STRAND 2 INVESTIGATING MATTER

Strand Outcome: Describe the changes and explain the differences in structures and properties of the types of matter.

Sub-strands

2.1 States of Matter
2.2 Atomic Structure and Bonding
2.3 Elements, Compounds and Mixtures

2.1 States of Matter

Achievement Indicators

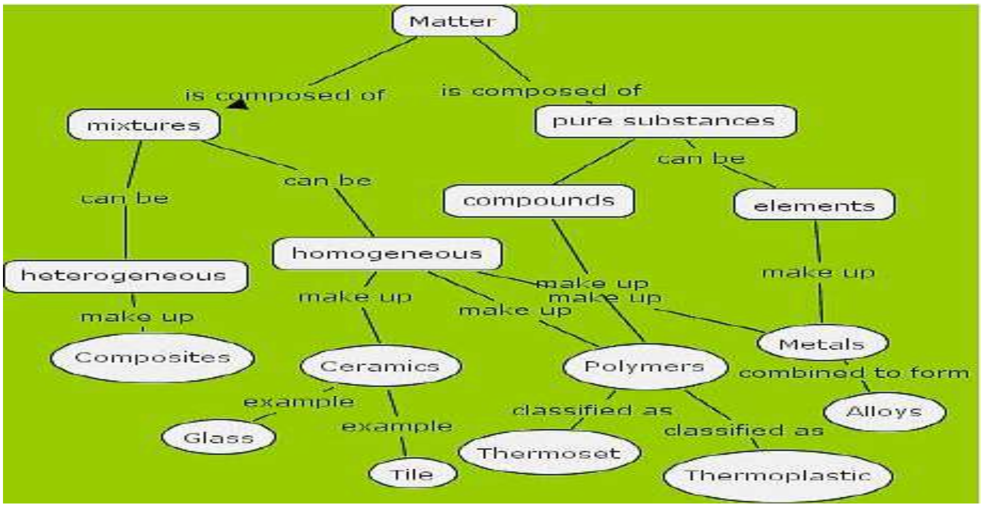
Upon completion of this sub-strand, students will be able to:

- ✓ Describe and illustrate the change in state of matter when adding and removing energy using the particle model.
- ✓ Formulate and explain the heating and cooling curves of ice (water vapour) and naphthalene.
- ✓ Measure and compare the densities of solids, liquids and solutions.
- ✓ Compare and explain the relationship between temperature and density of liquids and solutions.
- ✓ Evaluate and discuss the relationship between density and concentration of solutions.
- ✓ State and describe the diffusion of gas using gas particles behaviour.
- ✓ Show and explain gas pressure using the particle model when temperature or pressure changes.

Matter is anything that takes up space and has mass. Everything around us is made up of matter. All matter exists in three states: solid, liquid and gas. These three states can be clearly understood when considering the substance, water.

The solid form of water is ice, the liquid form of water is water that we drink and the gaseous form of water is water vapour. This unit looks at what happens to substances when they are heated or cooled causing them to move or change from one state to another.

Concept map on Matter:



The Particle Model of Matter

Matter is made up of tiny particles called atoms. These particles are so small that they are invisible. In order to study the behaviour of matter, scientists thought up a way to explain it using a model. This model, called the **Particle Model of Matter** helps us to understand what matter is and the way matter behaves.

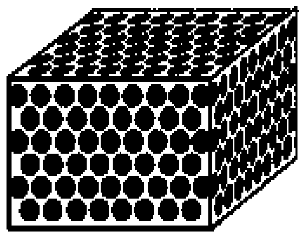
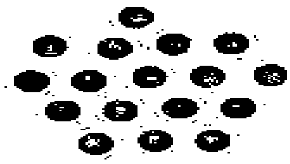
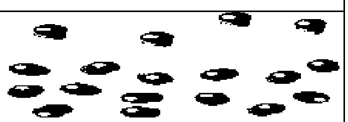
The Particle Model of matter simply states three things about matter:

1. Matter is made up of very small particles.
2. Particles in a matter are constantly moving.
3. The higher the temperature, the faster the particles will move.

States of Matter

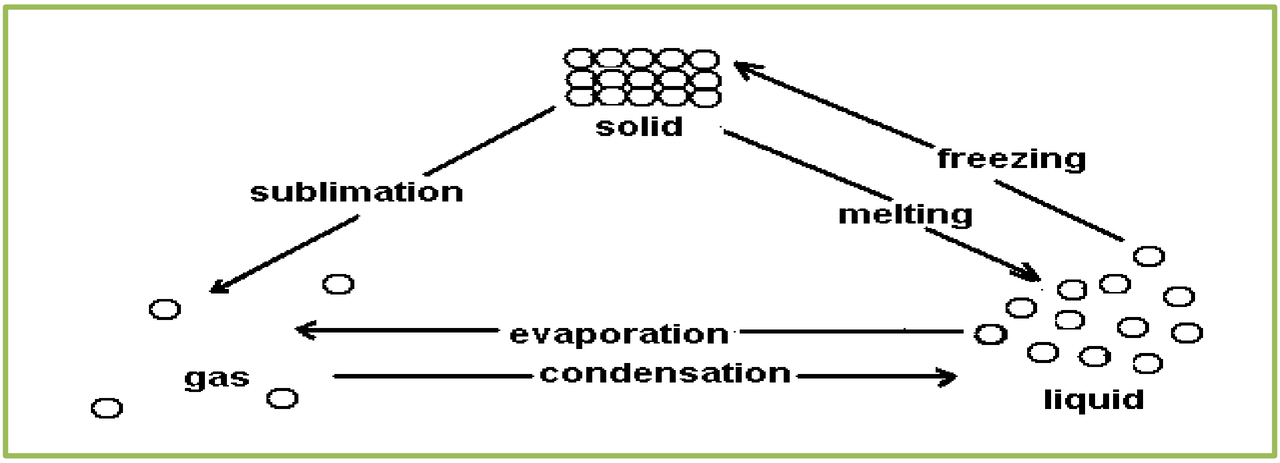
The particle model helps us to understand what matter looks like in the three states. It also helps us to understand the properties of the substance that are in a certain state.

This is discussed in greater detail in the table given below:

State of Matter	Property of State	Diagram
Solid	Particles are held very closely together. Particles are fixed in a certain position and vibrate in that position. The amount of vibration in a fixed position depends on the temperature: the higher the temperature, the faster the vibration. **Result of properties** Solids are hard	
Liquid	Particles are close together but are not set in one place. Particles in a liquid may freely move around and bump into each other. The higher the temperature, the faster the movement. **Result of Properties** Liquids flow out of vessels and take up the shape of the container they are in.	
Gas	The particles are far apart and free to move; Particles in gases travel a longer distance before bumping into each other because they are far apart; The hotter the gas, the faster the motion.	

Changes of State

When water is placed in a freezer, the liquid water becomes ice. It is said that the liquid water changes from liquid state to solid state. This means that water has changed from one state of matter to another. When changes of state are physical changes, there is no new substance formed. The figure below shows some changes of state:



Thus, when water changes from liquid to solid (ice), how can this be explained using the particle model of matter?

In liquid water, the particles are close together and able to glide over each other. When the particles are cooled, they lose energy and move more closer together until they form solid water or ice.

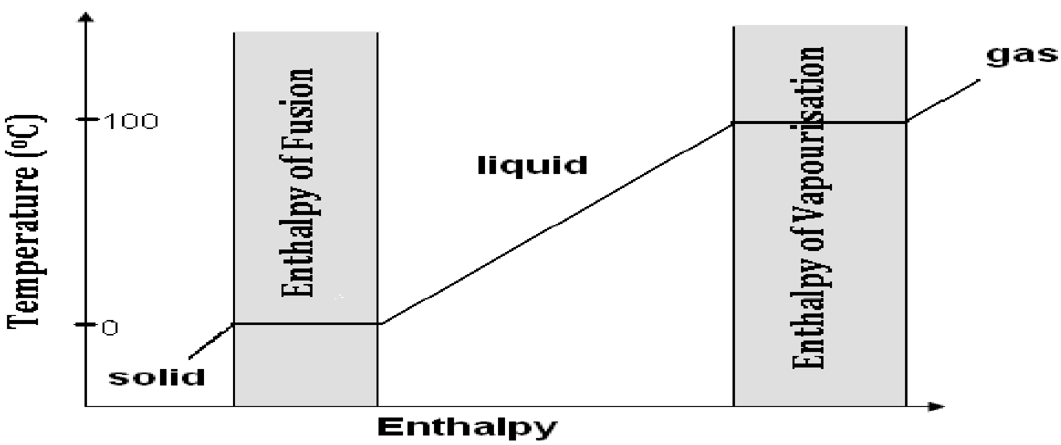
The Heating Curve of Ice

The property of a substance depends on what state of matter the substance is in. For instance, when a substance is solid, it is hard, when it is liquid it is soft and when it is in gas form, it can push a piston to power turbines when compressed.

In this section, we will look at what happens to the particles of matter when it is changing from one state to another. In order to understand this, we must look at energy. For instance, a piece of wood, when burning can produce enough energy to warm a test tube of water. This heat energy is given a special name called **enthalpy** which is the energy contained in a substance whether kinetic or potential. In the case of water, ice has the lowest enthalpy and water vapour has the highest enthalpy.

When ice is heated, or given more energy, a graph can be drawn to show the changes in the temperature of water as more temperature is added to the water.

The Heating Curve of Water



The areas on the curve that appear flat indicate that energy is being used by the particles to change state from solid to liquid. This energy is going into the particles converting them to the next state of matter.

Example

When water is heated to 100℃, it will begin to boil. The temperature will not rise beyond 10O℃ even if more heat is added to it. So where is all the heat energy going? It is going to the particles in the liquid form, causing them to move further apart and become gas. The energy that is causing this change of state from liquid to gas is called the **Enthalpy of Vaporisation.**

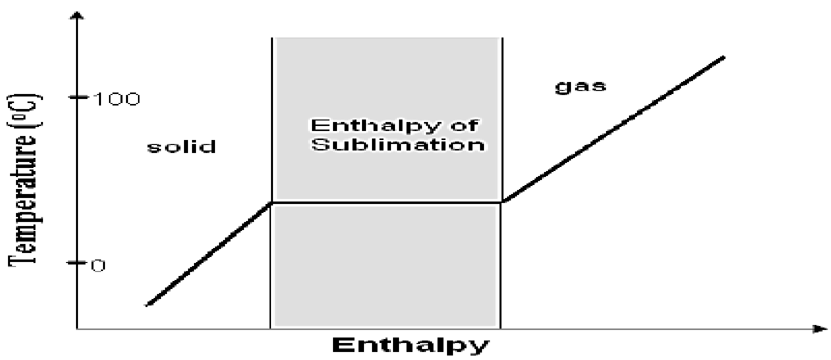
In the case of ice melting, the energy is causing the particles to move from their fixed position in the solid state, to be further apart and become liquid. This energy is called the **Enthalpy of Fusion.**

The changes discussed above are reversible changes. Thus, when water gains enthalpy, it vaporises and when it loses enthalpy, it condenses.

The Heating Curve of Naphthalene

Naphthalene has only two states – solid and gas. This is because naphthalene **sublimes** (changes directly from solid to gas).

The Heating Curve of Naphthalene



The place on the graph that appears flat is where enthalpy increases but temperature does not. This means that heat is being added but no apparent change is seen.

So where is this heat energy going to?

It is going to the naphthalene particles causing them to move further apart from each other and become gas.

This change in enthalpy is called **Enthalpy of Sublimation.**

Density

The density of an object is said to be how much matter is packed in that object. The more compactly matter is packed within an object, the higher the density of the object.

In solids, the particles are packed very closely together compared to particles in the liquid. Thus, solids are denser than liquids. This is evident when solids are placed in a liquid. They sink.

Example

Consider a block of wood and a block of metal of the same size. When weighed in your hand, the block of metal would weigh more. If the two blocks were examined more closely, it will be found that the piece of wood has small air spaces within it while the particles in the metal block are more closely packed. This is why the block of metal is denser than the block of wood.

Calculating Density

The density of a substance is calculated by dividing its mass by its volume.

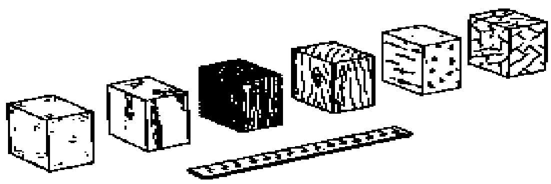
$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

The unit of density is grams per cubic centimetre (g/cm^3) or grams per millilitres (g/ml).

Density of Solids

1. Regular solid

Measure the three dimensions of each regular object, repeating each measurement at two or more places. Depending on the size of the measurement, use the ruler, vernier callipers or a micrometer.



i. Calculate the volume, V, of the object.

ii. Measure the mass, m, of the object, using the balance.

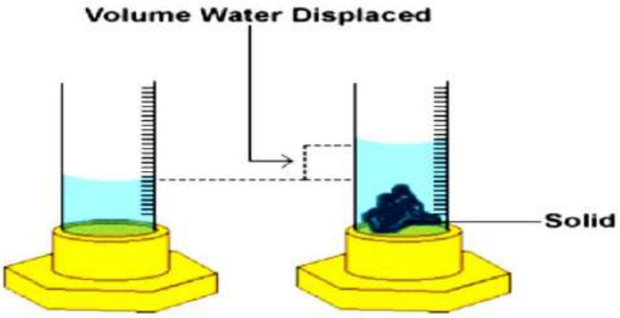
iii. Calculate the density, ρ, of each sample, using ρ = m/V.

2. Irregular Solids

i. Place the irregular solid on the scale to find its mass. Note down the mass.
ii. Find a beaker/measuring cylinder that can contain your irregular solid. You can also use other containers that measure volume.
iii. Fill the beaker with enough liquid (such as water) that the irregular solid could be completely submerged.

Write down the volume of the liquid.

iv. Place the irregular solid into the beaker and record the new volume.



v. Subtract the new volume from the original volume to find the volume of the solid.

For example, if the original volume equals 40 ml and the new volume equals 65 ml, subtract 40 from 65 to get 15 ml as the volume of the solid.

Note: Each ml equals 1 cubic centimeter (cm^3), so you can change the unit without changing the number. In this example, 15 ml becomes 15 cm^3.

Volume of water displaced = Final volume – Initial Volume
Volume of water displaced = Volume of solid
NB: 1 ml = 1 cm^3

vi. Divide the irregular solid's mass by the irregular solid's volume to find its density.

For example, if your irregular solid weighs 45 g, divide 45 g by 15 cm^3 to get a density of 3 g/cm^3.

Density of Liquids

Problem: You are given an unknown liquid. Find the density.

Materials: 100 ml graduated cylinder, triple beam balance, calculator, unknown liquid.

Procedure:

1) Find the mass of the empty graduated cylinder.

2) Pour unknown liquid 1 into the graduated cylinder to the 50 ml level.

3) Find the mass of the graduated cylinder with 50 ml of unknown liquid.

We can calculate density of a liquid using the formula:

Density = Mass/Volume

Where mass is that for just the liquid (you must subtract out the mass of the graduated cylinder).

Class Activity

Given:

Mass of empty graduated cylinder = **78 g**
Mass of graduated cylinder with unknown liquid = **117.5 g**

Find:

a) Mass of the unknown liquid. (b) Volume of the unknown liquid.
c) Density of the unknown liquid.

Exercise 2.1.1

1. A rock has a mass of 210 g and occupies a volume of 70 cm^3. What is its density?
2. An unknown liquid occupies a volume of 5 mL and has a mass of 40 g. Find its density.
3. A rock has a density of 4 g cm^{-3} and a mass of 16 g. What volume does this rock occupy?
4. An unknown substance from planet X has a density of 10 g cm^{-3}. It occupies a volume of 80 mL. What is the mass of this unknown substance?
5. Pure water has a density of 1.0 g cm^{-3} and ocean water has a density of 1.025 g cm^{-3}. Why are the densities different?

Effect of Temperature on the Density of a Substance

- When a liquid or gas is heated, the molecules move faster, bump into each other, and spread apart. Because the molecules are spread apart, they take up more space, thus becoming less dense.
- Cooling a substance causes molecules to slow down and get slightly closer together, occupying a smaller volume that results in an increase in density.
- Therefore temperature can affect density.
- Hot water is less dense and will float on room-temperature water.
- Cold water is denser and will sink in room-temperature water.

As temperature increases, the density of liquids and gases decreases; as temperature decreases, the density increases.

Effect of Concentration on the Density of a Substance

Adding more solute to a solvent changes the composition of particles in a given volume of solution. This results in a change of the mass per unit volume of the solution. Hence, the density increases.

Kinetic Theory of Gases

The theory states that a gas consists of molecules that are in constant random motion.

Gas pressure

Gas pressure is the force exerted by the particles of gas per unit area on the walls of the container. The rapid motion and collisions of molecules with the walls of the container causes pressure (force on a unit area – Nm^{-2} = Pa).When you blow air into a balloon, the balloon expands because the pressure of air molecules is greater on the inside of the balloon than the outside. Pressure is a property which determines the direction in which mass flows. If the balloon is released, the air moves from a region of high pressure to a region of low pressure.

Diffusion of Gases

Diffusion is the movement of molecules from a region of high concentration to a region of low concentration. This allows them to spread out and mix with other particles.

Examples

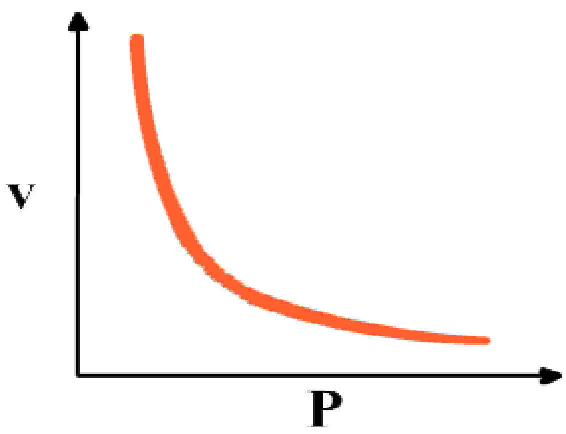
- The smell of aftershave or perfume diffuses and is detected by people on the other side of the room.
- Opening a bottle of cologne or perfume.
- Spraying air freshener.
- Smell of food being cooked.
- Smell of urine.

Relationship between volume, pressure and temperature

Have you ever wondered how an air powered water gun works? It uses the fantastic properties of gases to make a summer day more enjoyable!

Boyle's Law

Boyle's Law is a basic law in chemistry describing the behaviour of a gas held at a constant temperature. The law, discovered by Robert Boyle in 1662, states that *at a fixed temperature, the volume of gas is inversely proportional to the pressure exerted by the gas.* In other words, when a gas is pumped into an enclosed space, it will shrink to fit into that space, but the pressure that the gas puts on the container will increase.



Boyle's Law can be written out mathematically as:

P x V = constant

OR

$P_1V_1 = P_2V_2$; where P = pressure and V = volume

Real-World Examples

One example of Boyle's Law in action can be seen in a balloon. When air is blown into the balloon, the pressure of that air (a gas) pushes on the rubber, making the balloon expand. If one end of the balloon is squeezed, making the volume smaller, the pressures inside increases, making the un-squeezed part of the balloon expand out. There is a limit to how much the gas can be compressed. However, because eventually the pressure becomes so great that it causes the balloon (or any container) to break.

Another example is a syringe for taking blood. An empty syringe has a fixed amount of gas (air) in it. If the plunger is drawn back without the needle end being inserted into anything, the volume of the tube will increase and the pressure will drop, causing more air to move into the tube to equalise the pressure. If the syringe is inserted into a vein and the plunger drawn back, blood will flow into the tube since the pressure in the vein is higher than the pressure in the syringe.

Charles's Law

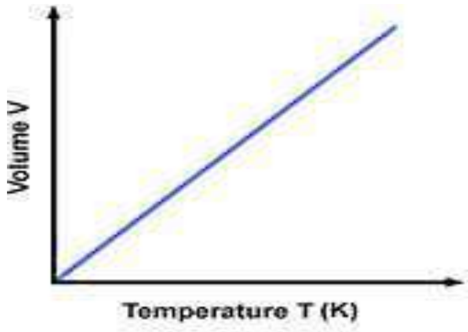
Charles's law states that if a given quantity of gas is held at a constant pressure, its volume is directly proportional to the absolute temperature. Hence, as the temperature of the gas increases, the gas molecules will begin to move around more quickly and hit the walls of the container with more force, thus increasing the volume.

Jaques Alaxandre Cesar Charles (1746-1823)

Charles's law can be written out mathematically as:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Graphically:



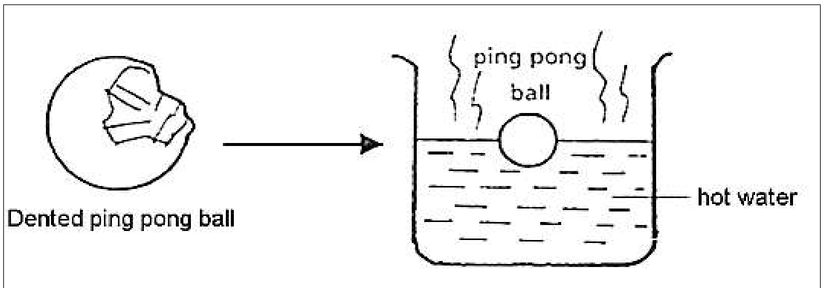
Note: Use only the *Kelvin* temperature scale when working with temperature in all gas law formulas.

Helium Balloon on a Cold Day

On a cold morning, if a helium balloon is kept outside, the balloon will crumple. However, if the balloon is taken inside a warm home, the balloon returns to its original shape. This is because the gas takes up more space when it is warm.

The Dented Ping Pong Ball

A dented ping pong (table tennis) can be restored by placing it into a saucepan half filled with water. Apply gentle heat to the saucepan, stirring constantly. If the ball is not cracked by the dent, the air inside will expand as it heats, pushing out the dent and restoring the ball to its original shape.



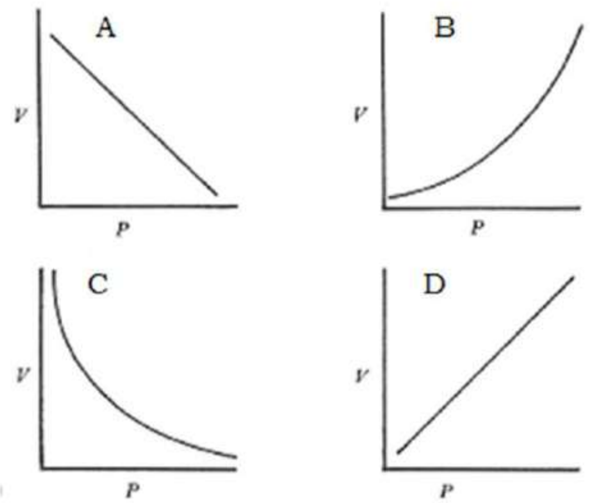
Source: http://www.oldschool.com.sg

Exercise 2.1.2

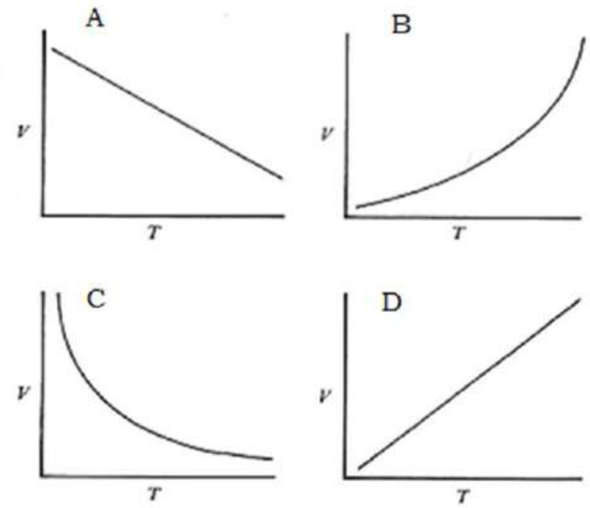
1. Enthalpy of fusion is the amount of heat energy needed to:

    A. make the particles move.
    B. change water from liquid to gas.
    C. change water from solid at 0℃ to liquid at 0℃.
    D. change water from solid at 0℃ to liquid at 100℃.

2. Volume is related to pressure by Boyle's Law. Which of the graphs below represents Boyle's Law?



3. Volume varies with temperature according to Charles' Law. Which of the graphs below represents Charles' Law?



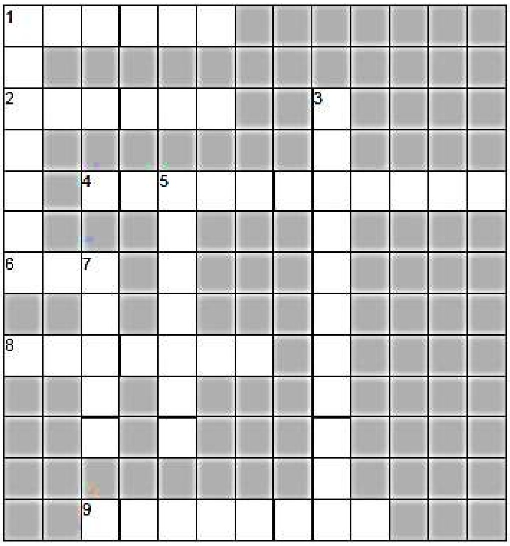
4. Gas pressure is caused by:

    A. The weight (mass) of the molecules of gas.
    B. The repulsion between gas molecules.
    C. The collision of the molecules with the walls of the container.
    D. The kinetic energy of the gas molecules.

5. Mere noticed that as she spray-painted her bicycle, the spraycan grew steadily colder. How can this be explained in terms of the kinetic theory of gases?

6. Fill in the Cross word puzzle below.

States of Matter



Across

1. Anything that has mass and occupies space.[6]
2. State where particles take the shape of the container and have a definite volume.[6]
4. Change from a solid to a gas and vice versa.[11]
6. State where particles take the shape of the container and do not have a definite volume.[3]
8. Change from solid to liquid.[7]
9. Change from a liquid to a solid.[8]

Down

1. Temperature at which a solid changes to a liquid is its ____ point.[7]
3. Change from a liquid to a gas.[11]
5. Temperature at which a liquid changes to a gas is its ____ point.[7]
7. State which has a definite shape and volume.[5]

7. Complete the concept Map below and present to the class. You can add more items to the concepts given.