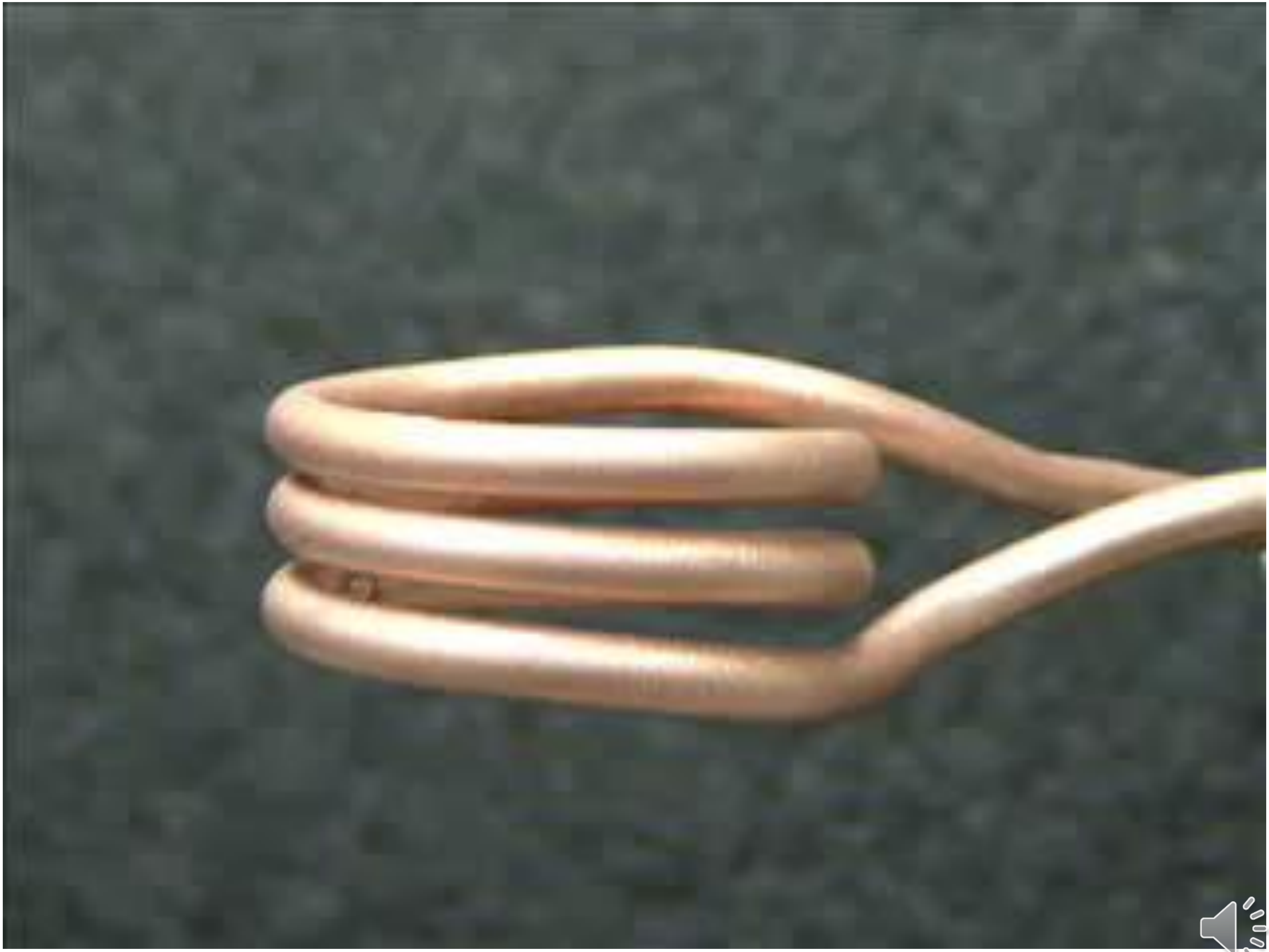
(a) Direct Induction Heating

This method is based on **electro-magnetic induction.** **The currents are induced in the body to be heated by electro-magnetic induction.** When a power supply sends an electrical current through a copper coil, **electromagnetic field is created within the coil.** When a metal to be heated is placed within the induction coil and enters the magnetic field, **circulating eddy currents تيار عكسي** are induced within the metal-part (to be heated). **These eddy currents flow against the electrical resistivity of the metal, generating precise and localized heat without any direct contact between the metal-part and the coil.**



Applications:

- heat treatment of metals by eddy current heaters.
- used in furnaces.

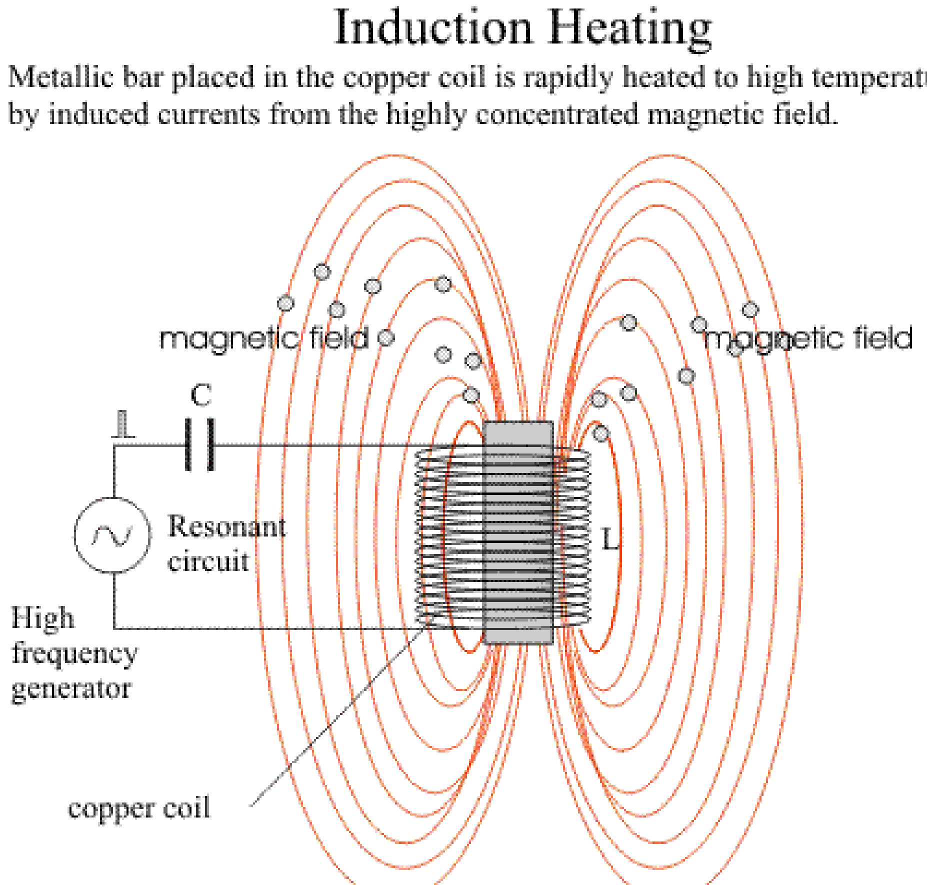


Video 4: Induction heating (Click to play)

(b) Indirect Induction Heating

This method is also based on **electro-magnetic induction.** The currents are induced in the heating element by **electro-magnetic induction**. These currents cause the heating element to heat up. The heat developed in the heating **element is transferred to the body to be heated by convection or radiation.**

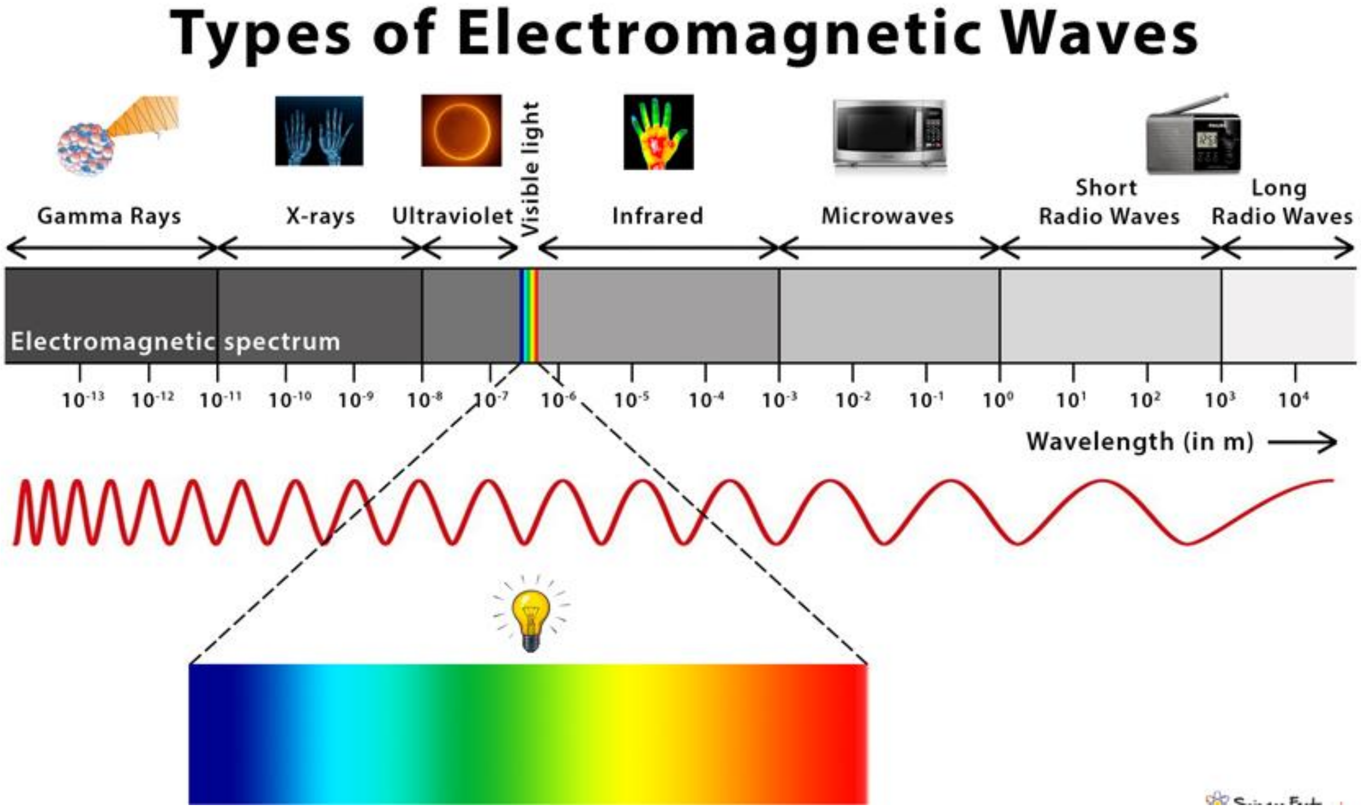
Applications: heat treatment of metals by induction oven



(2) Dielectric Heating

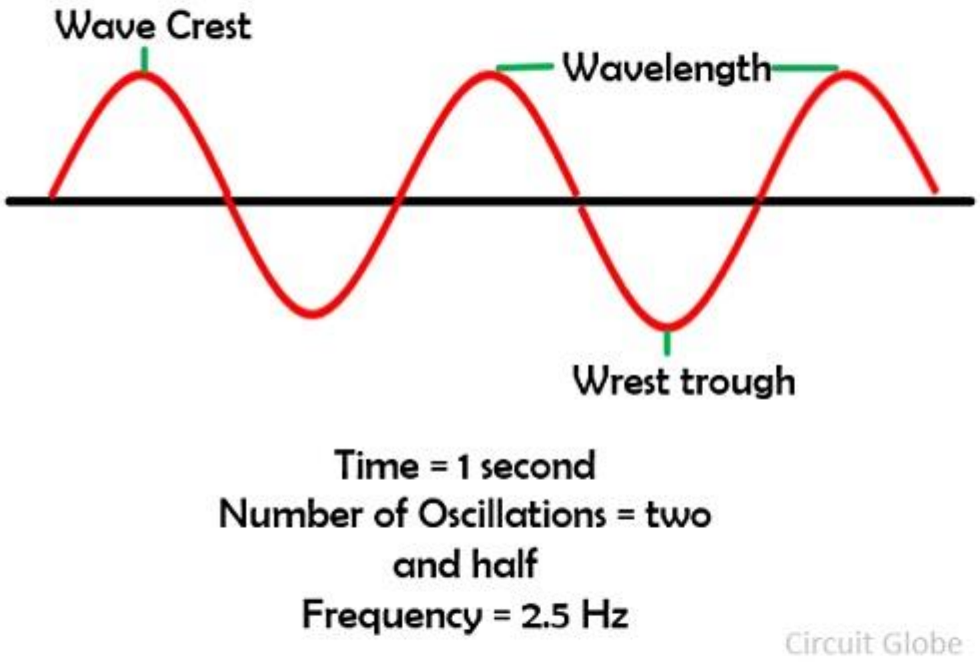
Dielectric heating - also known as electronic, radio frequency, and high-frequency heating - is the process in which a radio frequency (RF) alternating electric field, or **radio wave** or **microwave electromagnetic radiation heats a dielectric material**.

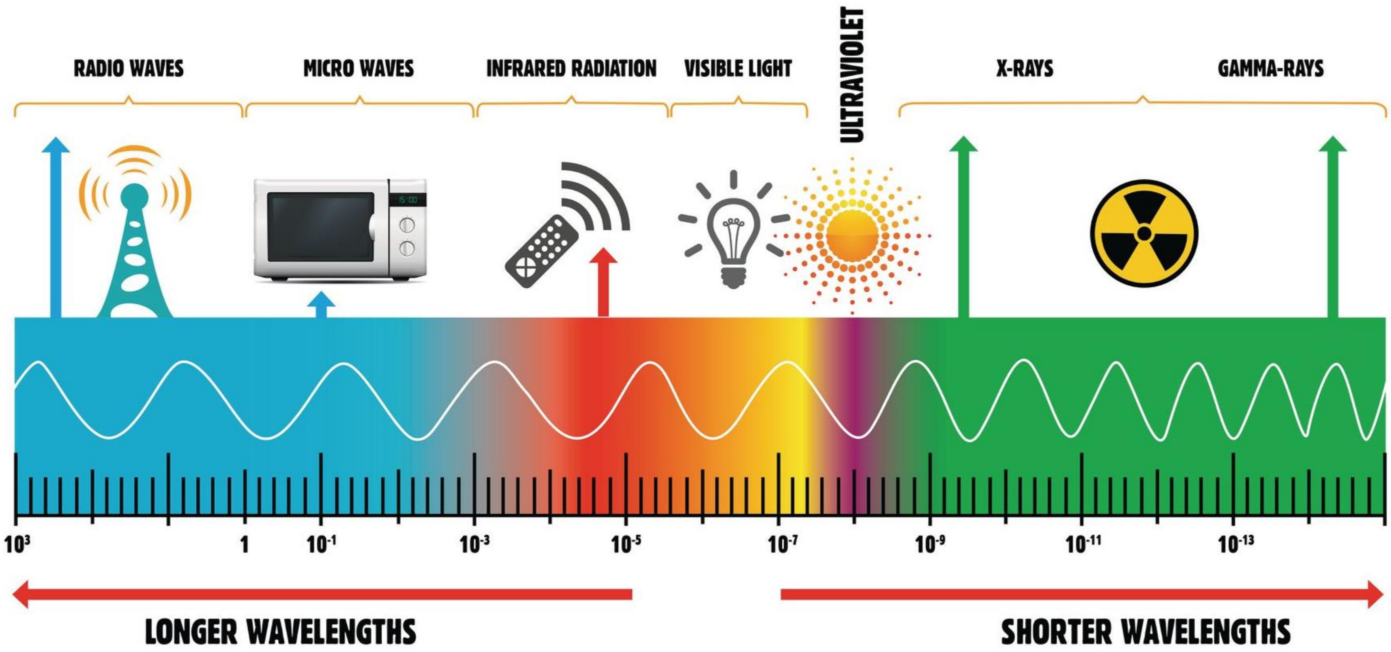
At higher frequencies, this heating is caused by **molecular dipole rotation** within the **dielectric material**. A microwave oven uses dielectric heating to cook food.



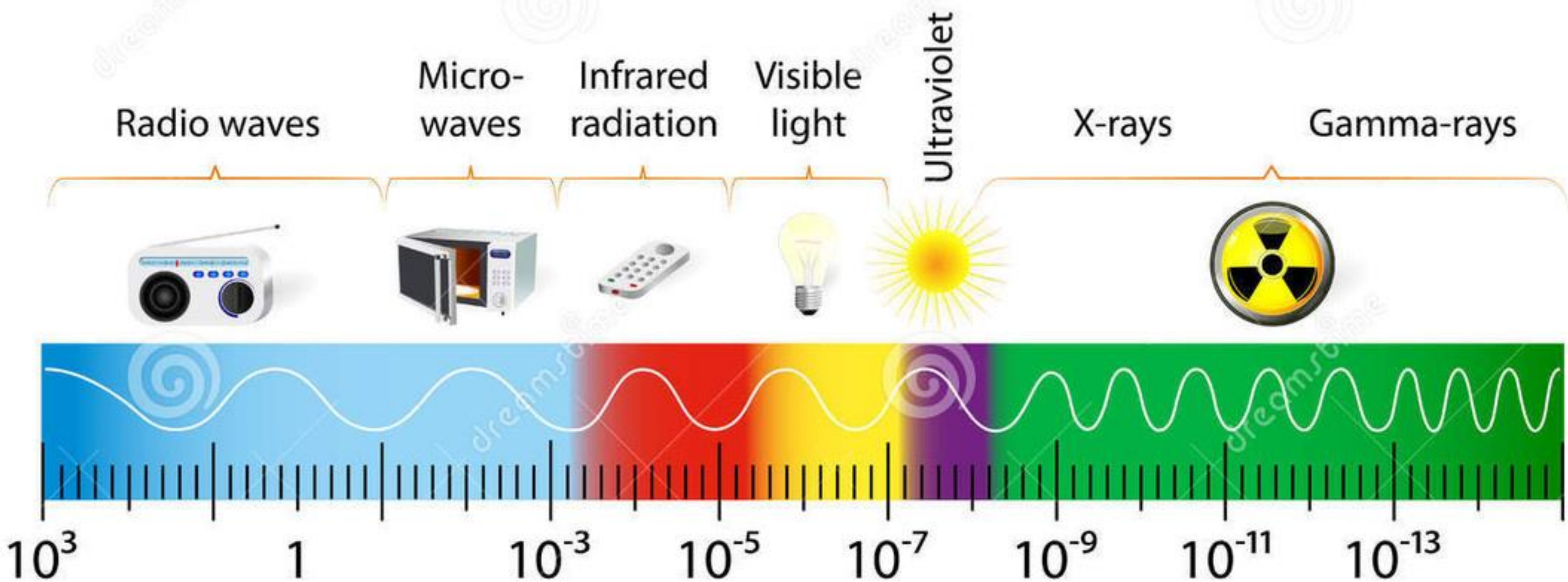
What is wave frequency?

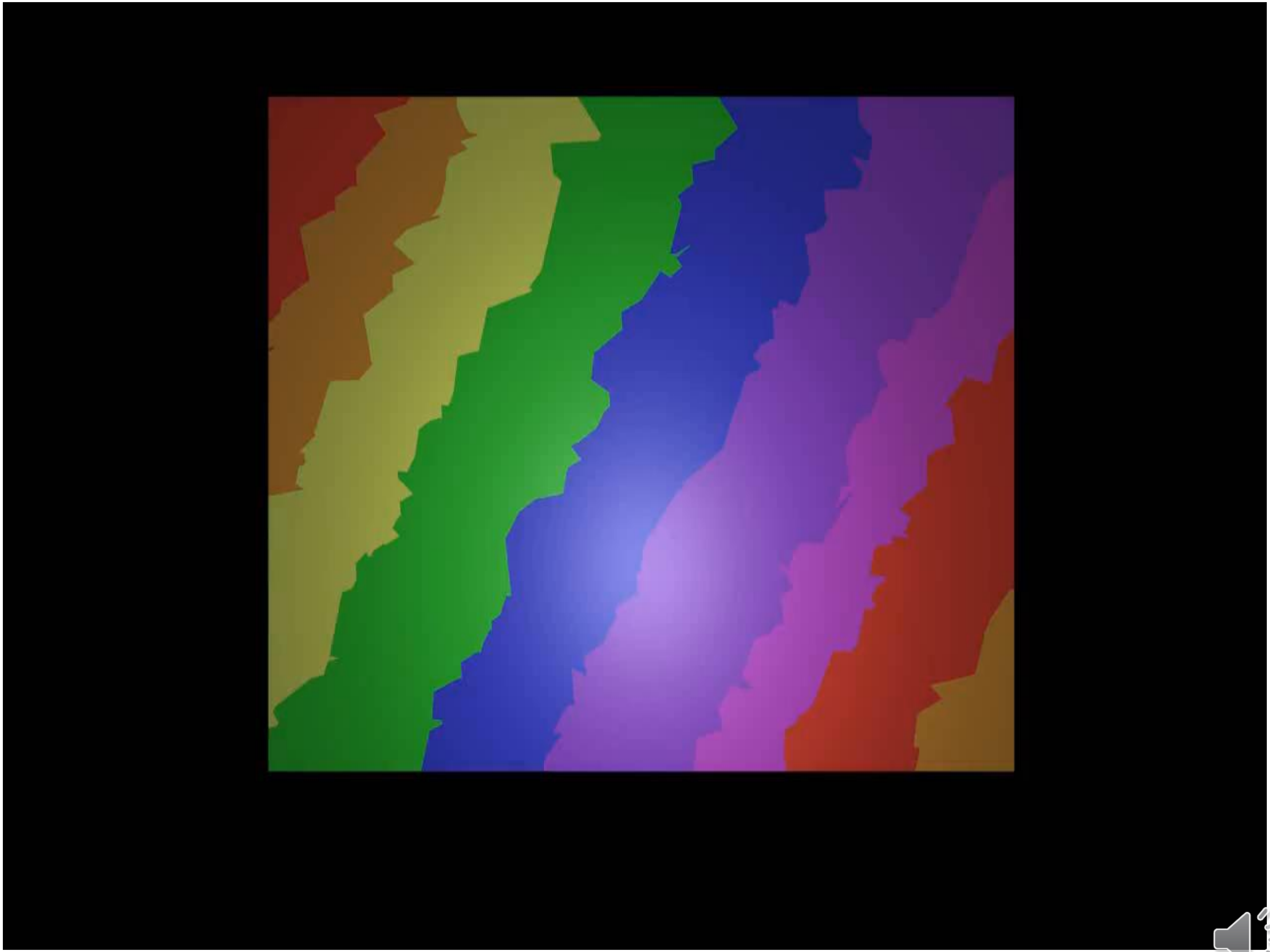
Wave frequency is the number of **waves** that pass a fixed point in a given amount of time. The SI unit for **wave frequency** is the **hertz (Hz)**, where 1 hertz equals 1 **wave** passing a fixed point in 1 second. A higher-**frequency wave** has more energy than a lower-**frequency wave** with the same amplitude.





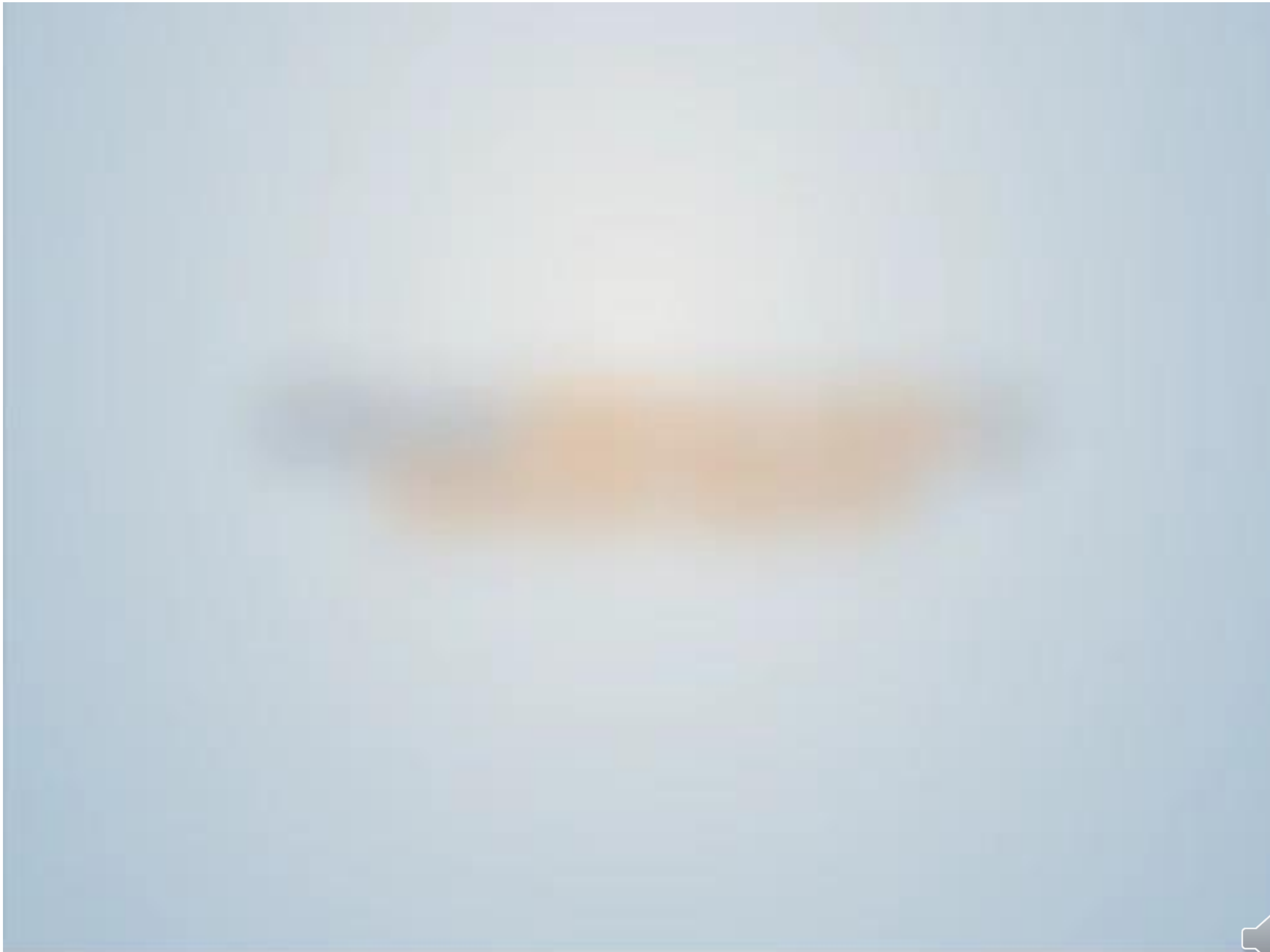
THE ELECTROMAGNETIC SPECTRUM





Video 5: Electromagnetic radiation (Click to play)

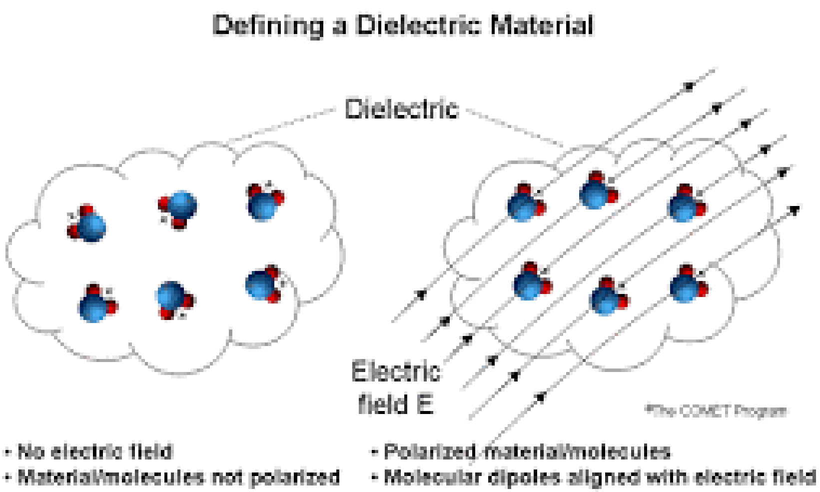
Video 6: Spectroscopy (Click to play)



Video 7: Molecular spectra (Click to play)

What does dielectric mean?

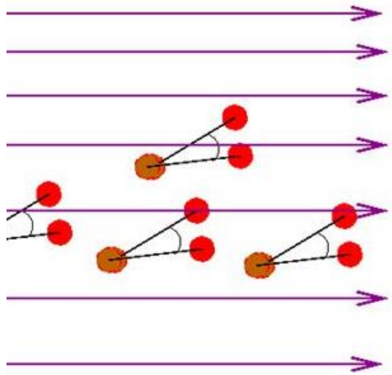
A **dielectric material** is a substance that is of **poor conductivity to electricity, i.e., insulator**. Unlike metals, dielectric material has no loosely bound or free electrons that may move inside the material. **Instead of electron movement, electric polarization occurs for the material molecules.**



Dielectric Materials

• Many molecules and crystals have a non-zero Electric dipole moment.

• When placed in an external electric field these align with external field.



• The effect is to reduce the strength of the electric field within the material.

• To incorporate this, we define a new vector Field, the electric displacement, $\vec{D}$

What Is Dielectric Material ?

- **Insulating materials are also termed as dielectrics. The difference in the name between dielectric and insulator lies in the application to which these materials are put.**
- **When these materials are used to prevent flow of electricity through them on the application of potential difference, then they are called insulators or passive dielectrics.**
- **On the other hand, if they are used for charge storage then they are called dielectrics or active dielectrics.**

DIELECTRIC MATERIALS

Mica: is the widely used insulating material in switch gears armature windings, electrical heating devices like iron, hot plates etc. It is also used in capacitors for high frequency application. Mica is an inorganic compound of silicates of aluminium, soda potash and magnesia. It is crystalline in nature and can be easily split into very thin flat sheets. The two important types of mica are: (i) muscovite and (ii) phlogopite. Mica has a good dielectric strength and mechanical strength. Its dielectric constant varies between 5 and 7.5, loss tangent between 0.0003 and 0.015 and dielectric strength between 700 and 1000 kV/mm.

Asbestos: is also used as an insulator in the form of paper, tape, cloth and board. Asbestos is widely used in panel boards, insulating tubes and cylinders in the construction of air cooled transformers. Asbestos is an inorganic material, which is used to designate a group of naturally occurring fibre material. Asbestos has good dielectric and mechanical properties.

Ceramics: are generally non-metallic inorganic compounds, e.g. silicates, aluminates, oxides, carbides, borides, nitrides and hydroxides. Ceramics used as dielectrics may be broadly described as alumina, porcelains, ceramics, titanates, etc. These have excellent dielectric and mechanical properties. The dielectric constant of most commonly used ceramics varies between 4 and 10. These are used in switches in plug holders, thermocouples, cathode heaters, vacuum type ceramic metal seals etc. Ceramic capacitors may be operated at high temperatures and can be moulded into any shape and size.

Electric grade ceramics are used for the manufacturing of insulators, terminal blocks, plates, frames, coils, etc. They must have low losses, good insulating properties and high strength.

What does the dielectric constant tell us?

The **dielectric constant** is a measure of **the amount of electric potential energy to be stored as induced polarization in a given volume of material** under the action of an electric field. It is expressed as the ratio of the dielectric permittivity of the material to that of a vacuum or dry air.

What is Permittivity?

The ability of a material to be polarized and store charge within it.

What is meant by dielectric property?

Dielectric properties of materials are defined as a molecular property that are capable of **impending electron movement resulting in polarization** within the material on exposure to an external electric field.

What does dielectric loss mean?

Dielectric loss is the dissipation of energy through the movement of charges in an alternating electromagnetic field as polarization switches direction.

What is the dielectric strength?

The maximum electric field that can be maintained by a dielectric material (insulating) without a breakdown (conducting).

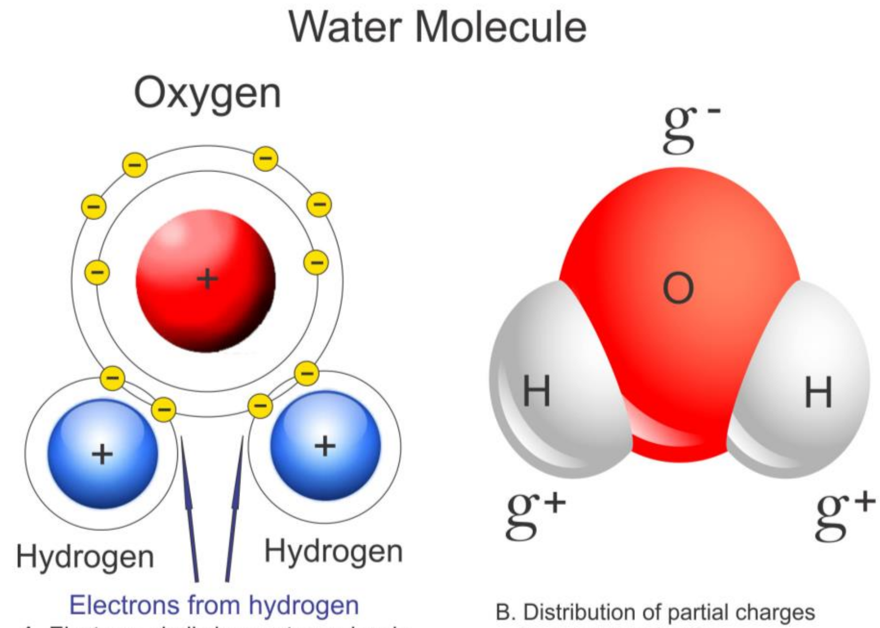
Dielectric Constant
VS
Permittivity

Comparison Chart

Dielectric Constant	Permittivity
The dielectric constant is the ratio of permittivity of the dielectric in use to the permittivity of a vacuum.	Permittivity is the ability of a material to store an electric field in the polarization of the medium.
It refers to the relative permittivity of a dielectric material which holds the ability to collect and store energy in the form of electrical charge.	Permittivity is a constant of proportionality exists between the electric displacement and electric field intensity.
It has no unit or dimension as it's a relative measure of ratio of two similar quantities.	The permittivity of a dielectric material is measured in Farad per meter (F/m or F.m-1).

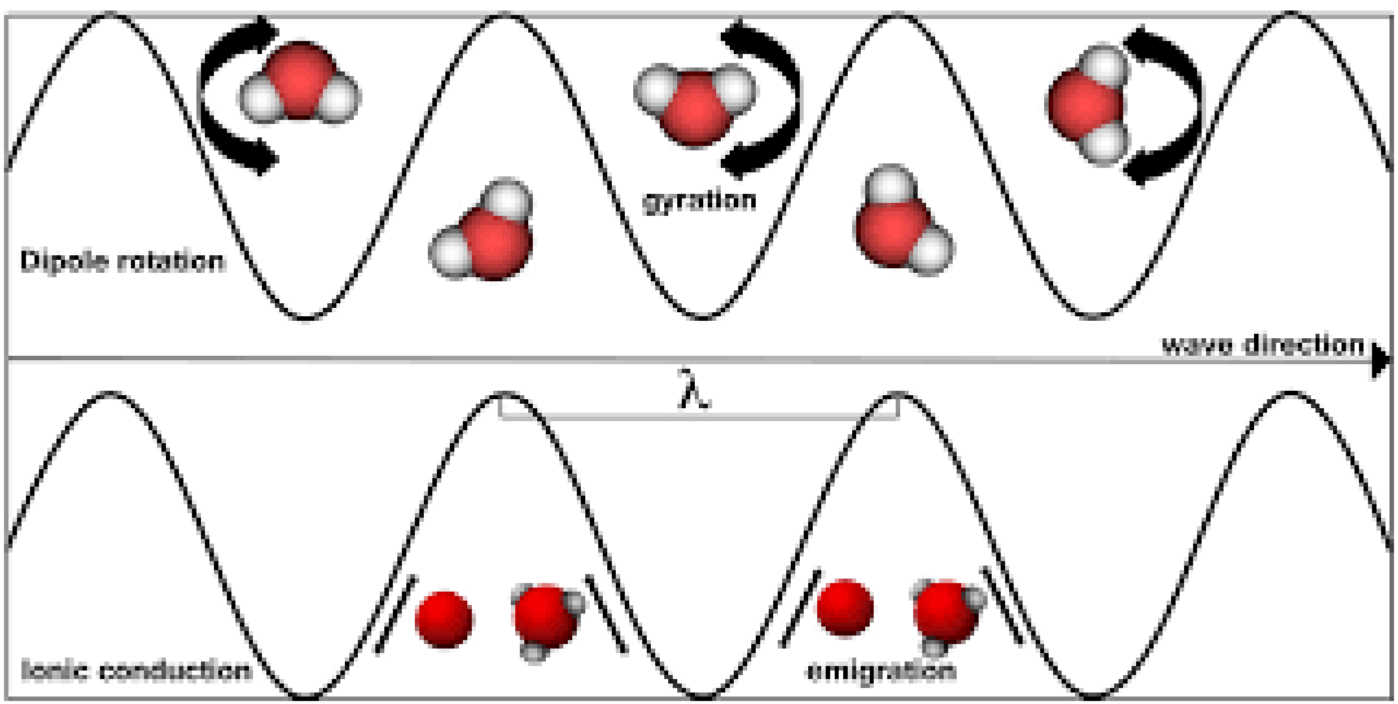
7. Dielectric heating (Dipole rotation)

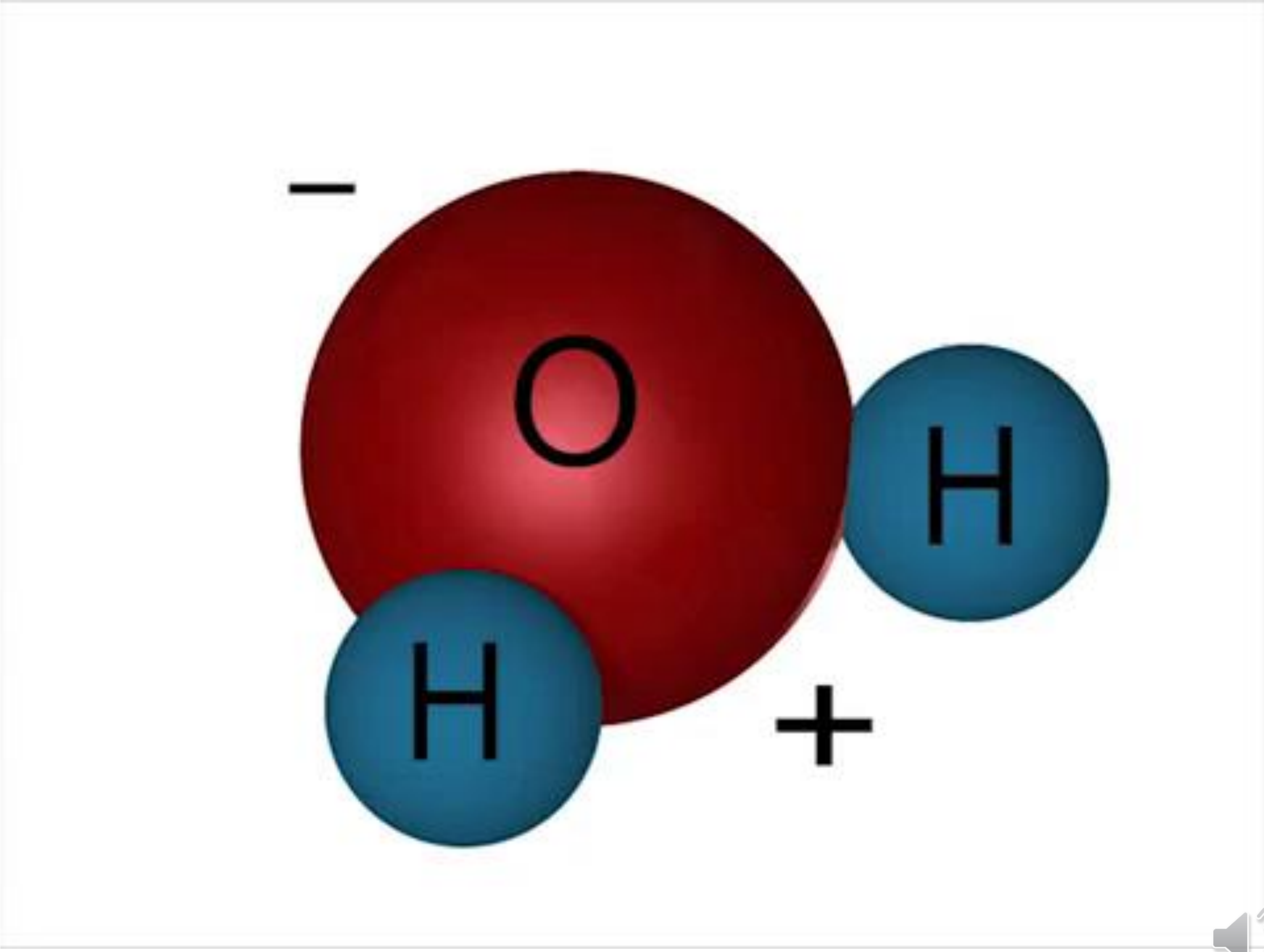
Molecular rotation occurs in materials **containing polar molecules having an electrical dipole moment, with the consequence that they will align themselves in an electromagnetic field.** If the field is oscillating, as it is in an **electromagnetic wave (like microwave)** or **in a rapidly oscillating electric field, these molecules rotate continuously by aligning with it (microwave or electrical field).** This is called **dipole rotation**, or **dipolar polarization**.



A. Electrons shells in a water molecule

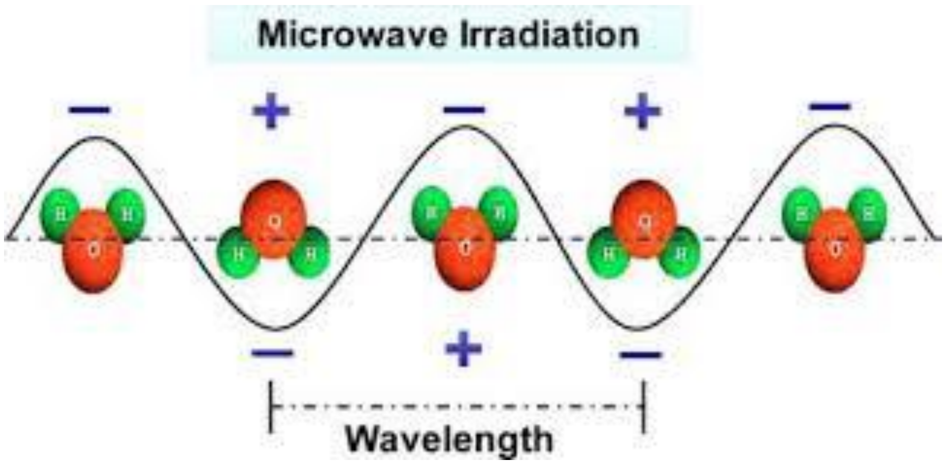
B. Distribution of partial charges in a water molecule



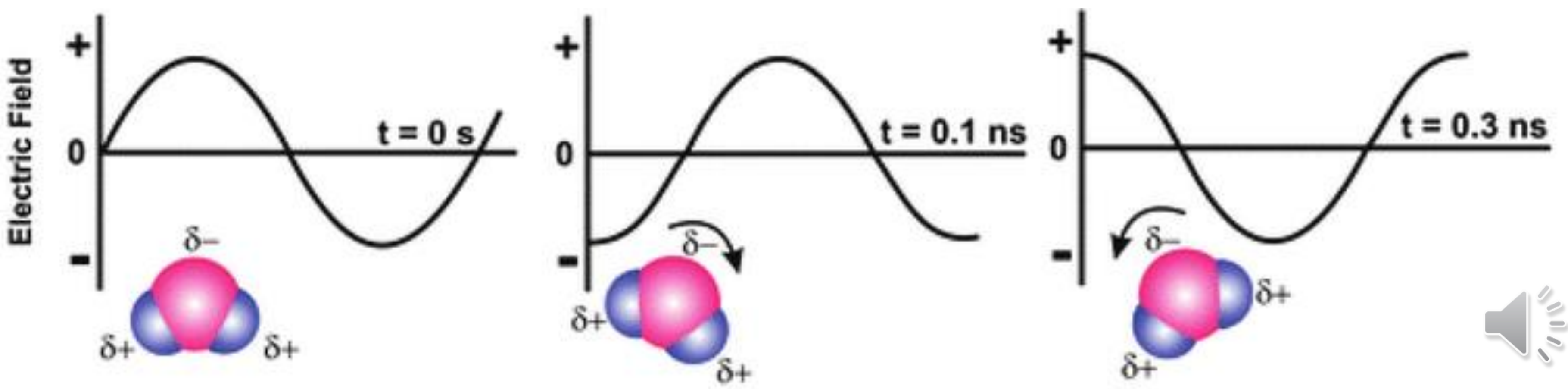


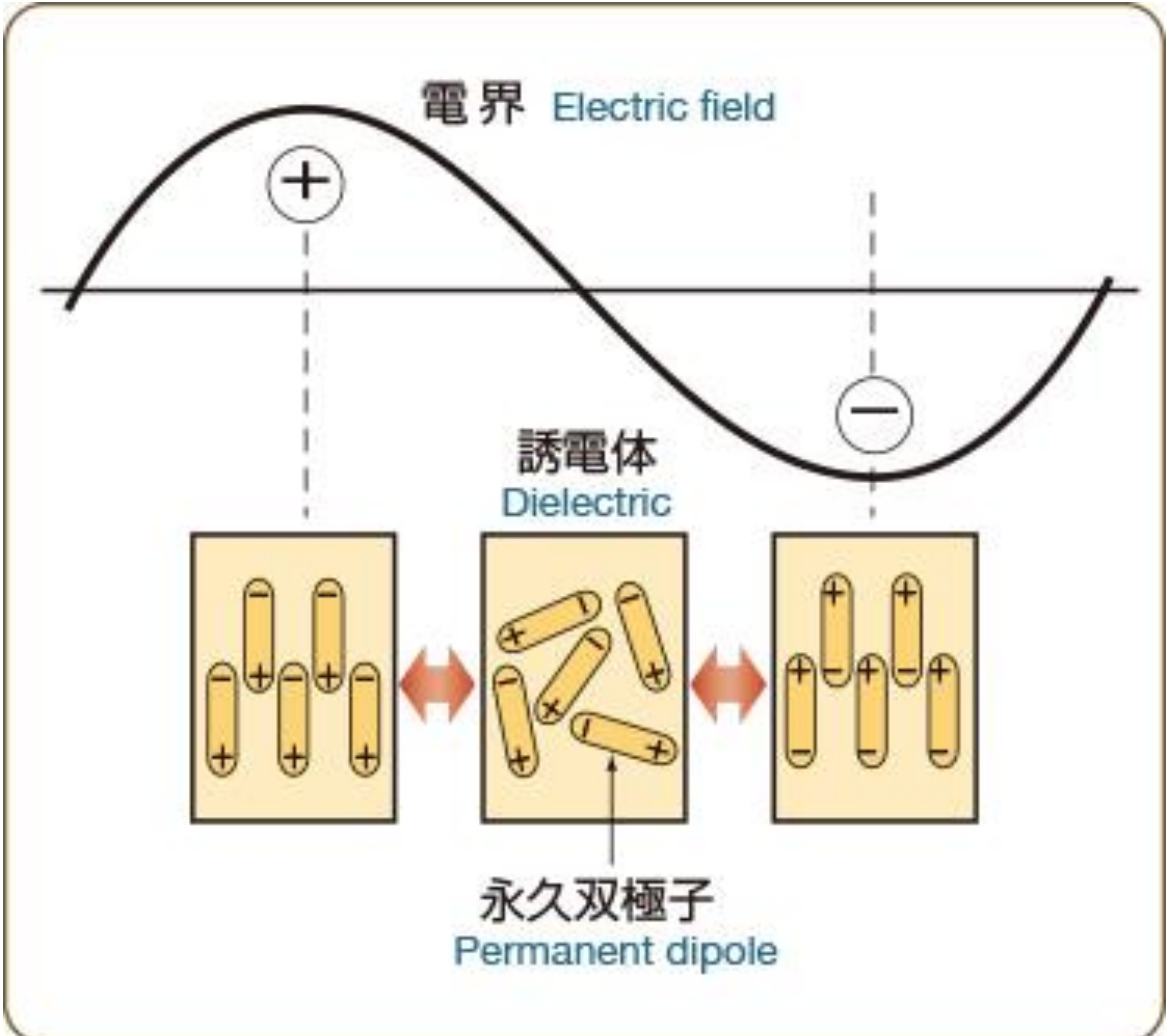
Video 8: Polarity of water molecule (Click to play)

As the electrical field alternates, the molecules reverse direction. **Rotating molecules push, pull, and collide with other molecules** (through electrical forces or microwave), **distributing the energy to adjacent molecules and atoms in the material**. This consequently is associated with the conversion of material molecules **kinetic energy/energy of motion into heat and the increase of the material temperature.** Thus, **dipole rotation** is a mechanism by which energy in the form of **electromagnetic radiation (microwave)** **can raise the temperature of an object.**



Dipole rotation is the mechanism normally referred to as **dielectric heating** and is most widely observable in the **microwave oven** where it operates **most effectively on liquid water**, and also, but much less on fats and sugars. **This is because fats and sugar molecules are far less polar than water molecules.**

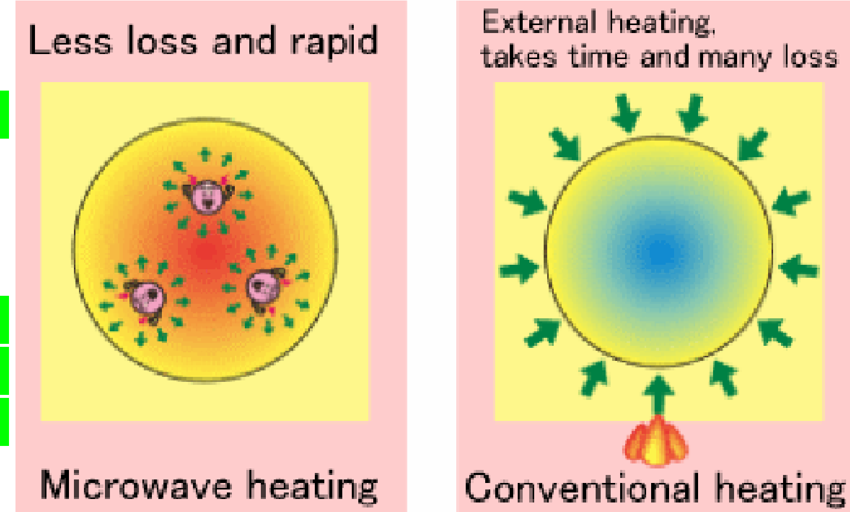



電界 Electric field
誘電体
Dielectric
永久双極子
Permanent dipole

Video 9: Polarity of water molecule

Microwave heating

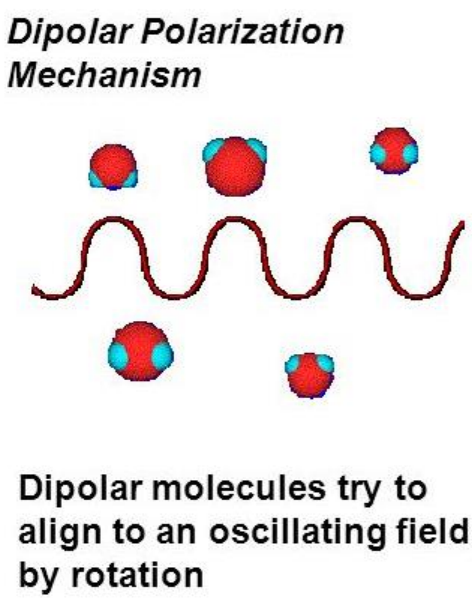
Microwave heating, **is a sub-category of dielectric heating** at frequencies above 100 MHz, where an electromagnetic wave can be launched from a small dimension emitter and guided through space/air to the target. Typical domestic microwave ovens operate at 2.45 GHz, but 915 MHz ovens also exist. In general, the microwave **wavelengths** are bracketed between 1mm **(more penetrative)** to 1m **(less penetrative).**

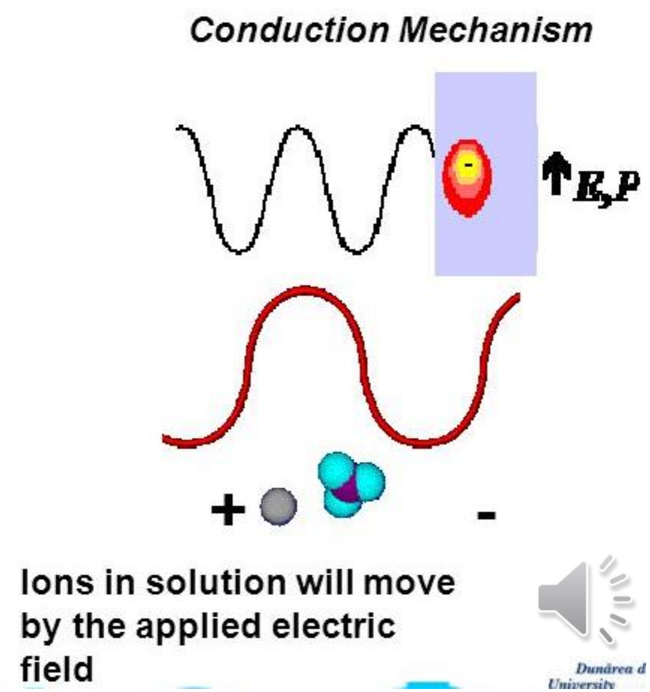


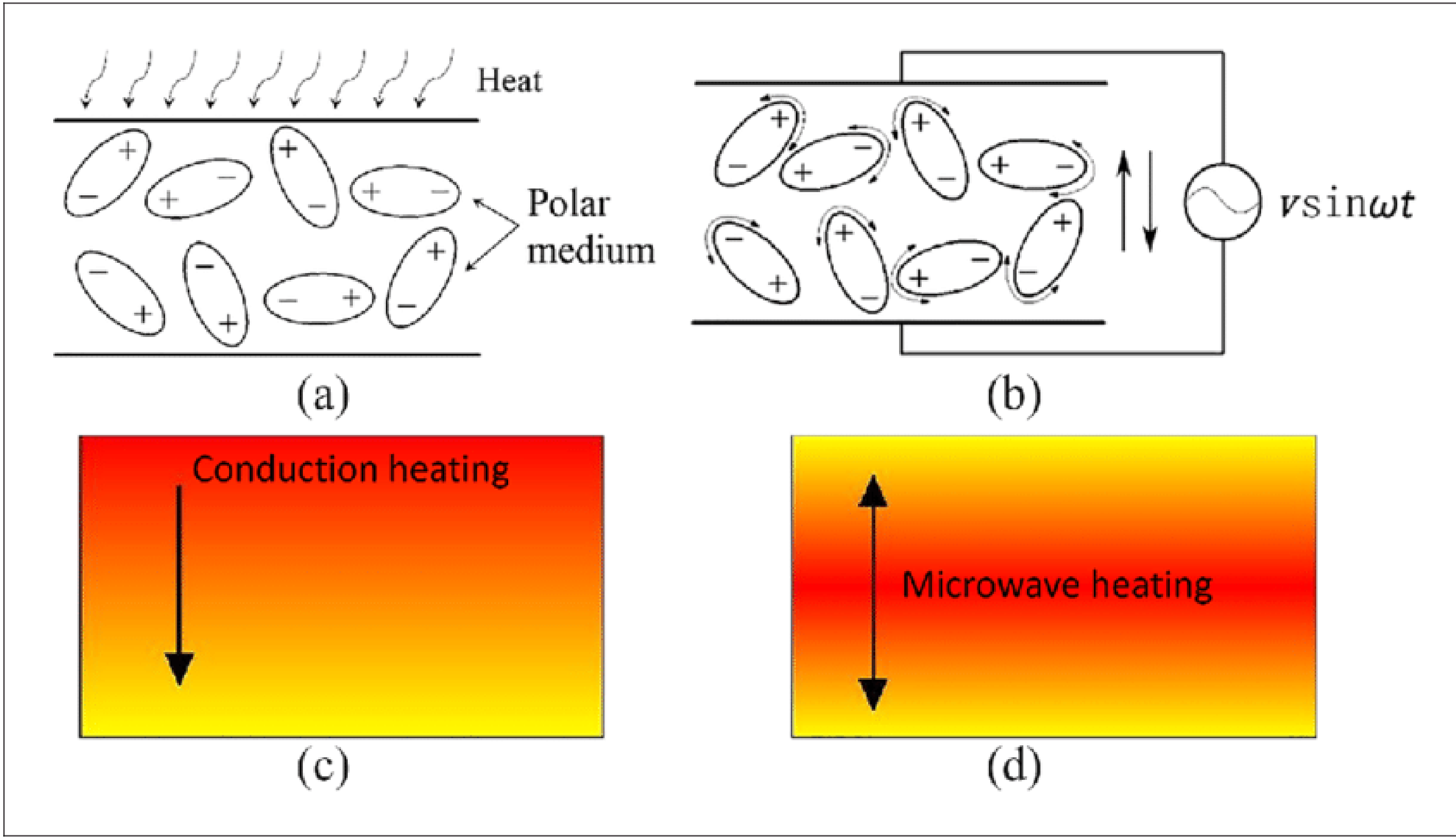
The **microwave absorption** is done by the material to be heated in a non-contact process due to the **material molecules dipole rotation**. The **microwave absorption** is related to the material loss tangent. **The higher the loss tangent, the higher is the microwave absorption.**

Application for industrial microwave heating:

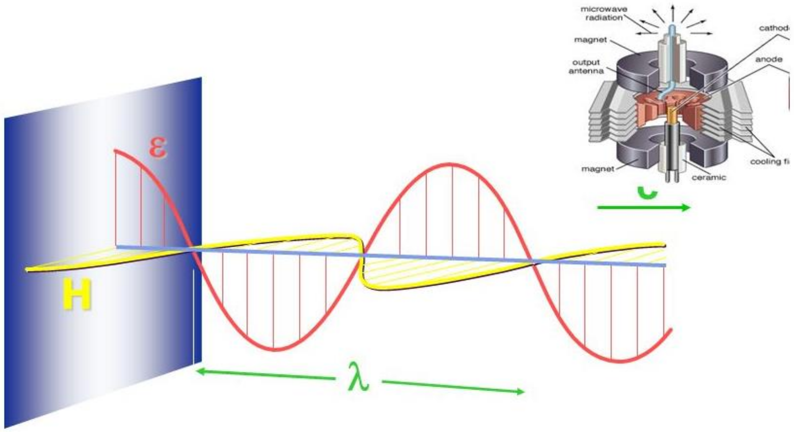
1. Pasteurization
2. Flash pasteurization
3. Microwave chemistry
4. Sterilization
5. Food preservation
6. Biofuel production






Heat
Polar medium
vsinωt
(a)
(b)
Conduction heating
Microwave heating
(c)
(d)

Theory of microwave heating



Microwaves are electromagnetic radiations

Microwaves are not ionising radiation

Microwaves energy is largely below the energy necessary to break the bonds of common organic molecules

Energy

Microwaves radiation (2.450 MHz) quantum energy (eV)

0,0016

Chemical bond energy (eV)	
H-OH	5,2
CH3-CH3	3,8
Hydrogen bond (water)	0,21

Wavelengths range from 1mm to 1m

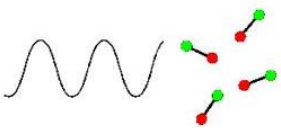
Frequency allowed for commercial, medical and scientific applications:

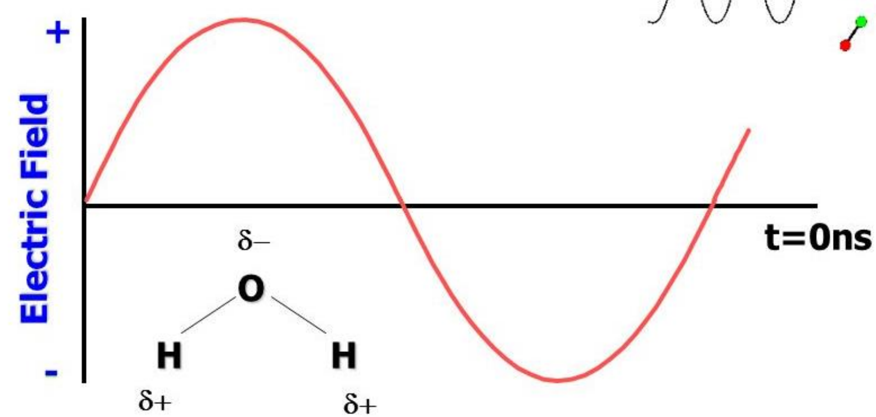
2,450 MHz (12.2 cm wavelength)

Heating is caused by

- Dipole rotation
- Ionic migration

Dipole rotation





Loss of energy in form of heat

Interaction Microwave/Materials

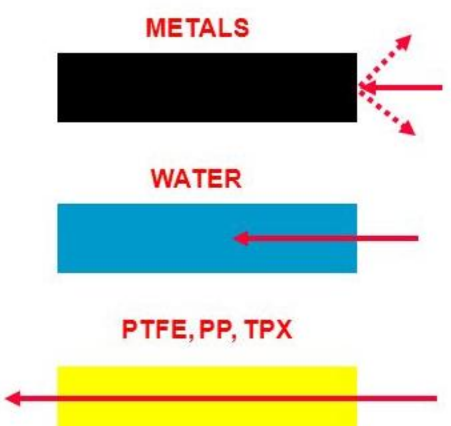
The three parameters of the microwaves:

- **Dielectric constant e'** (polarizing level of a molecule in an electromagnetic field)
- **Dielectric loss e"** (efficiency of the microwave conversion in heat)
- **Tangent loss δ** (material capability of absorbing microwaves = e"/e')

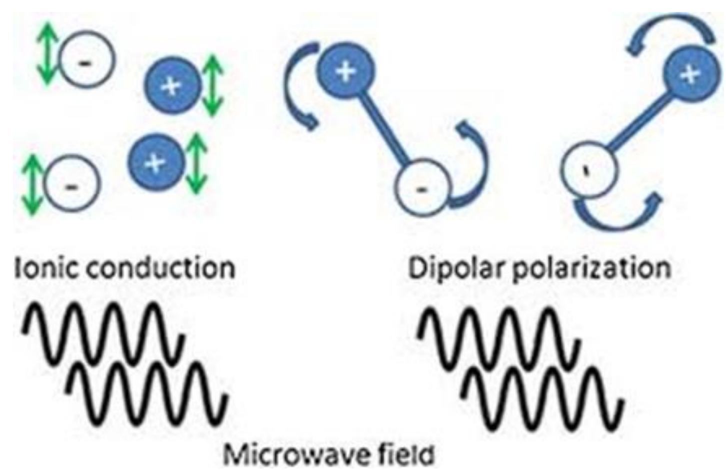
Material	Temperature (°C)	Loss tangent (x10-4)
Water	25	1570
Fused quartz	25	0,6
Ceramic F-66	25	5,5
Porcelain No 4462	25	11
Phosphate glass	25	46
Borosilicate glass	25	10,6
Corning glass No 0080	25	126
Plexiglass	27	57
Nylon 6-6	25	128
Polyethylene	25	3,1
Polystyrene	25	3,3
Teflon PFA	25	1,5

The higher the loss tangent of a material, the higher its ability to absorb microwave. The loss tangent is always dependent on the temperature

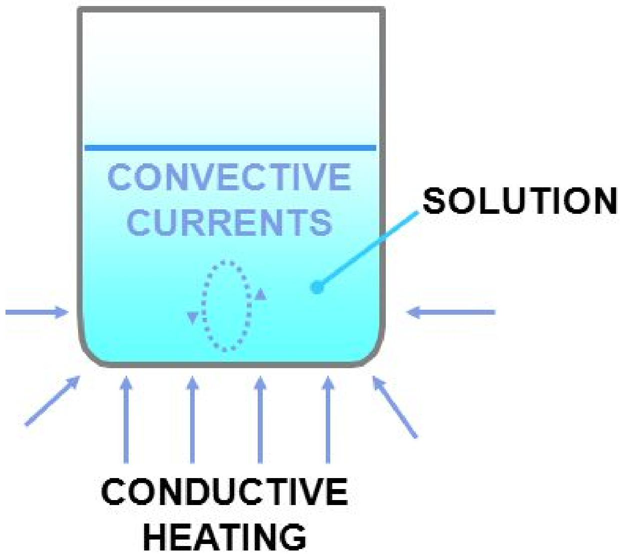
Interaction of materials with microwaves



- Reflective
- Absorptive
- Transparent to Microwaves

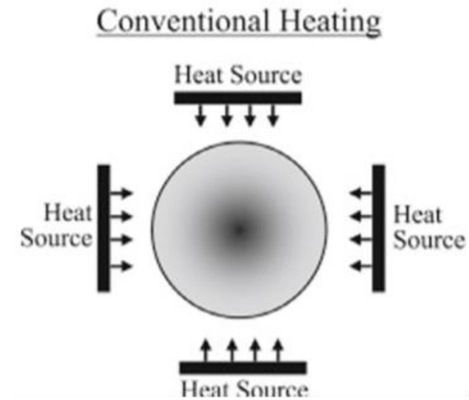


Conventional Heating

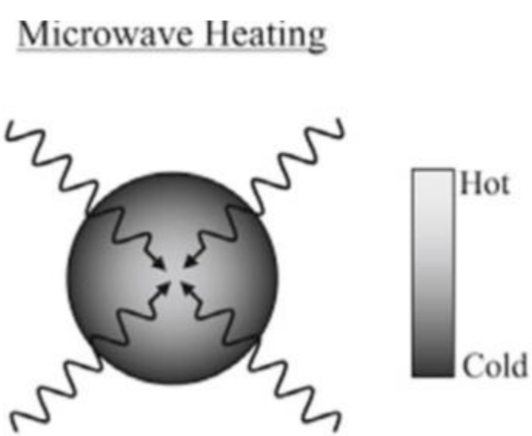


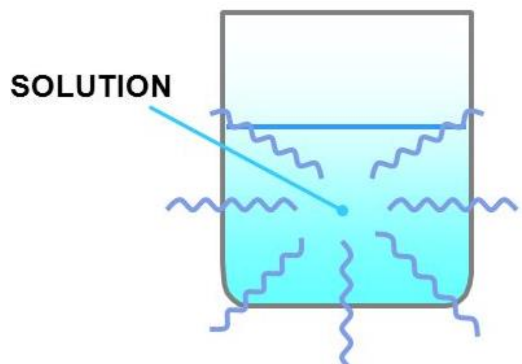
The temperature of the outside surface of the vessel is in excess of the boiling point of the solution

Container is heated first then the solution.



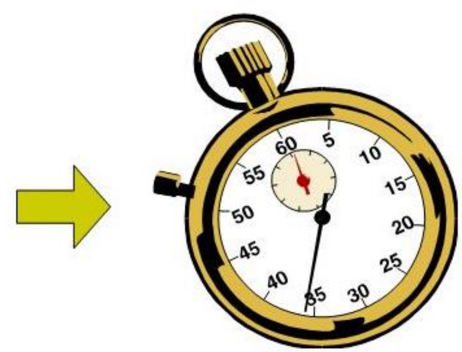
Microwave heating





MICROWAVE HEATING

Solution is heated first

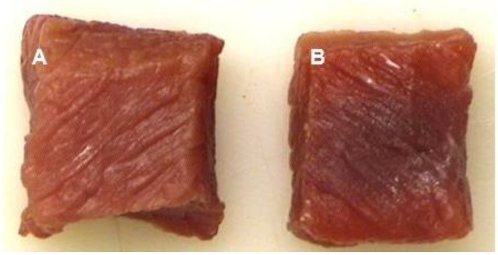


Shorter Reaction Times

Microwave effect

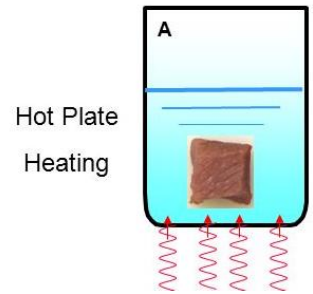
This is an experimental proof

Fresh sample of animal's muscle were sectioned in two mirror blocks (Fig.1 A-B), approximately 8cm3 each (20x20x20mm)

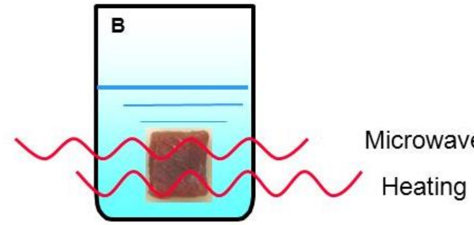


Microwave effect

Place a beaker containing 100ml ethanol on an electronic controlled hot plate. Set the temperature at 70°C. When temperature is reached immerse the specimen A in this solution for 5 minutes.

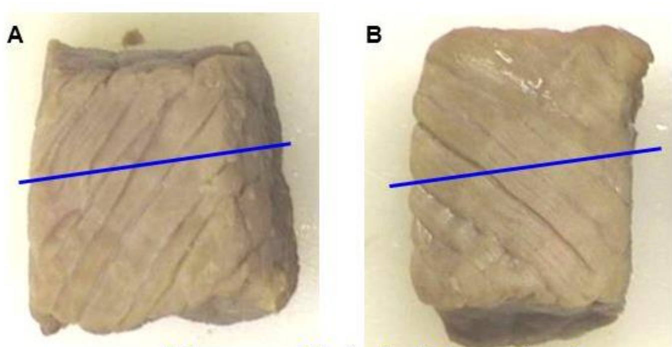


Place a beaker containing 100ml Ethanol in an laboratory RHS type microwave tissue processor. Set the temperature at 70°C. When the temperature is reached immerse the specimen B in this solution for 5 minutes.



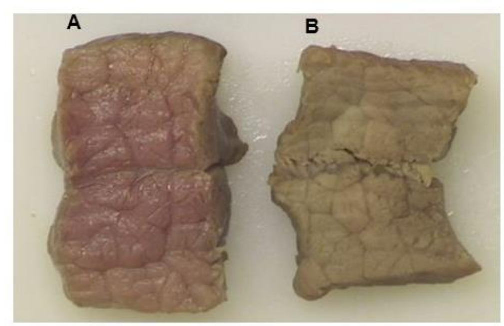
Microwave effect

After 5 minutes samples were removed from respective solution



...and immediately bisected

Microwave effect

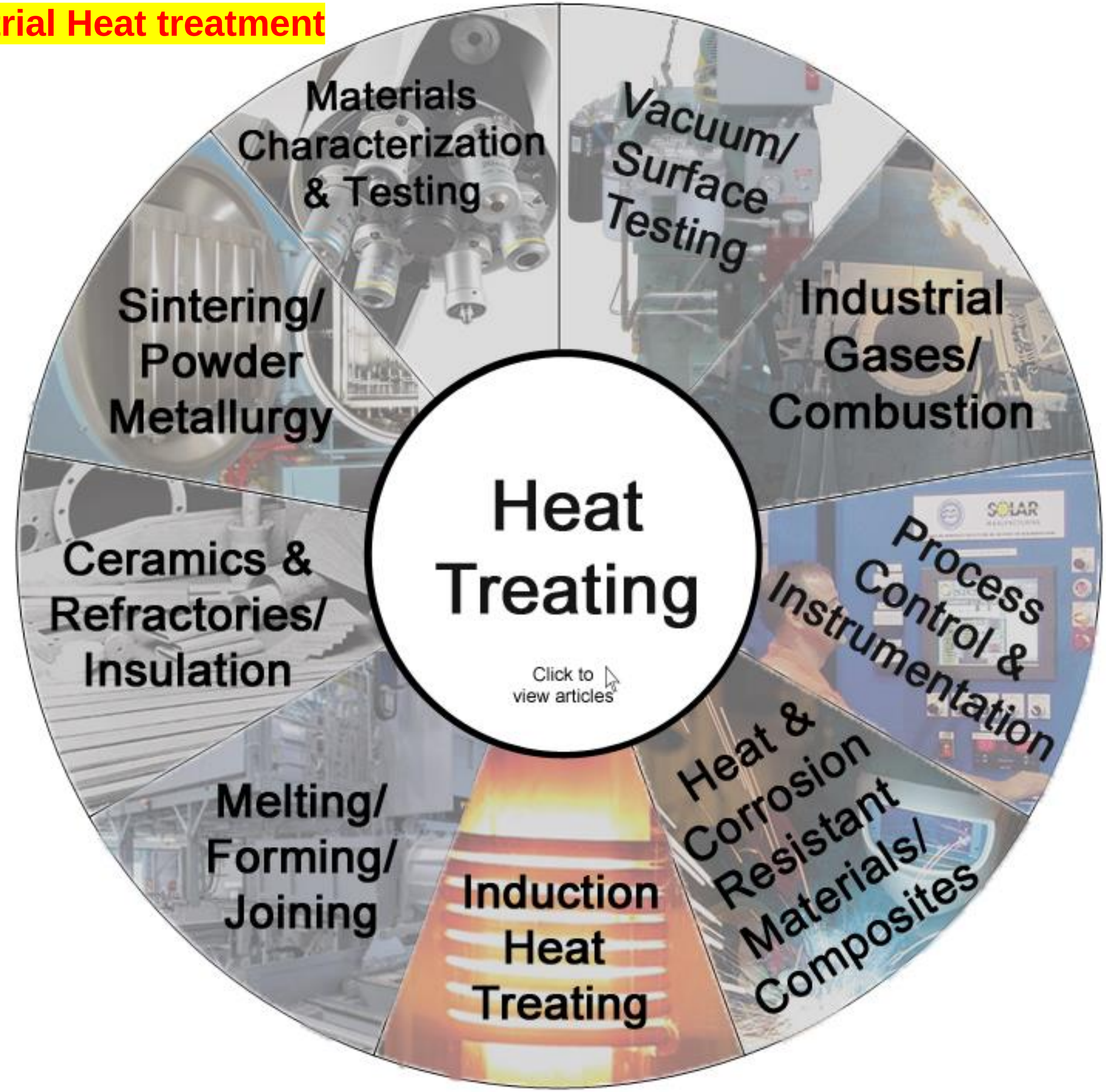


RESISTANCE HEATING	MICROWAVE HEATING
Slight hardening in the outer part only	Complete hardening in the total area
no sign of alcohol penetration and dehydration in the internal area.	the MW stimulated enhanced diffusion of alcohol into the inner area
The specimen was still soft	complete dehydration/hardening is indicated by the color change

8. Comparison between Conventional and Microwave Heating

CONVENTIONAL HEATING	MICROWAVE HEATING
Heat is applied from the outside and gradually penetrates the surface of the material to heat or dry via thermal conduction.	Microwave energy penetrates deeper into the body of the material, generating heat and enabling targeted heating of specific elements.
• Slow to heat large volumes and difficult to control	• Rapid heating and precise control
• Lengthy processing times require significant amounts of energy	• Reduced processing times require less energy
• Typically a batch process with limited production flexibility	• Can be used in a continuous process to enable just-in-time production
• Occupies a large plant footprint with limited scope for distributed manufacture	• Smaller plant footprint offers opportunity for remote location
• Generally powered by natural gas or other fossil fuels	• Powered by electricity, so renewable energy sources can be exploited

9. Industrial Heat treatment



End of Lecture