



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**
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7. **Mechanism of microwave heating (dielectric heating)**
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1. What is Heat?

Heat is energy to be transferred to or from a thermodynamic system without transfer of matter.

How 'Heat' Moves

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Review of past terms:

- Define "Energy":

The ability to do work or cause change.

- What is the basic unit of measure for energy?

Joules.

How 'Heat' Moves

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- Define "Heat":

Heat is the movement of thermal energy from a substance at a higher temperature to another substance at a lower temperature.



2. What is the measuring unit of heat?

The unit of heat is the **joule (J)**. It is also the **energy dissipated as heat when an electric current of one ampere passes through a resistance of one ohm for one second.**

However, in many applied systems, **calorie (Cal)** which is the **amount of energy transfer required to raise the temperature of one gram of pure liquid water by one degree Celsius** is used. Sometimes the kilo-calorie (kcal) is specified as a unit of heat; $1 \text{ kcal} = 1000 \text{ cal}$.

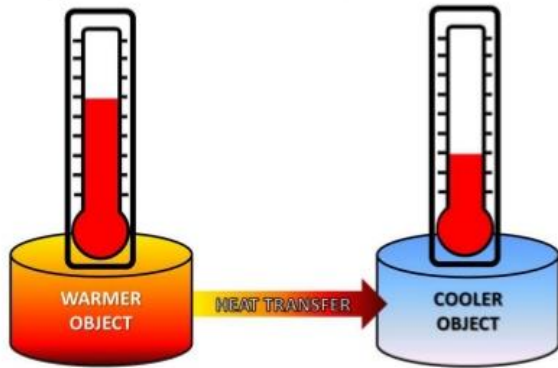
The standard unit for the **rate of heat transferred** is **the watt (W)**, defined as **one joule per second.**



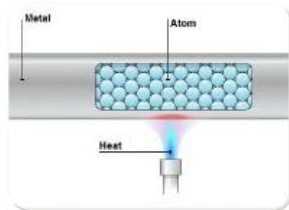
3. What is Heat Transfer?

Heat is transferred from one medium or object to another, or from an energy source to a medium or object. Such energy transfer occurs in three ways: conduction, convection and radiation.

Heat transfer is the transfer of heat energy from one source to another.



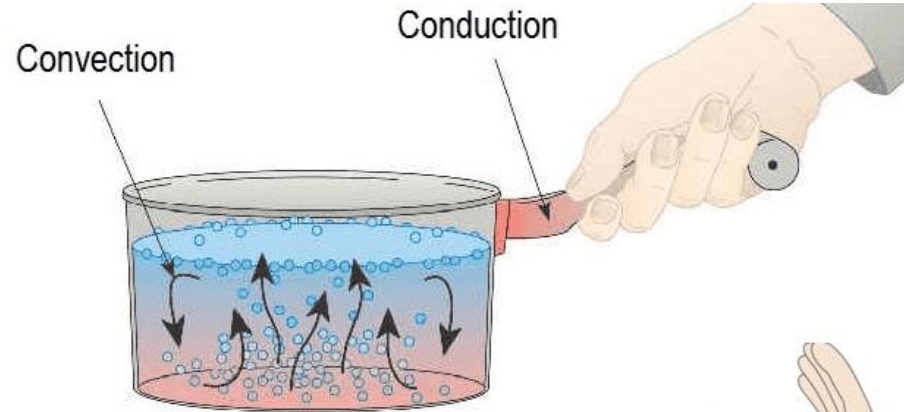
The transfer of heat energy can occur in three primary ways: Conduction, Convection and Radiation



Thermal energy in the form of heat can move in three ways.
Conduction
Convection
Radiation

Heat moves in only one direction:

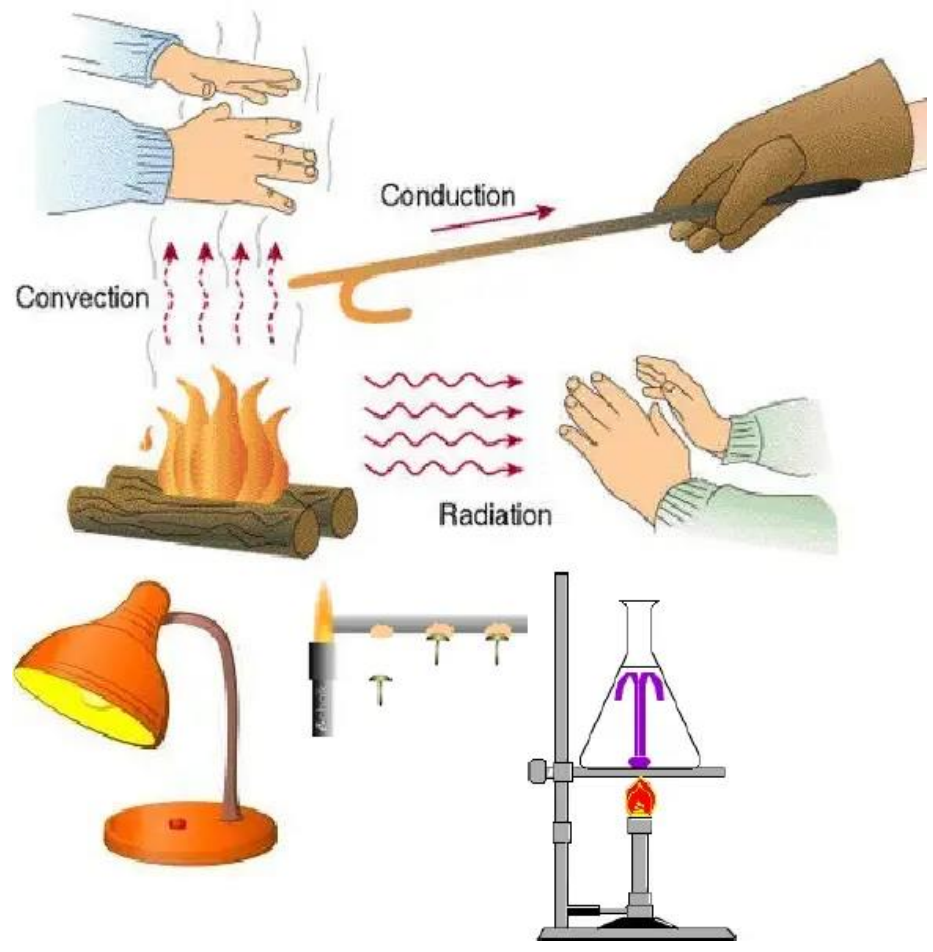
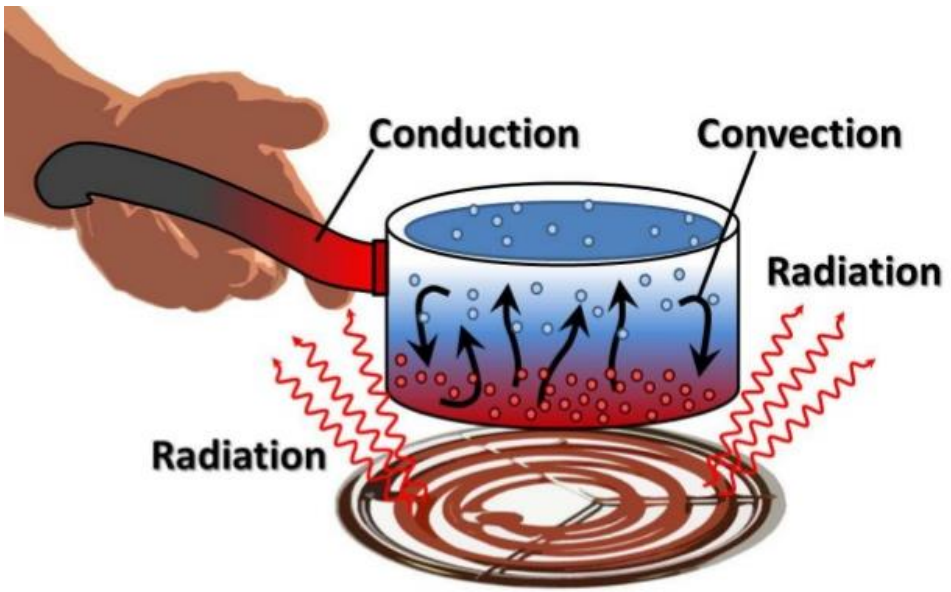
- Under normal conditions and in nature, heat energy will ALWAYS flow the warmer object to the cooler object.
- Heat energy will flow from one substance to another until the two substances have the same temperature.



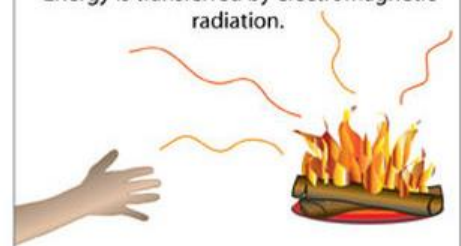


Radiation

$$q = \epsilon\sigma T^4$$





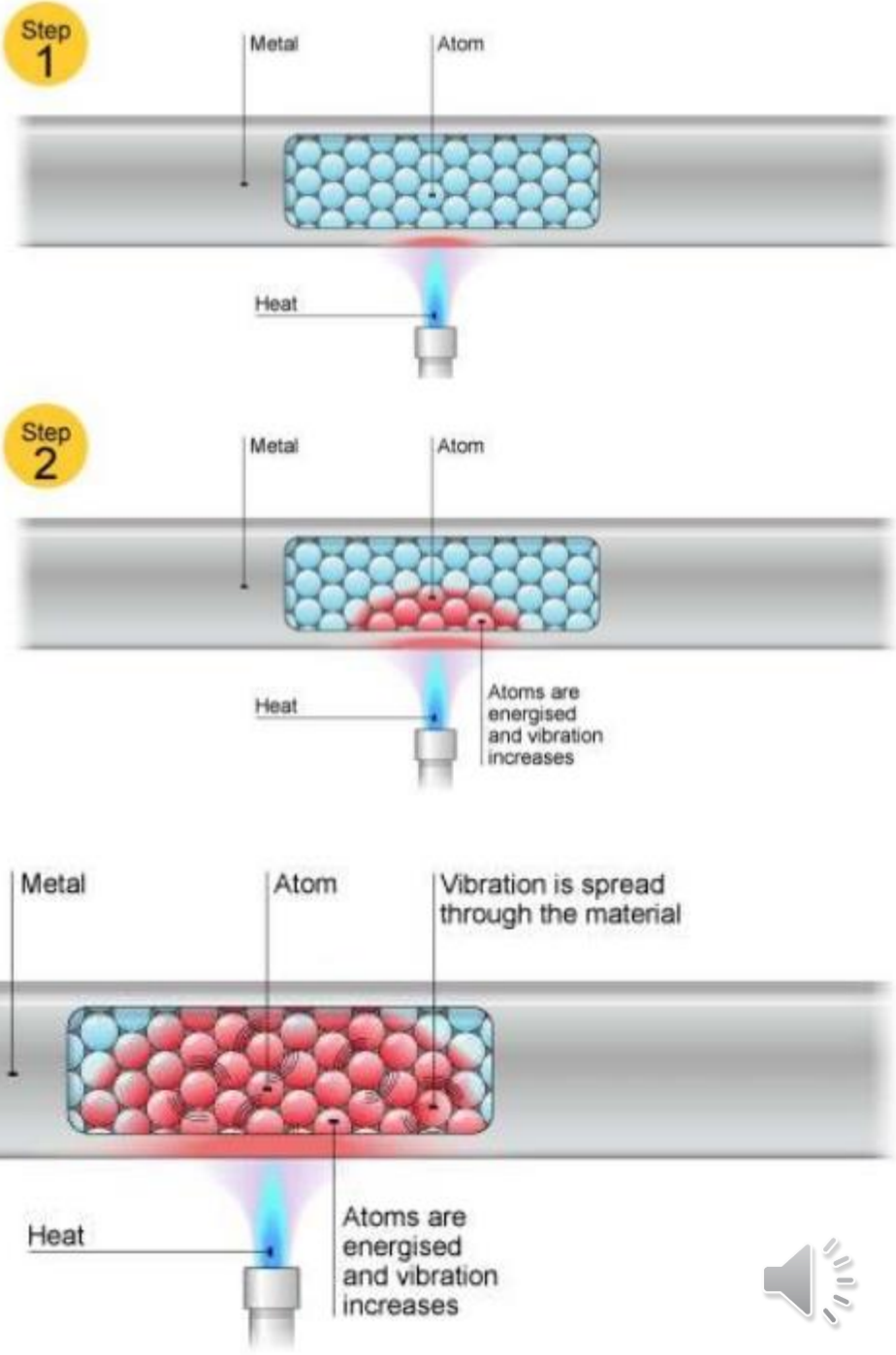
<p>Conduction Energy is transferred by direct contact.</p> 	<p>Convection Energy is transferred by the mass motion of molecules.</p> 
<p>Radiation Energy is transferred by electromagnetic radiation.</p> 	



Heat by Conduction

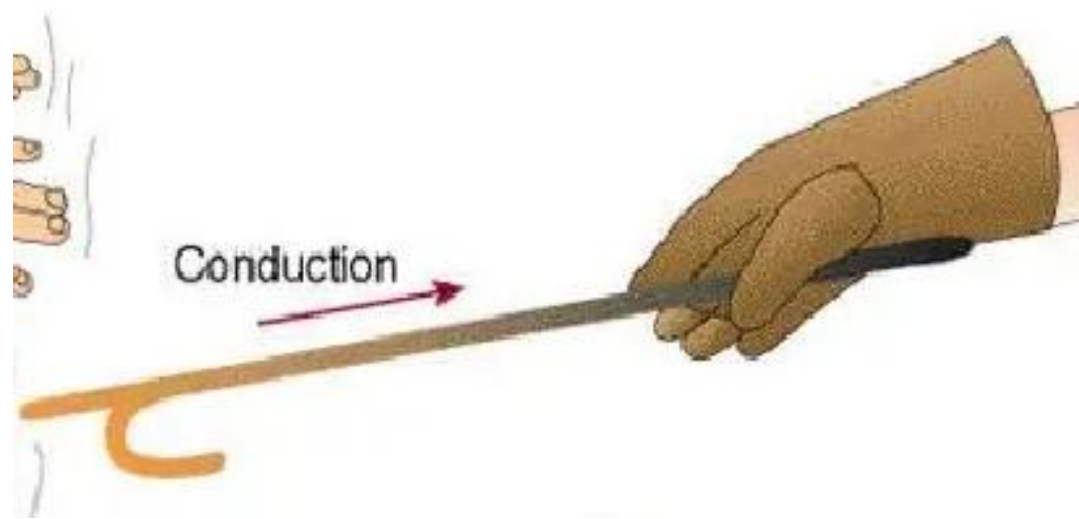
Heat conduction occurs when heat is transferred inside a solid by the collision of atoms from a region of higher temperature to a region of lower temperature. As the atoms collide, they get hotter.

In heat conduction, all movement is happening at an atomic level. When a metal pan is put onto a hob the heat is transferred from the hob through the metal in the bottom of the pan by conduction. Most metals are good conductors, but some metals are more conductive than others.



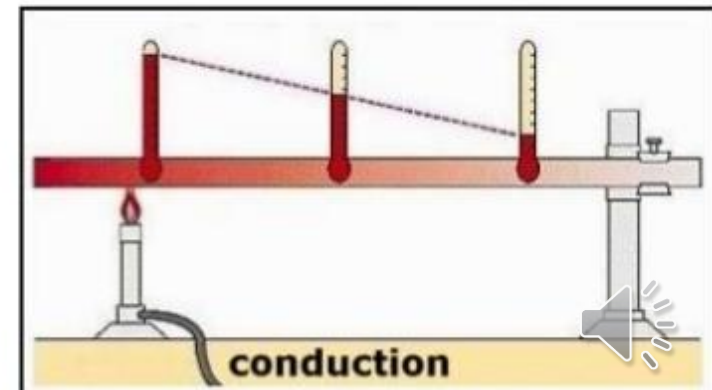
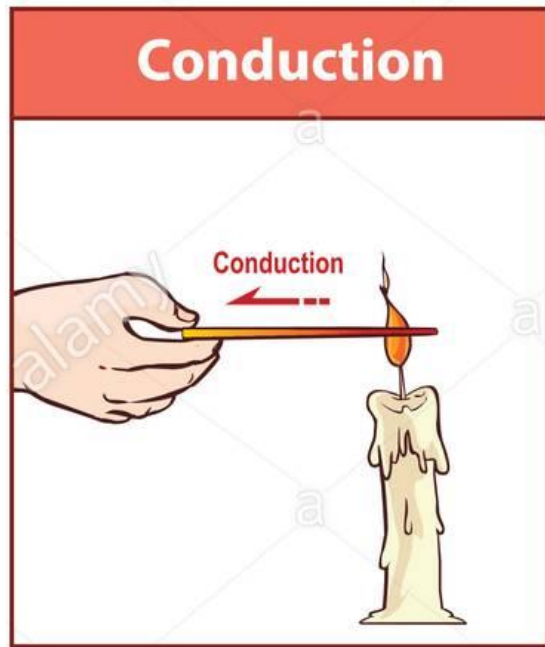
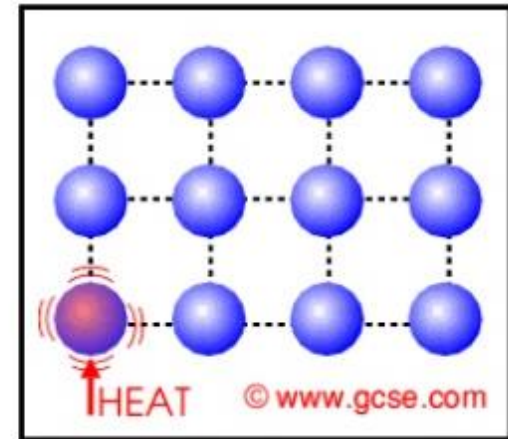
Solids, such as the metal rod, transfer heat by conduction.

The particles at the end of the rod nearest the fire **vibrate, causing neighboring particles to vibrate in turn.** Eventually the other end of the rod will become hot even though it is not above the fire.



Conduction occurs when heat is transferred between particles that are in contact with each other.

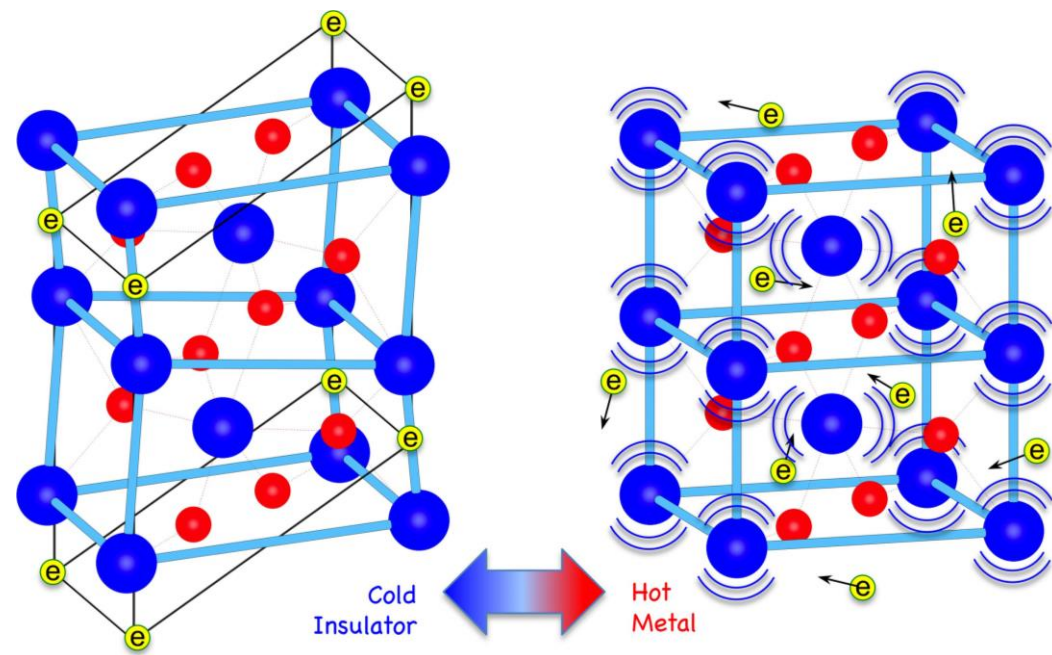
Heat energy is transferred from molecules with more vibration (hotter) to those with less vibration (cooler).



In solids, the heat is conducted by the following two mechanisms:

i. **By lattice vibration** (the faster moving molecules or atoms in the hottest part of a body transfer heat by impacts some of their energy to adjacent molecules).

ii. **By transport of free electrons** (Free electrons provide an energy flux in the direction of decreasing temperature – For metals, especially good electrical conductors, the electronic mechanism is responsible for the major portion of the heat flux except at low temperature).



Why are metals good thermal conductors?

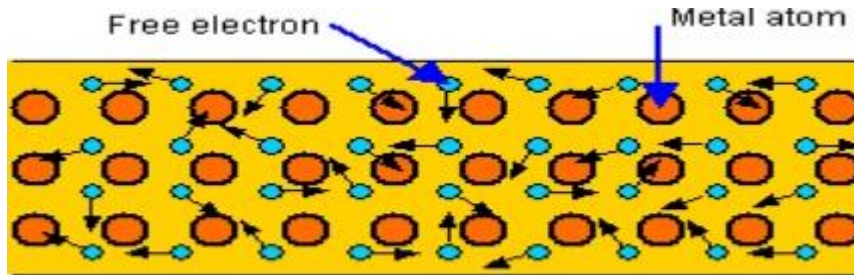
The diagram shows a metal bar being heated by a flame on the left. The bar is filled with yellow spheres representing atoms and small white dots representing free electrons. A large red arrow points from the hot end to the cold end, indicating the direction of heat conduction. To the right, several atomic models are shown, illustrating the structure of atoms in a metal.

There are delocalised electrons ('free' electrons) in metals

These free electrons can move freely throughout the metals

When heated, these free electrons gain kinetic energy and move from the hotter end to the colder end, carrying energy with them.

This process is much faster than conduction by the vibration of the molecules.



Conduction

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CONDUCTION:

- *The transfer of heat from one particle of matter to another by direct particle to particle contact.*
 - Conduction occurs primarily in solids because the particles are tightly packed together.
 - The particles themselves DO NOT change positions.

Conduction

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Example: A metal spoon in a pot of water being heated on an electric stove.

- First, the electrical energy is converted to thermal energy by the stove.
- The rapidly vibrating particles of the hot electric coil collide with the particles of the cool pot.
- Heat energy is transferred, causing the particles in the pot to vibrate faster.

Conduction

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- The rapidly vibrating particles of the pot now collide with the particles of the water at the bottom of the pot.
- The water particles absorb energy and vibrate and flow more rapidly and its temperature increases.
- Now, the energetic (hot) particles of water collide with the particles of the submerged end of the spoon.
- As the particles of the spoon absorb energy and vibrate more rapidly. The temperature of the spoon increases.

Conduction

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- As the particles at this end of the spoon absorb energy and vibrate faster they collide with other particles in the spoon. As they collide, energy is transferred to the other particles (similar to momentum) and they begin to vibrate more rapidly.
- This process of conduction is repeated all along the metal spoon until the entire metal spoon becomes hot.

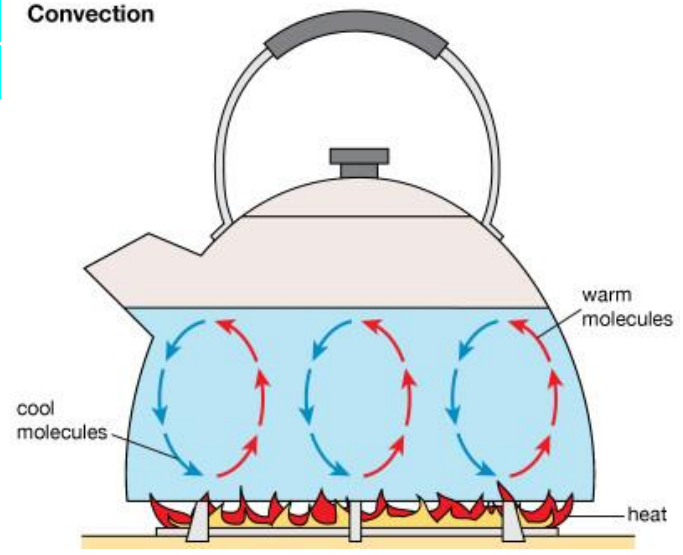


Heat by convection occurs when the motion of a fluid (liquid or gas “air”) carries energy from a warmer region to a cooler region. It’s the main process of heat transfer in cooking.

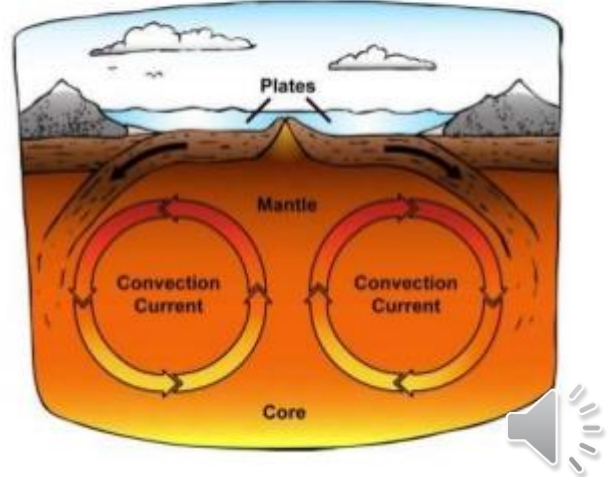
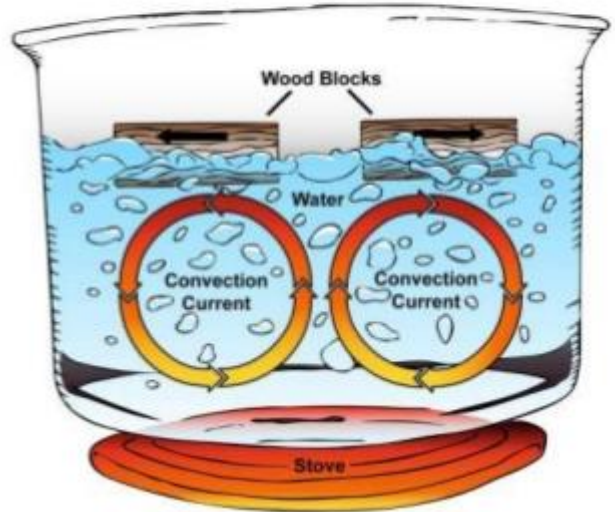
Fluids (both liquids and gases) transfer heat by **convection**.

The hotter air particles rise upwards from the fire and eventually cool. The cooler air particles sink towards the fire and so are heated by it. This process sets up what is known as a **convection current**.

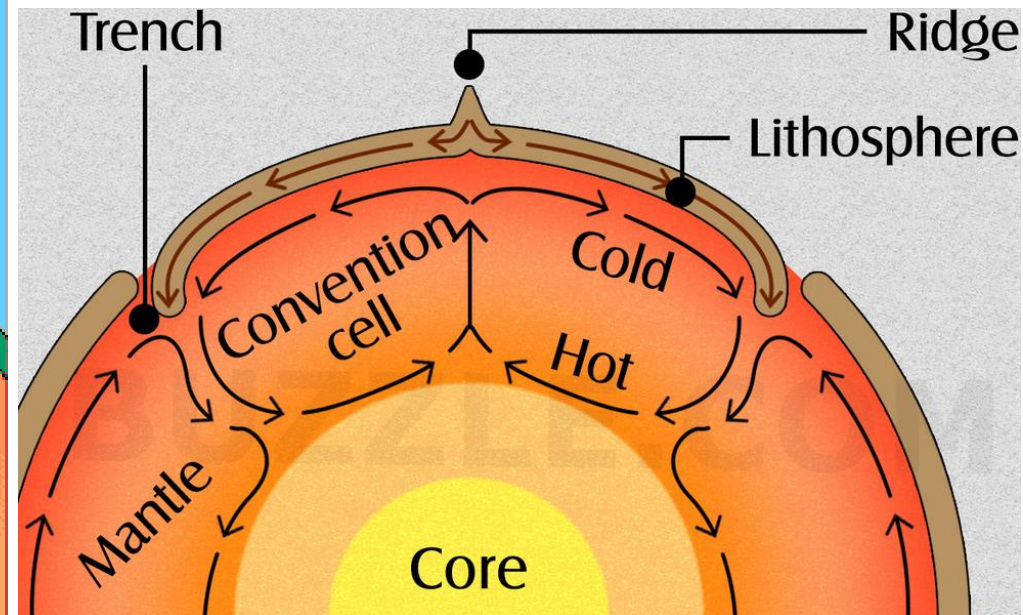
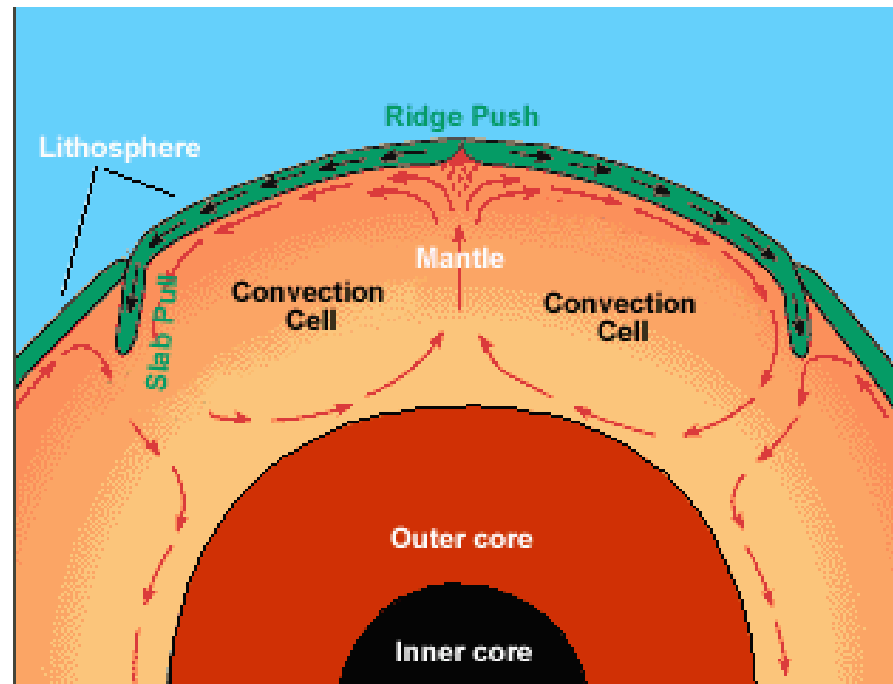
Convection



Convection occurs in objects that “flow.” Warm air/liquids rises and cool air/liquids fall due to density change. This creates a ‘convection current.’



Heat convection (along with conduction) is believed to take place inside the Earth, transferring kinetic energy from the inner core through the outer core and mantle to the crust. In this situation, the outer core and the mantle behave like liquids over long periods of time.



Convection

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Convection: the transfer of thermal energy (heat) through the bulk movement of matter.

- Convection occurs in **FLUIDS** (liquids and gases).
- Convection produces **CURRENTS** in both gases and liquids.
- Thermal Energy heat is carried by the particles as they move from one location to another.

Convection

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Example: Heating water:

- When the water at the bottom of the pot (nearest the burner) is heated, the particles absorb energy by conduction as they touch the hot pot.
- The water particles vibrate more rapidly.
- The particles also move farther apart and the hot water becomes less dense than the surrounding cool water.
- This causes the heated (hot) water to rise.

Convection

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- The surrounding denser cooler water is forced downward near the burner by the rising hot water.
- This process continues to repeat.
- This **FLOW** creates a circular motion known as a **convection current**.

Application: How do convection currents form in a room when the heater is turned on?

Convection

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- The warm air from the heater vent will rise. Why?
 - The warm air is less dense than the surrounding cooler air.
- The cool air is pushed down by the rising warm air.

What is the best location for a heat vent in a room and why? Near the ceiling or the floor?

Floor:

Because the warm air will rise to the ceiling.

How about the return vent?



Convection

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Convection currents occur in the environment as well. They produce:

- Global winds that contribute to Earth's weather.
- Ocean and lake currents



Convection

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Brainstorming: On a hot summer day the breeze near the beach blows toward the water. However, later in the day the breeze reverses direction and blows toward land and will get increasingly stronger. Why?



Convection

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Answer: In the morning the water may be warmer than the sand causing the air over the water to rise.

In the afternoon, the sand has become much hotter than the water and the air above it rises. The air over the water rushes in to fill its void causing a wind.



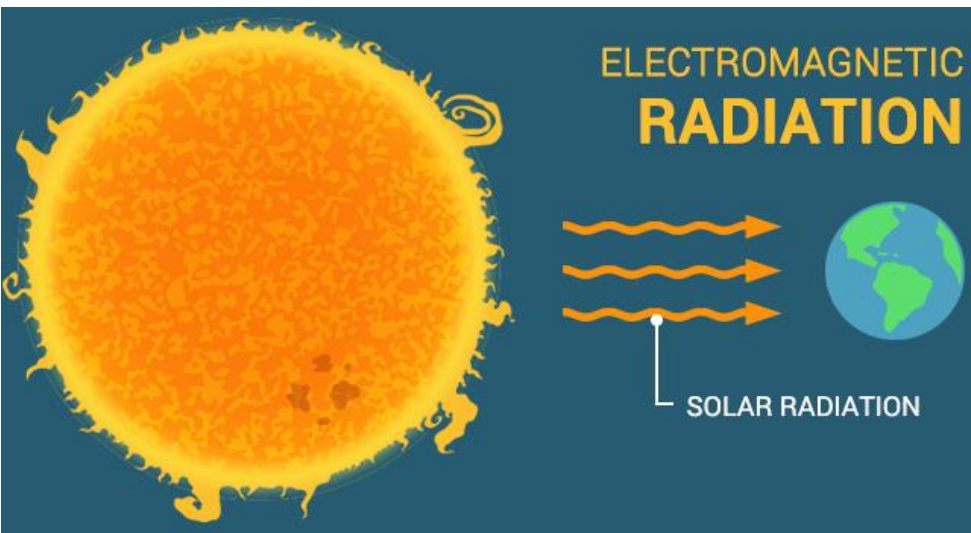
Heat by Radiation

When hot, all objects radiate heat. **Radiation** doesn't need a medium to carry heat – it can even carry heat through a vacuum.

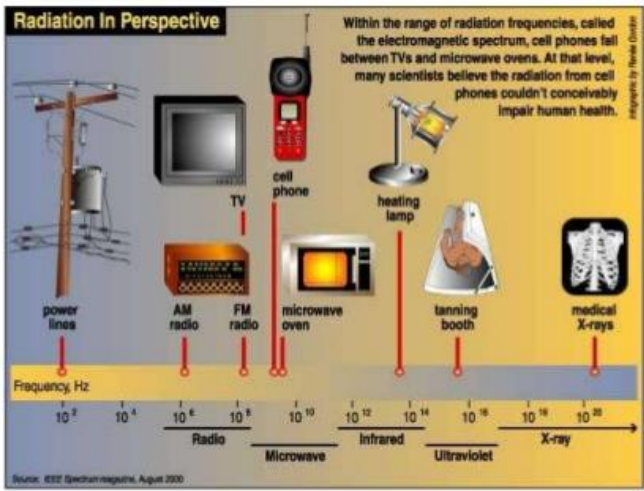
Radiation is used in two forms of cookery - grilling and microwaving.

Radiation does not require an intervening medium; it can occur through a vacuum.

Radiation is responsible for the warming of the Earth by the sun.



Radiation is when heat energy travels as a wave in a straight line through empty space.

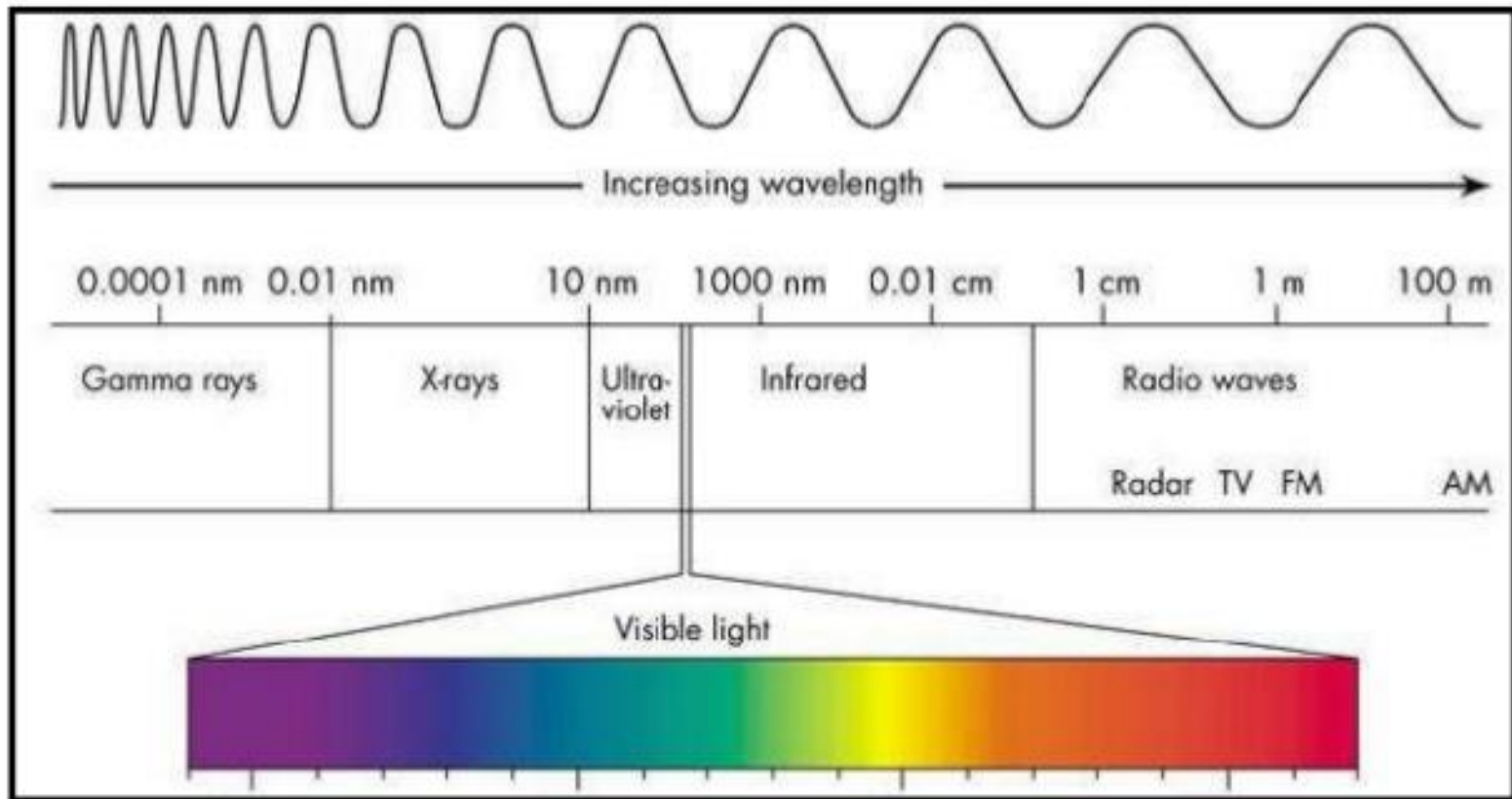


Does NOT require contact. Several kinds of radiation.

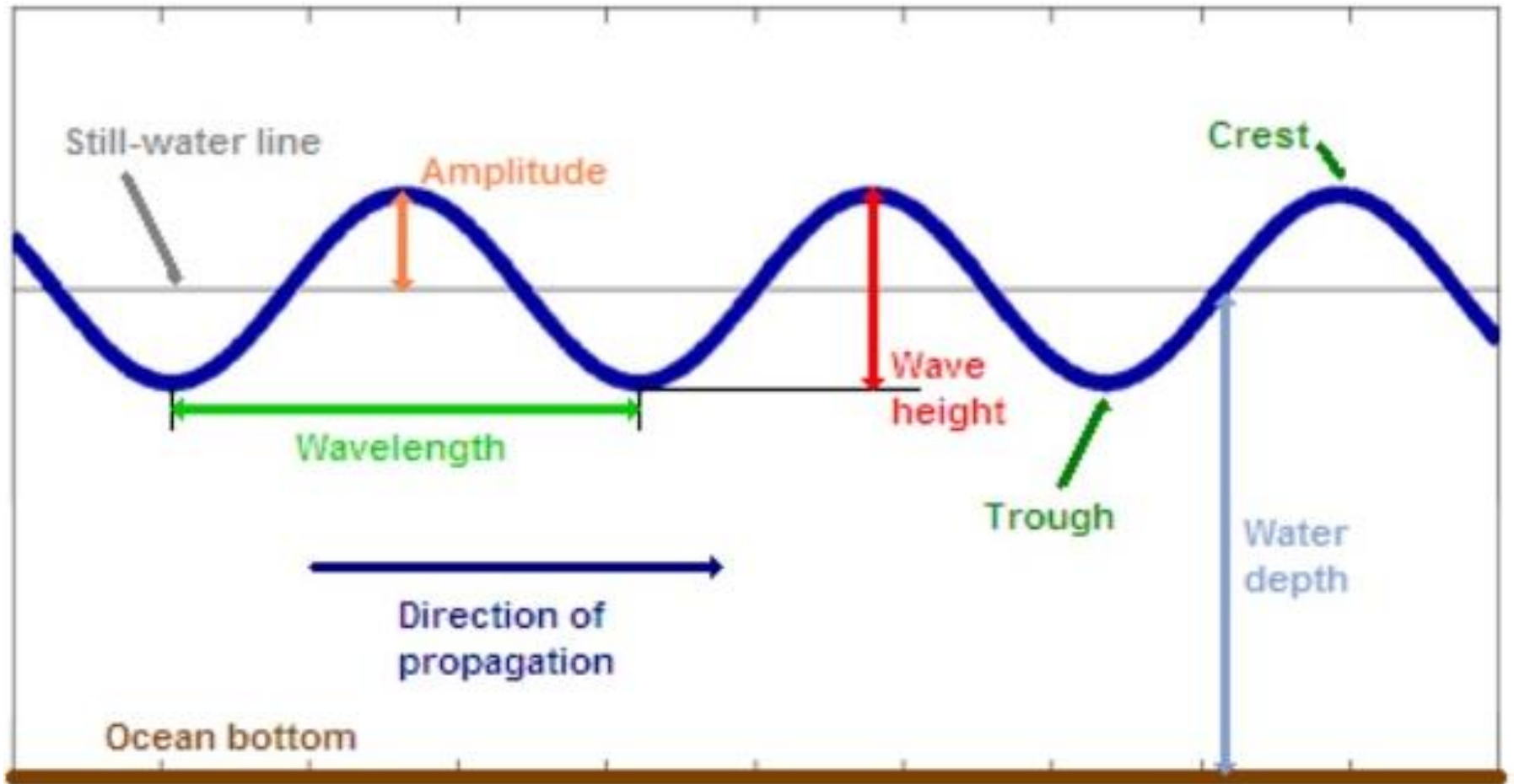


Microwave ovens use high frequency electromagnetic waves which penetrate the food and are absorbed by the water molecules inside. The water molecules vibrate when hit by a microwave at exactly the right frequency and this vibration generates heat. The food is further heated by the energy from this molecule being transferred by conduction to neighboring molecules.

Radiation waves vary in wavelength and frequency. Simple waves have several primary parts.

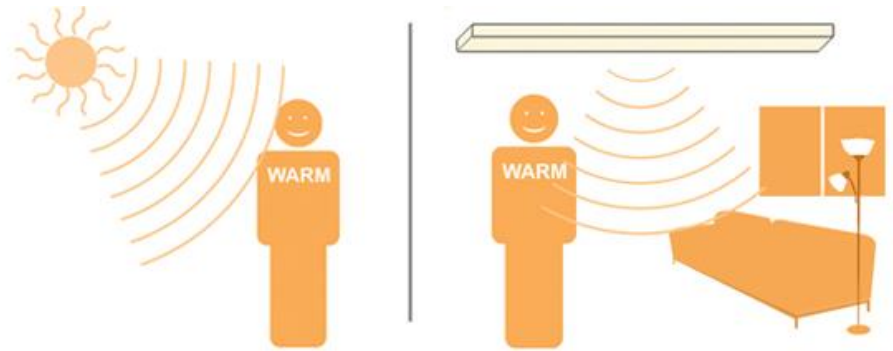


Simple Waves



The properties of **radiant heat** in general, are similar to those of light. Some of the properties are:

- i. **Radiant heat** **does not require** the presence of a **material medium** for its transmission.
- ii. **Radiant heat** **can be reflected** from the surfaces and obeys the ordinary laws of reflection.
- iii. **Radiant heat** **travels with velocity of light.**
- iv. Like light, **Radiant heat** shows **interference and polarization** etc.
- v. **Radiant heat** follows the law of inverse square.



Radiation

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- **Radiation:** the transfer of (thermal) energy by electromagnetic waves.
- Radiation does not require matter to transfer thermal energy.
 - All the sun's energy that reaches Earth travels through millions of kilometers of empty space (a vacuum).
- All matter can radiate energy.
 - You feel the radiation of thermal energy from a bonfire, a heat lamp and a light bulb.

Radiation

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- Other examples of the transfer of heat by Radiation:
 - a. Charcoal grill.
 - b. Hot tin roof.
 - c. Burner on a stove top.
 - d. ?
 - e. ?

Radiation

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Key Point: For radiation to be felt as heat it must first be absorbed by a material.

Example: Why do blue jeans feel hotter in the sun than a yellow shirt, even though they are both exposed to the same amount of sunlight?

- The blue jean fabric absorbs more radiant energy from the sun than the yellow shirt because of its dark color.



The Nature of Heat

What happens when you put ice in a warm soft drink?

- The heat energy moves from the soft drink into the ice by conduction (particle to particle contact) causing the ice to melt.

Review

Describe the three kinds of heat transfer.

- Conduction** - transfer of heat energy from one particle to another by direct contact. (Primarily in solids)
- Convection** - transfer of heat energy in fluids-gases and liquids) through the bulk movement of matter from one place to another. (Produces currents)
- Radiation** - transfer of energy through electromagnetic waves. (Matter is not required!) (Radiant & infrared radiation from the sun)

Conduction

- Direct contact of particles
- Solids/liquids /gases
- The handle of a cooking utensil

Radiation

- Transfer of energy by waves
- Only radiant energy that is absorbed becomes thermal energy
- Lightbulb
- Fireplace

Convection

- Transfer of energy by bulk movement of matter (fluids)
- Currents (wind, water)
- Hot air balloon



Contrast:
Conduction
Convection
Radiation

- Direct contact of particles
- Solids/liquids/gases
- Solids - good conductors
- Gases - poor conductors

Conduction

- Transfer of energy by waves
- Only radiant energy that is absorbed becomes thermal energy
- Shiny/light colors - reflect
- Dull/dark colors - absorb

Radiation

- Transfer of energy by bulk movement of matter (fluids)
- Currents (wind, water)
- Hot air balloon

Convection



Heating Methods

Radiation

The transfer of heat by electromagnetic waves

e = nature of the surface

$$H = Ae\sigma T^4$$

Stefan-Boltzmann Law

$$\sigma = 5.670400 \times 10^{-8}$$

Conduction (Heat Current)

Convection

the transfer of heat by mass motion of a fluid from one region of space to another.

(Really complicated)

The rate at which heat flows through a material: dQ/dt

Heat current in conduction

$$H = dQ/dt = kA(T_H - T_C)/L$$

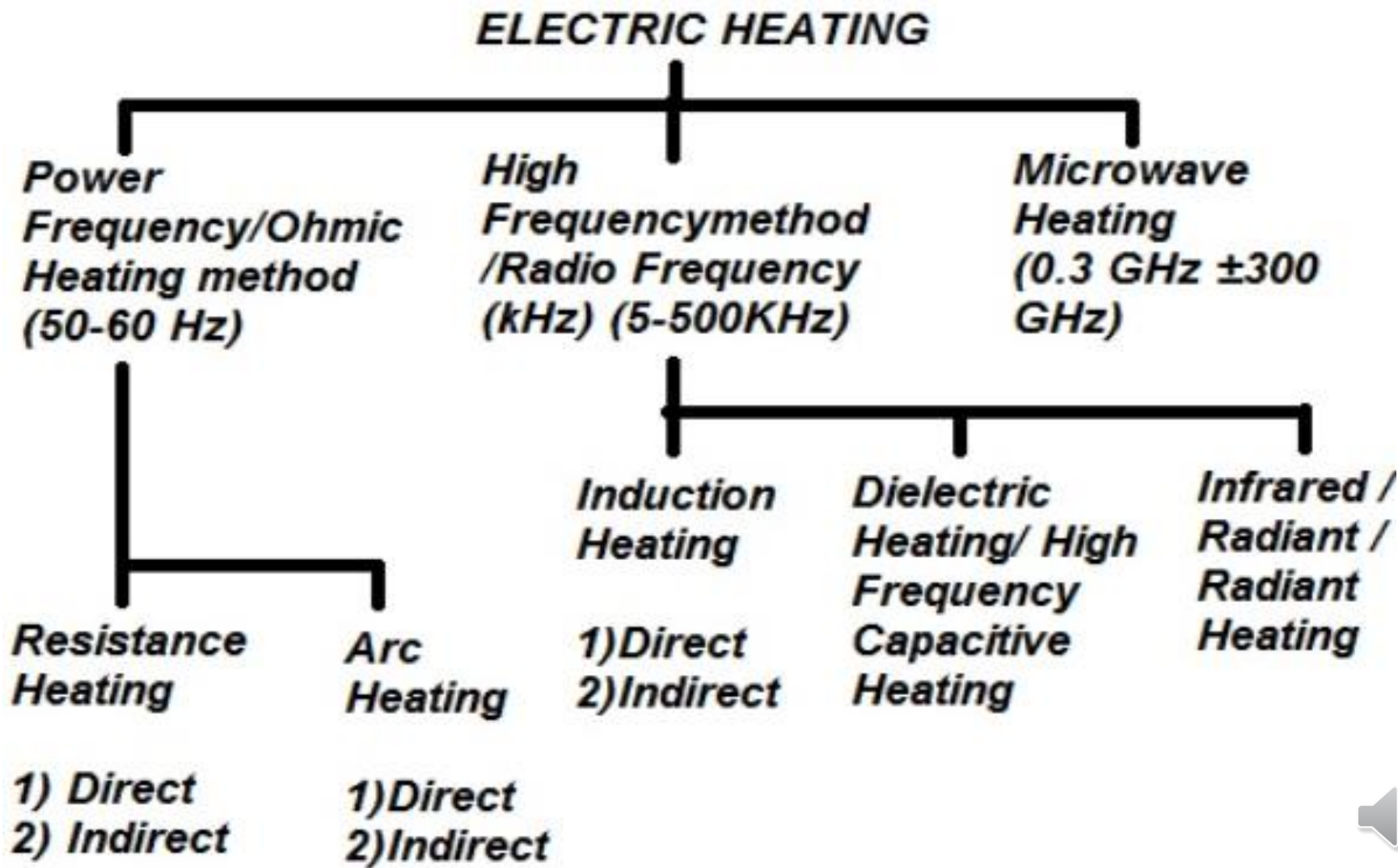
$$R = L/k$$

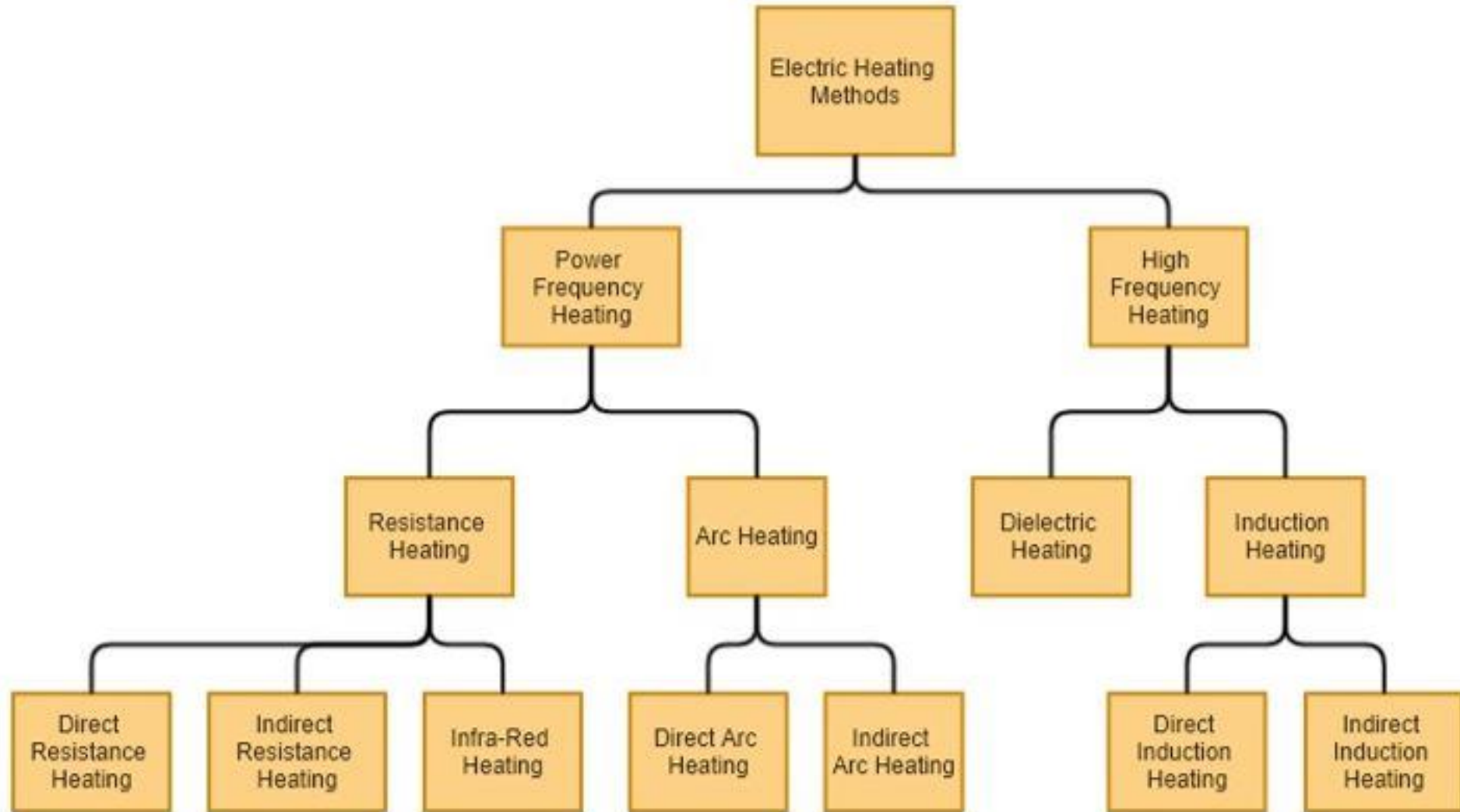
Thermal Resistance



4. What is Electric Heating?

Electric heating is any process in which **electrical energy is converted to heat.** Common applications include heating of buildings, cooking, and industrial processes. The **heating element** inside every electric heater is simply an electrical resistor and works on the principle of Joule heating: **an electric current through a resistor converts electrical energy into heat energy.**







Video1: Heating Elements (Click to play)



5. Power frequency heating

Power frequency heating can be classified into two types; **resistance heating** and **arc heating**.

(1) Resistance Heating

Resistance heating can be classified into 3 types: **direct resistance heating**, **indirect resistance heating** and **infra-red heating**.

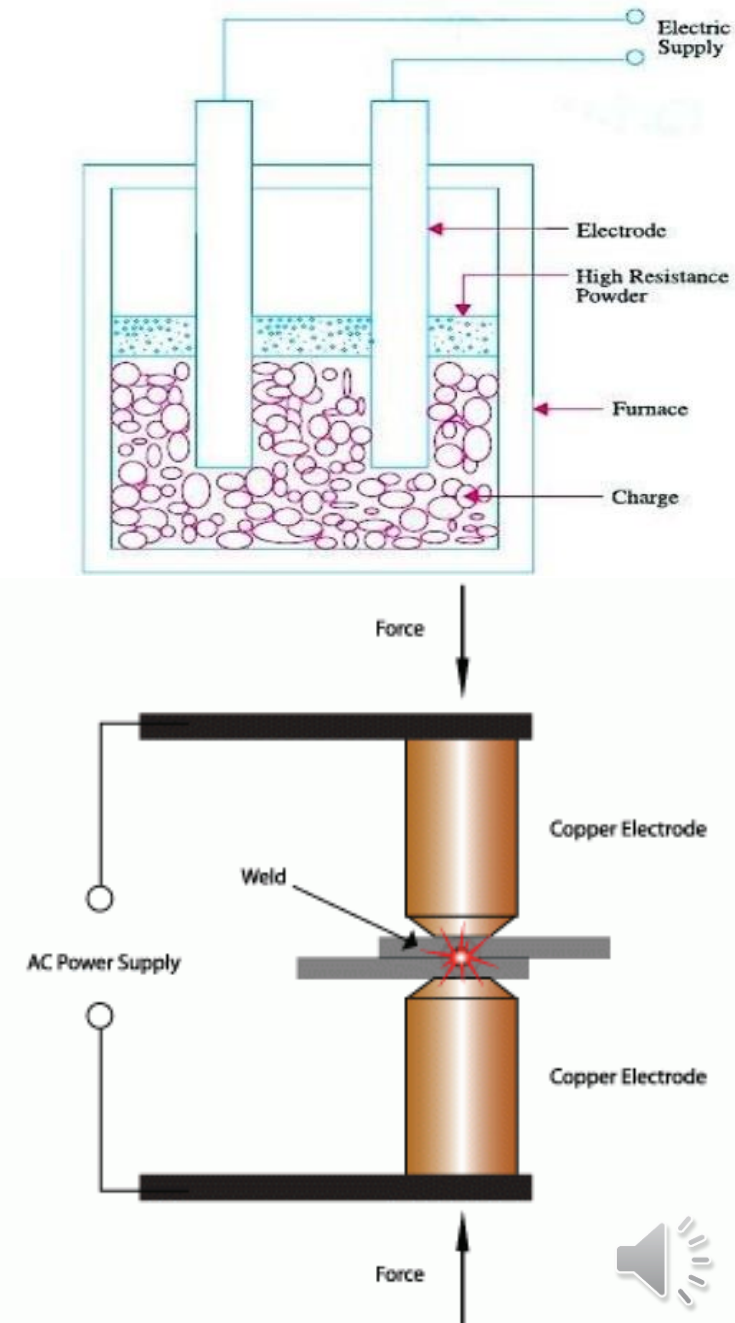
(a) Direct Resistance Heating

In this type of heating, **electric current is passed directly through the body to be heated**. Since the body has resistance, current causes heat generation in the body. Hence, it raises the body temperature.

Applications

- i. electrode boiler for heating water
- ii. resistance welding

Direct methods of resistance heating.

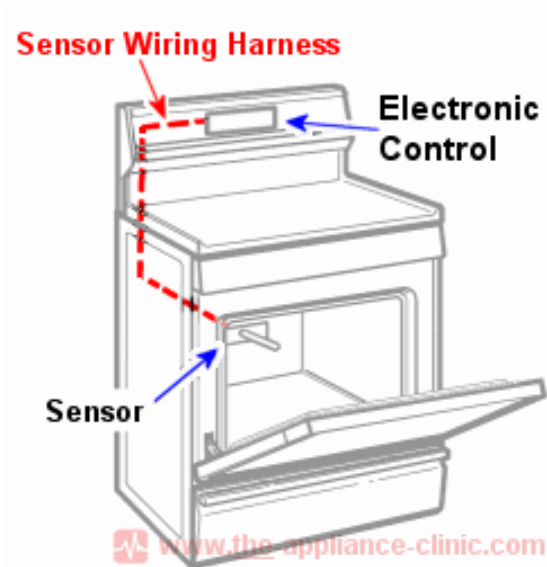


(b) Indirect Resistance Heating

In this type of heating, **electric current is passed through a resistive element (heating element).** The power is delivered to the body to be heated by **convection or radiation.**

Applications:

- i. resistance ovens
- ii. cooking
- iii. heat treatment of metals
- iv. immersion heaters



(c) Infra-red Heating

In this type of heating, **incandescent lamp is used for heating the body.** The body is heated due to **electromagnetic radiations produced by the lamp.**

Applications: used for drying wet paints on an object.



(2) Arc Heating

Arc heating is based on the **arc formation between separated electrodes (carbon or graphite) causing generation of high temperature (3000°C) due to air ionization and electrical current flow between the electrodes.** This high temperature is responsible for heating of a body. Arc heating can be classified into two types, i.e., direct arc heating and indirect arc heating.

(a) Direct Arc Heating

An arc is produced between the electrode(s) and body to be heated. Hence, the heat is directly transferred to the body by **conduction**.

Applications: It is used in **industrial furnaces.**

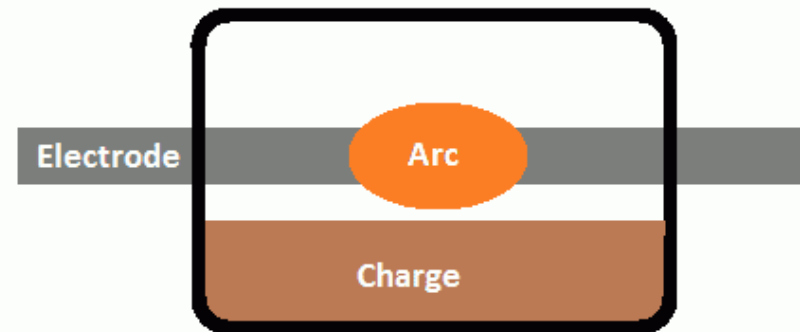
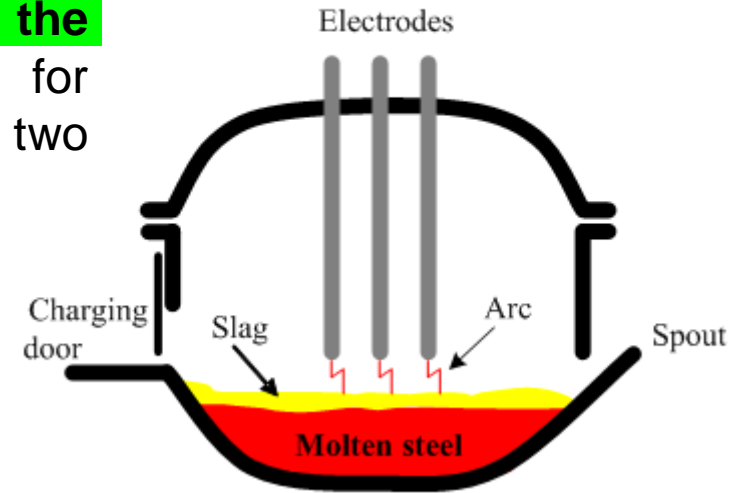
(b) Indirect Arc Heating

The arc is produced between two electrodes. Hence, the heat generated in the arc is transferred to the body by **radiation**.

Applications: It is used in furnaces.

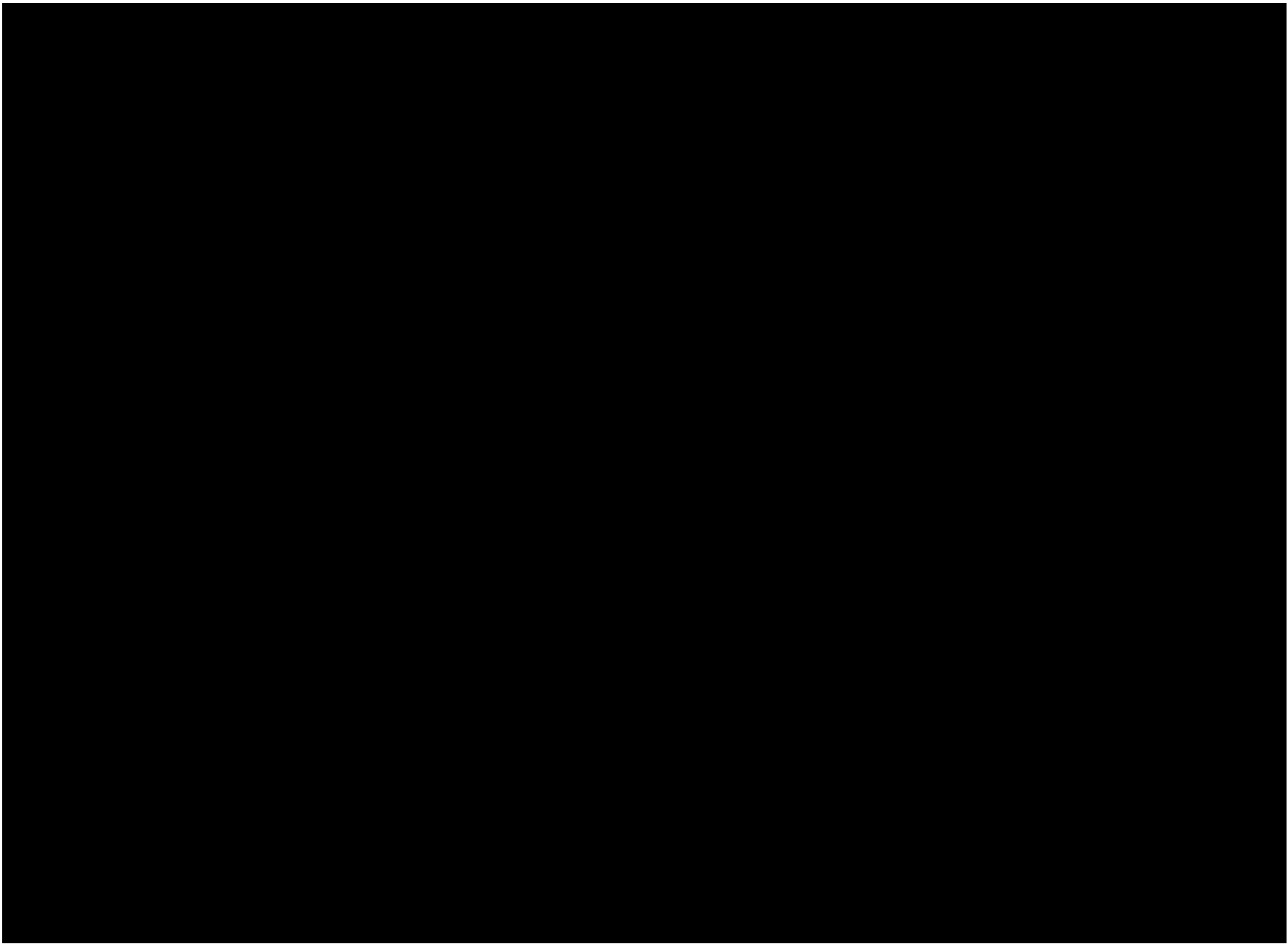
Direct ARC Furnance

Electric - arc furnace



Indirect Arc furnace





Video 2: Direct arc heating (Click to play)





Video 3: Indirect arc heating (Click to play)

End of Lecture