2.0 Heat affects matter in different ways

2.1 States of Matter and The Particle Model of Matter

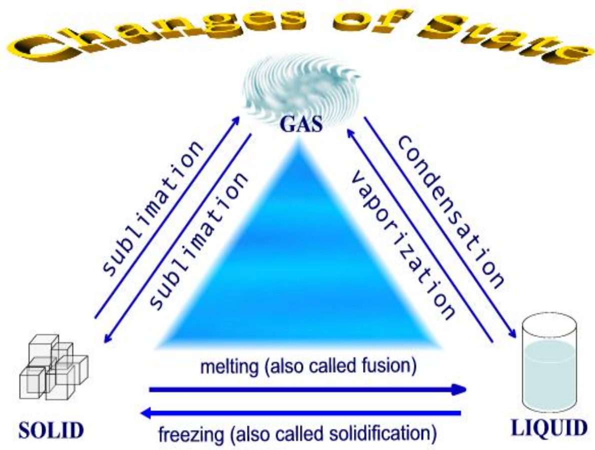
Matter is made up of tiny particles and exists in three states: solid, liquid and gas.
The Particle Model of Matter is a scientific description of the tiny particles that make up all things. The key elements in this model are:

- **All matter is made of tiny particles too small to be seen**
- **The particles are always moving**
- **The particles have spaces between them**
- **Adding heat to matter makes the particles move faster**

Changes of State: Water

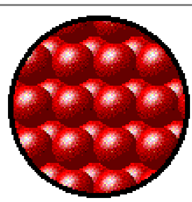
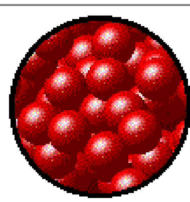
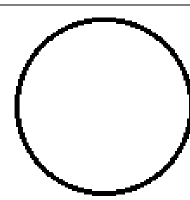
Substances such as water (or wax) can undergo observable changes through all three states of matter - solid liquid and gas.

- Ice is the **solid state** of water at 0^oC
- The **melting point** of water is 0^oC
- The **boiling point** of water is 100^oC
- **Condensation** occurs when water changes from a gas to a liquid



Any pure substance can exist in all three states of matter.

Heat and the Particle Model

Solid	Liquid	Gas
		
Particles are closely packed together	Particles can slip past each other	Particles have lots of space between them

The Effect of Heat on Particles

When heat is added to a substance, the particles move faster. When heat is lost from a substance the particles move slower.

- The motion of the particles increases when the temperature increases.
- The motion of the particles decreases when the temperature decreases.
- Heat energy transfers from high temperature matter to low temperature matter. Heat can affect matter by causing it to change state.

How The Particle Model Explains Changes of State

During a phase change, the average energy of the particles remains the same, but, the particles are rearranging themselves.

Solid	• The particles are tightly packed together. • Solids have a fixed shape.
Heating a Solid	• Particles become less organized as their energy increases, so the substance changes from a solid to a liquid to a gas. • The space between the particles increases, so its volume increases.
Melting a Solid	• Particles move very quickly and attractions between the particles break down, so the solid melts into a liquid state.
Liquid	• In a liquid, the particles are moving very quickly. • The particles have more kinetic energy • Liquids take the shape of their containers
Heating a Liquid	• At the surface, some of the particles are able to escape into the air, while others do not have enough energy to escape and remain in the liquid. • As the liquid expands, its volume increases • As high energy particles escape, the average energy of the remaining particles is less and so the liquid cools. The cool liquid then cools the surface on which it is resting. This is called evaporative cooling. It is common and useful in many situations: Joggers cooling down as their sweaty clothes dry out; Water cools down a roof on hot summer day; A wet cloth is placed on your forehead when you have a fever.
Boiling a Liquid	• The attractions between the particles are very weak • More and more high energy particles escape, and the liquid changes into a gas
Gas	• Particles move very quickly with a lot of kinetic energy • Particles fill up the space of the container they are in. • Large spaces between the particles.
Gas to a Liquid to a Solid	• As the energy of the particles becomes less, the particles rearrange themselves more orderly, so a gas changes to a liquid and then to a solid, when even more energy is lost – the particles are slowing down.

The total energy of the particles changes - by increasing or decreasing, because the particles are not increasing or decreasing their speed, just their arrangement. The average energy doesn't change. The energy change is hidden from a thermometer and is called **'hidden hea**t' or **'latent heat'**.

2.2 Heat and Temperature

Temperature is a measure of how hot or cold matter is. Temperature indicates the average energy (speed) – kinetic energy - of the particles in motion in a substance.
The amount of temperature change, when thermal energy is added to the particles is another property that particles in different materials have. Different materials will increase or decrease their average energy depending on how much thermal energy is provided.

- Heat Capacity is the amount of thermal energy that warms or cools an object by 1^oC (it depends on the mass and the type of particle the object is made of).
- Specific Heat Capacity is the amount of thermal energy that warms or cools 1 gram, of a specific type of particle, by 1^oC.

Total Kinetic Energy

The thermal energy of a substance is the total kinetic energy of all the particles the substance contains. Energy is the measure of a substance's ability to do work - or cause changes.
There are two important elements that occur:

- **Changes happen when there is a difference of energy (every useful energy system has a high-energy source that powers the changes)**
- **Energy is always transferred in the same direction: from a high-energy source** (hot) to something of lower energy (cold).

Energy Transfers

Heat is the energy that transfers from one substance to another because of the difference in kinetic energy. The average energy of the particles - the **temperature** of the substance - is affected, by increasing or decreasing. The change in temperature depends on the number of particles affected.

The Difference Between Heat and Temperature

Energy is not a substance. It cannot be seen, weighed or take up space. Energy is a condition or quality that a substance has. Energy is a property or quality of an object or substance that gives it the ability to move, do work or cause change.

Understanding The Difference

Thermal Energy is the total kinetic energy of all the particles in a substance
Heat is the energy that transfers from a substance whose particles have a higher kinetic energy to a substance who particles have a lower kinetic energy.
Temperature is a measure of the average kinetic energy of the particles in a substance.

Measuring Temperature With Thermometers

A relative idea about temperature is that it tells you how hot or cold something is. This can be done by using our senses: **Touch** (sensitive nerve endings on your skin can detect changes in temperature); **Sight** (the color of the material giving off heat). Relative ways to determine the temperature are not always reliable or safe. Thermometers are more reliable devices that measure temperature. The Italian scientist Galileo invented the first air thermometer around 1600 and it has, and will continue to be, improved upon.

History Of Thermometers

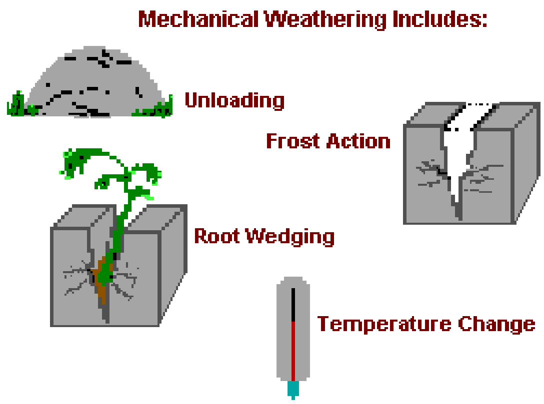
200 B.C.	The first thermometers were called thermoscopes
1590's	Several inventors invented a version of the thermoscope at the same time, Italian inventor Santorio Santorio was the first inventor to put a numerical scale on the instrument. Galileo Galilei invented a rudimentary water thermometer in 1593 which, for the first time, allowed temperature variations to be measured.
1630's	Early thermometers (like the one Galileo invented) did not have any scale (markings with numbers) to determine precise temperature.
1650's	
1701	Ole Romer created one of the first practical thermometers, which used red wine as the temperature indicator. The temperature scale for his thermometer had 0 representing the temperature of a salt and ice mixture (at about 259 K), 7½ representing the freezing point of water (273.15 K), and 60 representing the boiling point of water (373.15 K). Daniel Gabriel Fahrenheit (1686-1736) was the German physicist who invented the alcohol thermometer in 1709
1714	In 1714, Fahrenheit invented the first mercury thermometer, the modern thermometer. And in 1724, he introduced the temperature scale that bears his name - Fahrenheit Scale.

1742	The 1st precise scale was developed by Anders Celsius in 1742. He used 'degree' as the unit of temperature. Centigrade means "consisting of, or divided into, 100 degrees". All of his standards for comparison, to make his markings (on his scale), were based on the properties of water. 0^{o} was assigned the temperature at which ice melts at sea level 100^{o} was assigned the temperature at which liquid water boils at sea level The region between (above and below, as well) these two extremes was separated into 100 equal units (degrees) The two fixed temperatures that Celsius chose can be used to calibrate a thermometer. The Celsius temperature scale is also referred to as the "centigrade" scale. The term "Celsius" was adopted in 1948 by an international conference on weights and measures
1852	Lord Kelvin invented the Kelvin Scale in 1848. The Kelvin Scale measures the ultimate extremes of hot and cold. Kelvin developed the idea of absolute temperature, what is called the "Second Law of Thermodynamics", and developed the dynamical theory of heat. Absolute zero is the coldest possible temperature - 273^{o} and is used by scientists. The markings on the scale are not called degrees, but are simply called kelvins. (0^{o} Celsius is equal to 273.15^{o} Kelvin)
1861	The electrical-resistance-thermometer was invented in Germany. It used an electrical current to measure temperature. English physician, **Sir Thomas Allbutt** invented the first medical thermometer used for taking the temperature of a person in 1867.
1970's	Theodore Hannes Benzinger invented the ear thermometer. David Phillips invented the infra-red ear thermometer in 1984.
1990's	Dr. Jacob Fraden, invented the world's best-selling ear thermometer, the Thermoscan® Human Ear Thermometer.

2.3 Heat Affects the Volume of Solids, Liquids, and Gases

Observing The Effect of Heat

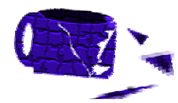
Cracks in rock, due to ice



Fitting a nut to a bolt

Hot water opens a jar lid

Boiling water cracks the cold mug



Thermal expansion is the process of expansion of a substance caused by an increase in thermal energy.

Expansion and Contraction in Solids

Solids can become longer or shorter depending on the temperature (average energy of the particles).

Expansion and Contraction in Liquids

When the particles in a liquid are heated, their average energy increases and they need more room, so they **expand**. When the particles in a liquid are cooled, the volume decreases, or **contracts**, because the particles need less room. This is demonstrated by the liquid used in a thermometer. As the liquid expands and contracts, it moves up and down the inside tubing (the *bore*) of the thermometer.

Expansion and Contraction in Gases

When the particles in a gas are heated, their average energy increases and they need more room, so they **expand**. When the particles in a gas are cooled, the volume decreases, or **contracts**, because the particles need less room. Under extremely high temperature conditions (like the temperatures inside the Sun, particles can be split into what makes them up (electrons and ions). This creates a fourth state of matter called **plasma**.

Heat Affects the Volume of Solids, Liquids and Gases

As the average energy of particles increases, the space between the particles increases. They expand (increase their volume) as the temperature increases. As the average energy of particles decreases, the space between the particles decreases. They contract (decrease their volume) as the temperature decreases.

	Solids	Liquids	Gases
Shape and Size	Keep their shape and size	Take the shape of the container	No definite shape or size
Compressibility (volume)	Cannot be compressed (fixed volume)	Almost incompressible (fixed volume)	Can be compressed (volume changes)

2.4 Heat Transfers by Conduction

Conduction

In solids, where the particles are closely packed together, thermal energy can be transferred from one particle to another very easily. Thermal conduction is the process of transferring thermal energy by the direct collisions of the particles. The space between the particles, in different solids, determines how quickly these collisions can take place. Good conducting materials are those materials where there is little space between the particles - like most metals. Poor conductors, like glass and wood are called heat insulators. These insulators when wrapped around an object slow down the rate of thermal conduction.

Conductors

Metals are good conductors of heat, so they are used extensively in cooking, because they transfer heat efficiently from the stove top or oven to the food. Hot and cold packs are used to treat muscle injuries. The Radiator of a car transfers heat away from the engine, so that the gasoline being used will not ignite. (Antifreeze is used to achieve this).
Applications

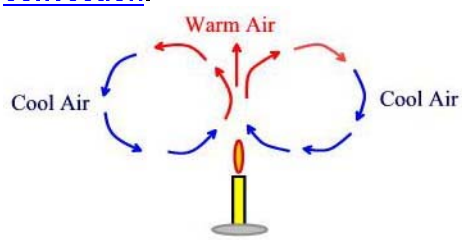
Insulators

Insulators are materials that do not easily allow heat transfer

2.5 Heat Transfers by Convection and Radiation

Understanding Convection

Thermal energy can be transferred in fluids, by the circular motion of the particles, called convection.



In convection, the warmer particles transfer their energy to the cooler particles as they move in a circular pattern, called, a 'convection current'. A simple experiment

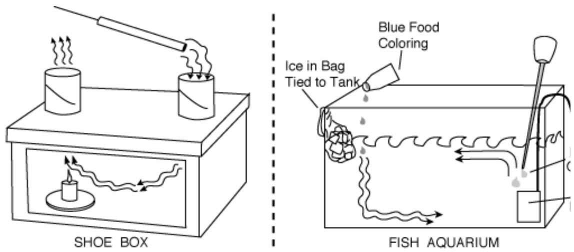
The **convection oven** is one of the many practical applications of convection.
The heat inside the oven helps to provide uniform beating as the convection current transfers the heat evenly inside.

Lava lamps are good examples to convection currents in action.

Convection Currents in Air

Birds and para-gliders make use of '**thermals**' to help them soar and glide - helping them to conserve energy when they migrate.
Heating occurs through convection currents in a fluid, such as radiator water heating - flowing from the basement to heat a radiator on a floor above.

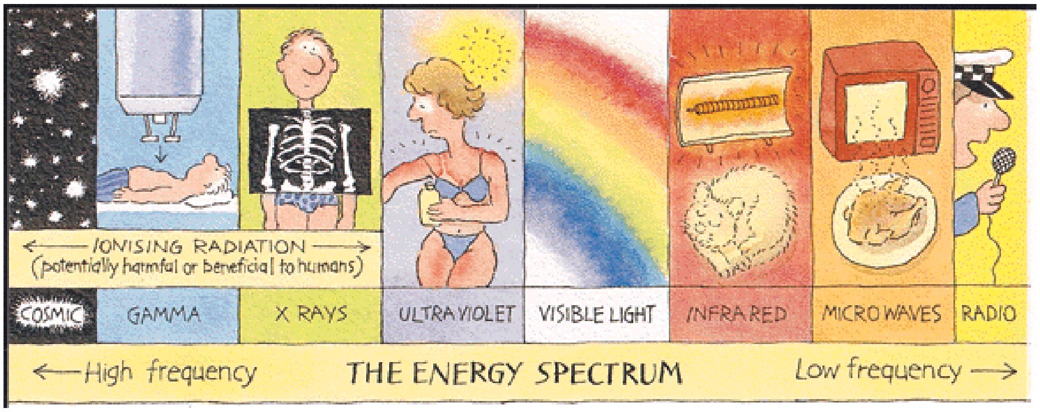
Convection currents are also involved in creating the force of magnetism that surrounds the earth.



As are the **convection box** and aquarium

Heat Transfers By Radiation

Energy can be transferred even though there are no particles to transfer the energy. This type of energy transfer is called **radiation**. Radiation is the [transfer of energy] without any movement of matter. Energy that is transferred in this way is called radiant energy or **electromagnetic radiation** (**EMR** for short). Radiant energy travels in waves. These waves can travel through space, air, glass and many other materials. There are different forms of EMR, including radio waves, microwaves, visible light and X-rays.



If the energy source is a warm object, like the sun, some of the thermal energy is transferred as a type of EMR called **infrared radiation** (IR) or '**heat radiation**'.

Waves of radiant energy can travel in a vacuum. All waves travel, across empty space, at an extremely high speed (300 Million m/s). Radiant energy travels in a straight line.
All kinds of radiant energy interact with matter:

Radiant Energy waves can be absorbed and reflected by objects.

- Absorption occurs if the energy penetrates part way into the object. Dull dark objects absorb radiant energy when they are cool, and emit radiant energy when they are hot. (eg. asphalt sidewalk)

- Reflection occurs if the energy cannot penetrate the surface of the material it comes into contact with. Light, shiny objects or surfaces do not absorb radiant energy readily and do not emit radiant energy readily. (eq. ice surface)

- Transmission occurs if the energy penetrates completely, passing through the object with no absorption of energy.

Radiation is a natural part of our environment and it [can be detected, measured and controlled.] The measurement of radiation is by the amount of radioactivity present, or the amount of radiant energy given off. Natural radiation reaches earth from outer space and continuously radiates from the rocks, soil, and water on the earth. Background radiation is that which is naturally and inevitably present in our environment. Levels of this can vary greatly.