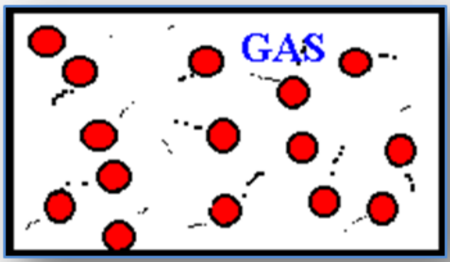
THE PARTICLE MODEL AND PROPERTIES OF THE GASES, LIQUIDS AND SOLIDS. STATES CHANGES



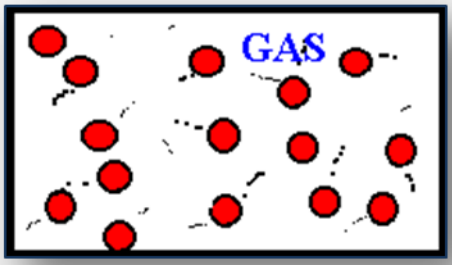
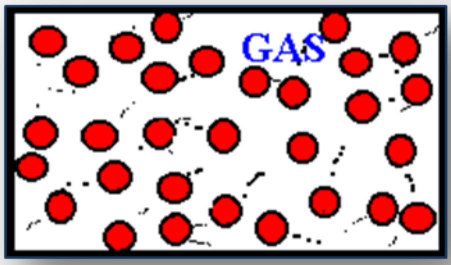
The particle model of a gas

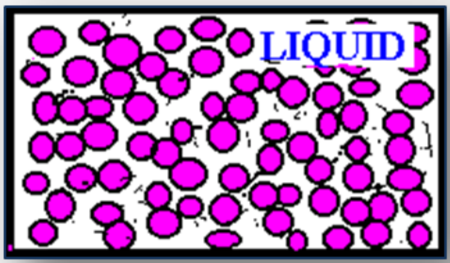
- **A gas has no fixed shape or volume, but always spreads out to fill any container.**
- There are almost **no forces of attraction between the particles** so they are completely free of each other.
- The particles are **widely spaced and scattered** at random throughout the container so there is no order in the system.
- The particles **move rapidly in all directions**, **frequently colliding** with each other and the side of the container.
- With **increase in temperature**, the **particles move faster as they gain kinetic energy**.

USING THE PARTICLE MODEL TO EXPLAIN THE PROPERTIES OF A GAS

- **Gases have a very low density** ('light') because the particles are so spaced out in the container (density = mass / volume).
    - **Density order: solid > liquid >>> gases**
- **Gases flow freely** because there are no effective forces of attraction between the gaseous particles - molecules.
    - **Ease of flow order**: **gases > liquids >>> solids** (no real flow in solid unless you powder it!)
    - Because of this **gases and liquids are described as fluids**.
- **Gases have no surface**, and **no fixed shape or volume**, and because of lack of particle attraction, they always spread out and fill any container (so gas volume = container volume).
- **Gases are readily compressed** because of the 'empty' space between the particles.
    - **Ease of compression order**: **gases >>> liquids > solids** (almost impossible to compress a solid)
- **Gas pressure**
    - When a gas is confined in a container the particles will cause and exert a **gas pressure** which is measured in atmospheres (atm) or Pascals (Pa = N/m^2) - pressure is force/area on which force is exerted.
        - The **gas pressure is caused by the force created by millions of impacts of the tiny individual gas particles on the sides of a container**.

- For example - **if the number of gaseous particles in a container is doubled, the gas pressure is doubled** because doubling the number of molecules doubles the number of impacts on the side of the container so the total impact force per unit area is also doubled.
  - This doubling of the particle impacts doubling the pressure is pictured in the two diagrams below.

	**2 x particles** ===> **P x 2**	



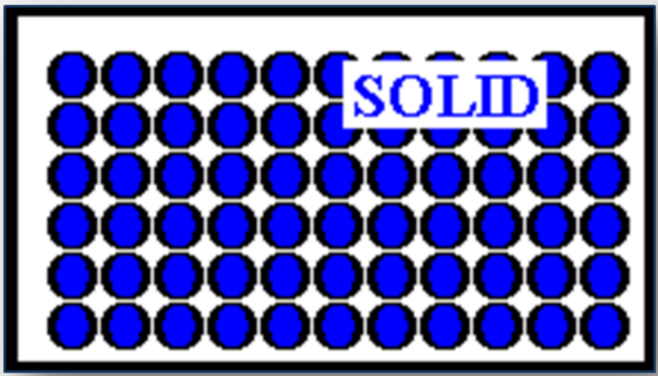
The particle model of a liquid

- **A liquid has a fixed volume at a given temperature but its shape is that of the container which holds the liquid.**
- There are much **greater forces of attraction between the particles in a liquid compared to gases**, but not quite as much as in solids.
- Particles **quite close together** but **still arranged at random** throughout the container, there is a little close range order as you can get clumps of particles clinging together temporarily.
- Particles **moving rapidly in all directions** but **more frequently collisions** with each other than in gases due to shorter distances between particles.
- With **increase in temperature**, the particles **move faster** as they **gain kinetic energy**, so increased collision rates, increased collision energy and increased rate of diffusion.

USING THE PARTICLE MODEL TO EXPLAIN THE PROPERTIES OF A LIQUID

- **Liquids have a much greater density than gases** ('heavier') because the particles are much closer together because of the attractive forces.
- **Liquids usually flow freely** despite the forces of attraction between the particles but liquids are not as 'fluid' as gases.

    - Note **'sticky' or viscous liquids have much stronger attractive forces** between the molecules BUT not strong enough to form a solid.
- **Liquids have a surface**, and a **fixed volume** (at a particular temperature) because of the increased particle attraction, but the shape is not fixed and is merely that of the container itself.
- Liquids are **not readily compressed** because of the lack of ‘empty’ space between the particles.
- Liquids **will expand on heating** but nothing like as much as gases because of the greater particle attraction restricting the expansion (will contract on cooling).
    - Note: When heated, the liquid particles gain kinetic energy and hit the sides of the container more frequently, and more significantly, they hit with a greater force, so in a sealed container the pressure produced can be considerable!
- The **natural rapid and random movement of the particles means that liquids ‘spread’ or diffuse**. Diffusion is much slower in liquids compared to gases because there is less space for the particles to move in and more ‘blocking’ collisions happen.
- **Evidence for random particle movement in liquids**:
    - If colored crystals of e.g. the highly colored salt crystals of potassium manganate (VII) are dropped into a beaker of water and covered at room temperature. Despite the lack of mixing, convection etc. the bright purple color of the dissolving salt slowly spreads throughout all of the liquid.



The particle model of a solid

- **A solid has a fixed volume and shape at a particular temperature unless physically subjected to some force.**
- The **greatest forces of attraction are between the particles** in a solid and they pack together as tightly as possible in a neat and ordered arrangement.
- The particles are **too strongly held together to allow movement** from place to place but the particles vibrate about their position in the structure.

With **increase in temperature, the particles vibrate faster** and more strongly as they gain kinetic energy.

USING THE PARTICLE MODEL TO EXPLAIN THE PROPERTIES OF A SOLID

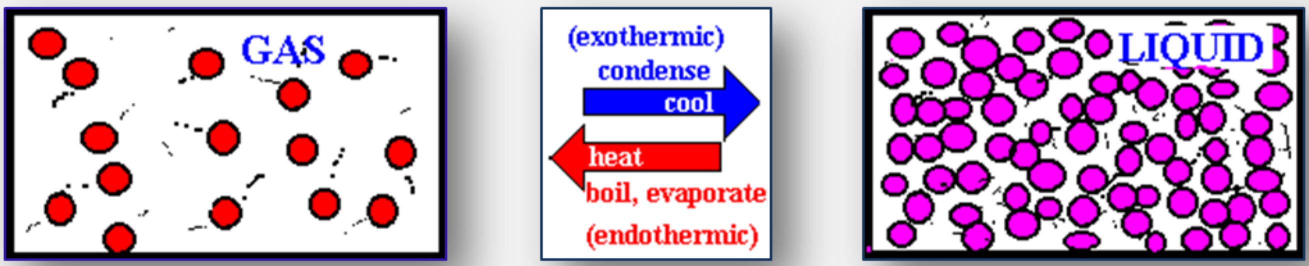
- **Solids have the greatest density** ('heaviest') because the particles are closest together.
- **Solids cannot flow freely** like gases or liquids because the particles are strongly held in fixed positions.
- Solids have a **fixed surface and volume** (at a particular temperature) because of the strong particle attraction.
- Solids are **extremely difficult to compress** because there is no real 'empty' space between the particles.
- Solids will **expand a little on heating** but nothing like as much as liquids because of the greater particle attraction restricting the expansion and contraction occurs on cooling.
    - The expansion is caused by the increased energy of particle vibration, forcing them further apart causing an increase in volume and corresponding decrease in density.
- **Diffusion is almost impossible in solids** because the particles are too closely packed and strongly held together with no 'empty space' for particles to move through.

CHANGES OF STATES FOR GAS ⇔ LIQUID ⇔ SOLID

We can use the state particle models and diagrams to explain changes of state and the energy changes involved.

These are **NOT** chemical changes **BUT PHYSICAL CHANGES**, e.g. the water molecules H_2O are just the same in ice, liquid water, steam or water vapor. What is different, is how they are arranged, and how strongly they are held together by intermolecular forces in the solid, liquid and gaseous states.

EVAPORATION AND BOILING (liquid to gas)



On **heating particles gain kinetic energy** and **move faster**.

- In **evaporation*** and boiling the **highest kinetic energy molecules can 'escape'** from the attractive forces of the other liquid particles.
- The particles lose any order and **become completely free to form a gas or vapor**.
- **Energy is needed to overcome the attractive forces** in the liquid and is taken in from the surroundings.
- This means heat is taken in, so **evaporation** and **boiling** are **endothermic** processes.

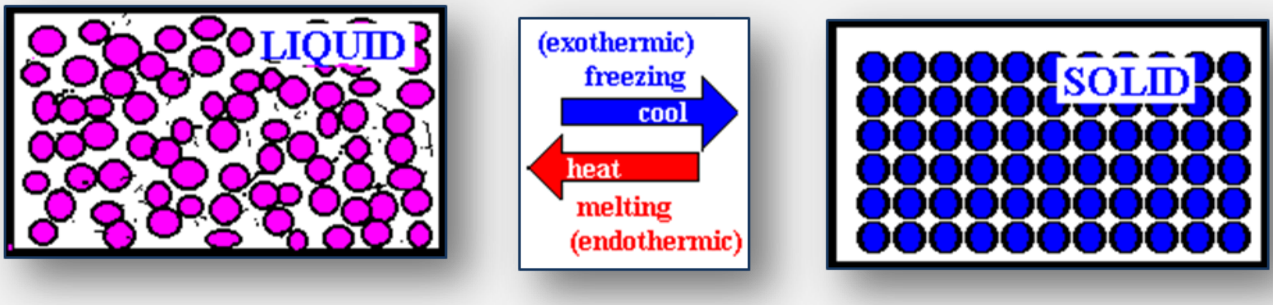
- If the **temperature is high enough boiling takes place**.
- **Boiling is rapid evaporation anywhere in the bulk liquid** and at a fixed temperature called the **boiling point** and requires continuous addition of heat.
- **Evaporation** takes place more slowly than boiling **at any temperature between the melting point and boiling point**, and **only from the surface**, and results in the liquid becoming cooler due to loss of higher kinetic energy particles.

CONDENSING (gas to solid)

- On **cooling, gas particles lose kinetic energy** and eventually become attracted together to form a liquid.
- There is an **increase in order as the particles are much closer together** and can form clumps of molecules.
- The process requires heat to be lost to the surroundings i.e. heat given out, so **condensation is exothermic**.
    - This is why steam has such a scalding effect, its not just hot, but you get extra heat transfer to your skin due to the exothermic condensation on your surface!

DISTILLATION

Simple and fractional distillation involve the processes of **boiling and condensation**



MELTING (SOLID TO LIQUID)

- When a **solid is heated the particles vibrate more strongly** as they gain kinetic energy and the particle attractive forces are weakened.
- Eventually, at the **melting point**, the attractive forces are too weak to hold the particles in the structure together in an ordered way and so the solid melts.
- The particles **become free to move around** and lose their ordered arrangement.
- **Energy is needed to overcome the attractive forces** and give the particles increased kinetic energy of vibration.

So heat is taken in from the surroundings and **melting is an endothermic process**

FREEZING (liquid to solid)

- On **cooling, liquid particles lose kinetic energy** and so can become more strongly attracted to each other.
- Eventually at the **freezing point** the forces of attraction are sufficient to remove any remaining freedom and the particles come together to form the ordered solid arrangement.

Since heat must be removed to the surroundings, so strange as it may seem, **freezing is an exothermic process.**

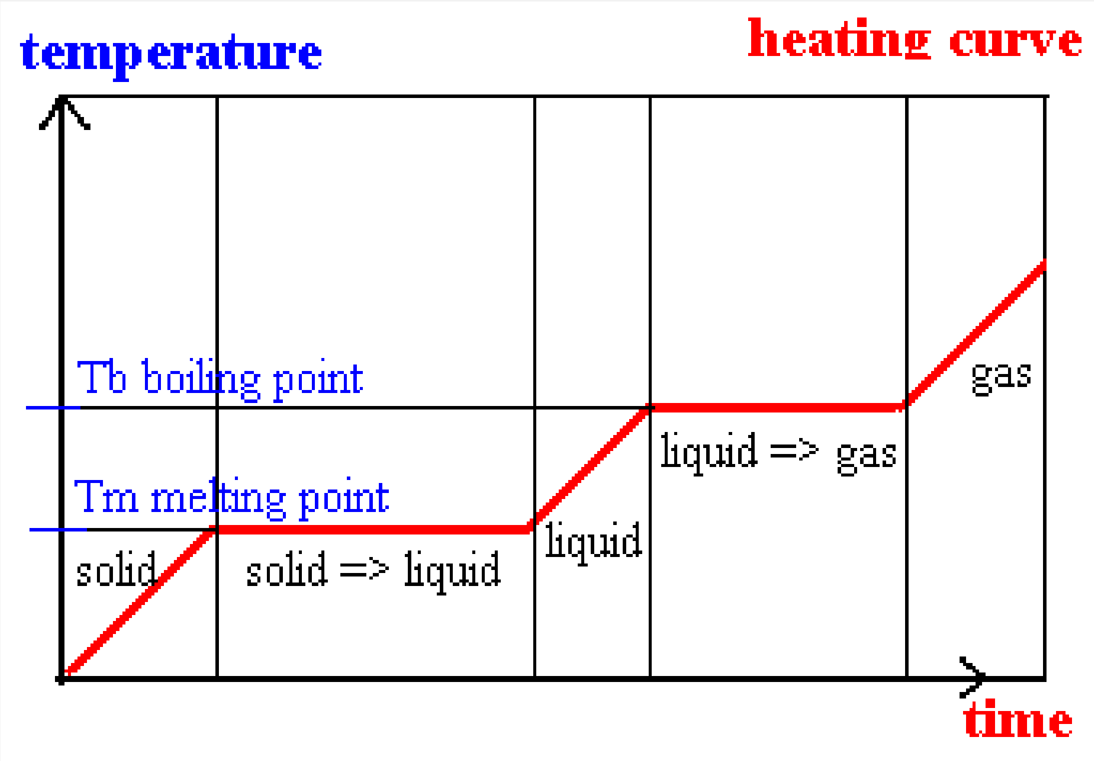
HEATING AND COOLING CURVES

And the comparative energy changes of state changes GAS ⇔ LIQUID ⇔ SOLID

HEATING CURVE: the temperature stays constant during the state changes of melting at temperature Tm and boiling at temperature Tb. This is because all the energy absorbed in heating at these temperatures (the latent heats or enthalpies of state change), **goes into weakening the inter-particle forces without temperature rise** (the heat gain equals the endothermic/heat absorbed energy required to reduce the intermolecular forces)**. In between the 'horizontal' state change sections of the graph, you can see the energy input increases the kinetic energy of the particles and raising the temperature of the substance.**

A heating curve summarises the changes:

SOLID ==> LIQUID ==> GAS

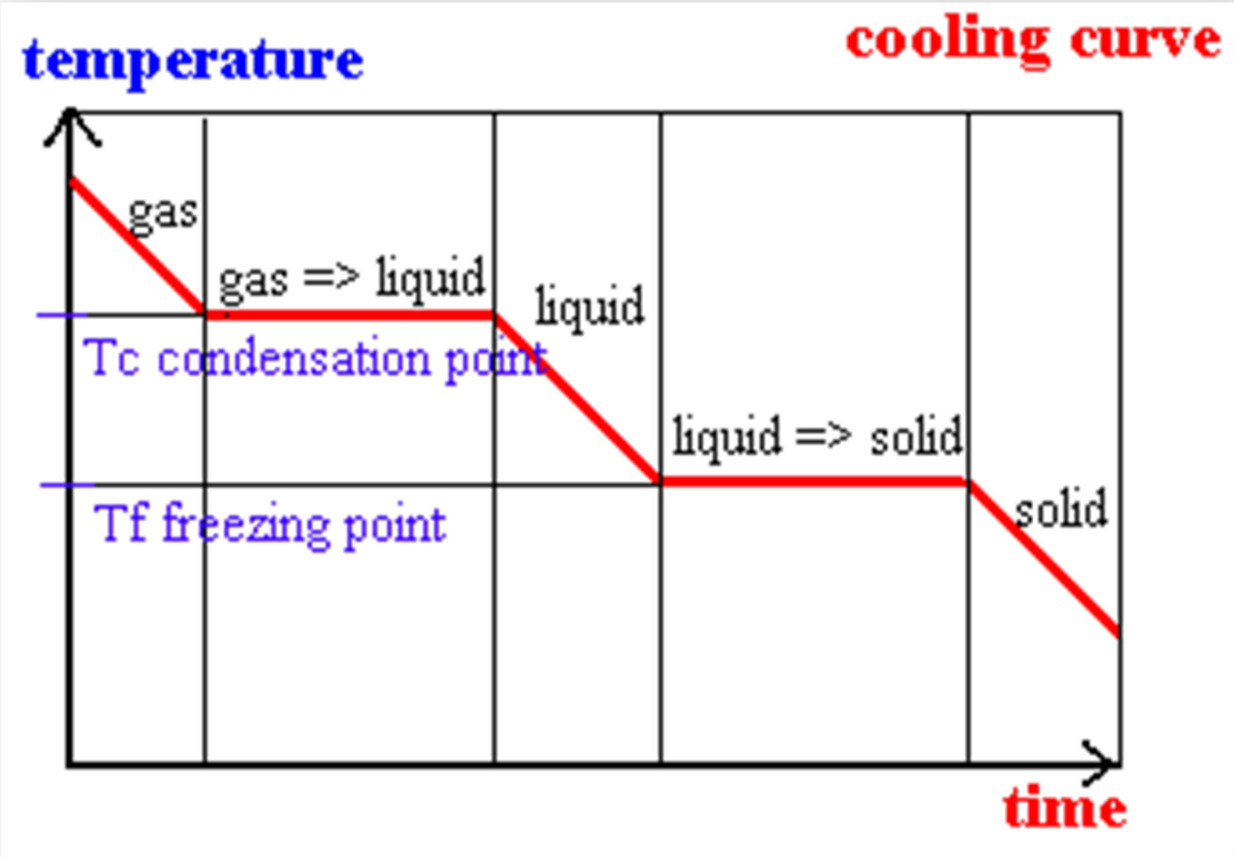


COOLING CURVE

The temperature stays constant during the state changes of condensing at temperature Tc, and freezing/solidifying at temperature T_f. This is because all the heat energy removed on cooling at these temperatures (the latent heats or enthalpies of state change), **allows the strengthening of the inter-particle forces without temperature fall** (the heat loss is compensated by the exothermic increased intermolecular force attraction)**. In between the 'horizontal' state change sections of the graph, you can see the energy 'removal' reduces the kinetic energy of the particles, lowering the temperature of the substance.**

A cooling curve summarises the changes:

GAS ==> LIQUID ==> SOLID



SUBLIMATION

- **Sublimation:**
  - **This** is when **a solid, on heating, directly changes into a gas** without melting, AND **the gas on cooling re-forms a solid directly** without condensing to a liquid. They **usually involve just a physical change** BUT its not always that simple!
- **Theory in terms of particles**:
  - When the solid is heated the particles vibrate with increasing force from the added thermal energy.
    - If the particles have enough kinetic energy of vibration to partially overcome the particle-particle attractive forces you would expect the solid to melt.
    - HOWEVER, if the particles at this point have enough energy at this point that would have led to boiling, the liquid will NOT form and the solid turns directly into a gas.
  - On cooling, the particles move slower and have less kinetic energy.
    - Eventually, when the particle kinetic energy is low enough, it will allow the particle-particle attractive forces to produce a liquid.
    - BUT the energy may be low enough to permit direct formation of the solid, i.e. the particles do NOT have enough kinetic energy to maintain a liquid state!
- **Examples**:
  1. Even at room temperature bottles of solid **iodine** show crystals forming at the top of the bottle above the solid. The warmer the laboratory, the more crystals form when it cools down at night!
     - $I_{2\,(s)} \rightleftharpoons I_{2\,(g)}$ (physical change only)
  2. The formation of a **particular form of frost** involves the direct freezing of water vapour (gas). Frost can also evaporate directly back to water vapour (gas) and this happens in the 'dry' and extremely cold winters of the Gobi Desert on a sunny day.