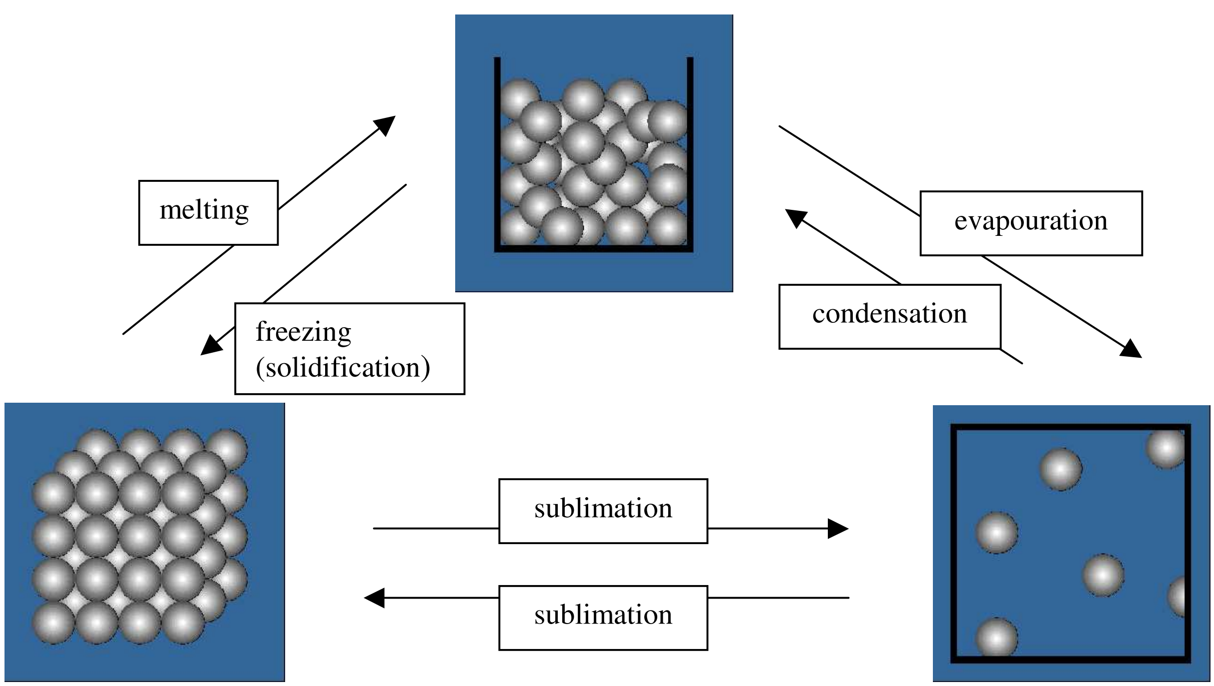
Characteristics of Solids, Liquids and Gases

	Solids	Liquids	Gases
Describe the strength of attractive forces between particles.	particles are very strongly attracted to each other	particles are somewhat attracted to each other	particles have very weak attraction for each other
Describe the amount of space between particles.	particles are as close together as possible	particles are very close together	particles are very far apart
Can the particles in this state be compressed?	particles are so close together, they can not be compressed	particles are very close together; they essentially can not be compressed	particles are very far apart so they can be significantly compressed
Do the particles in this state have a definite shape?	have a definite shape independent of their container	no definite shape; take on the shape of their container	no definite shape; take on the shape of their container
Do the particles in this state have a definite volume?	the volume is fixed	the volume is fixed	the volume can change
Can the particles in this state flow (is this state a fluid)?	the particles can not rotate around one another so they can not flow	the particles can rotate around one another so they can flow	the particles can rotate around one another so they can flow
Does the volume of this state increase when heated?	there is only very slight expansion on heating	there is only very slight expansion on heating	there is significant expansion on heating
Describe the types motion of particles in this state.	vibration only	vibration and rotation only	vibration, rotation and translation
Describe the relative potential energy of the particles.	extremely low (particles are very close together and "locked in place")	very low (particles are very close together but not "locked in place"	very high (particles are extremely far apart)

Study the following diagrams of the States of Matter. Label the names of the Changes of State between the different states.



Understanding Temperature, Pressure and the States of Matter

1. Carefully re-read the notes from the last two days. They contain a great deal of information.
2. In general, what determines the state of a substance at SATP?

   The state of a substance at room conditions is determined by the strength of int**er**-molecular attraction.

   In general, pure covalent substances are gases because their molecules are uncharged so they have very weak inter-molecular attraction.

   In general, polar covalent substances are liquids because their molecules have partially charged regions ($\delta-$ and $\delta+$). These partial charges attract the molecules to one another, so they have moderate inter-molecular attraction.

   In general, ionic substances are solids because they are made of fully charged ions. The particles have such strong inter-molecular attraction that they form a solid crystal lattice.
3. Describe what happens to the particles of a substance during:

   a) evapouration (boiling): during evapouration (boiling), the particles of a liquid are heated and start to move faster. Some of the particles have enough kinetic energy that they are able to overcome the forces of inter-molecular attraction which hold them to the other particles. The particles break away from the rest of the particles and become the gas state.

   b) sublimation of a solid: during sublimation of a solid, a few of the particles on the outside of the solid have enough kinetic energy that they can overcome the inter-molecular forces that are holding them to the rest of the particles. The particles break away from the rest of the solid and become the gas state. A good example of sublimation of a solid is “Airwick” air fresheners or deodorant “pucks” that are put in toilets and urinals.

   c) freezing: during freezing, the particles of a substance are cooled down so they move slower and slower. Eventually they are moving so slowly that they can not overcome the forces of attraction to the other particles of the substance, so they start to stick together. As more and more of the particles slow down, they are gradually attracted to one another and freeze to form a solid.
4. Define kinetic energy.

   Kinetic energy is the energy that particles have because of their motion. The faster they are moving, the higher their kinetic energy.
5. Define temperature. What does temperature tell us about the motion of the particles in a substance?

   Temperature is a measure of the average kinetic energy of the particles in a substance. Temperature tells us, on average, how fast the particles are moving. Not all of the particles are moving at the same speed, so temperature is the average speed.
6. Explain why the Kelvin temperature scale must be used to describe molecular motion.

   The Kelvin temperature scale is an absolute scale. Zero Kelvins (0 K) means zero motion. As the Kelvin temperature increases, the kinetic energy (molecular motion) of the particles increases in direct proportion.

   The Celsius temperature is based on the freezing and boiling points of water, so it has no direct relationship to the molecular motion of particles in general. Also, the Celsius scale includes negative values, and there is no such thing as negative motion, so it can not be used to describe molecular motion.
7. Convert between the following temperature units:

a) 25ºC	= 298 Kelvins	d) 0 K	= -273 ºC
b) 25K	= -248 ºC	e) 0ºC	= 273 Kelvins
c) 100ºC	= 373 Kelvins	f) 100K	= -173 ºC

8. Define potential energy.

   Potential energy is the energy that objects (particles) have because of their position and attraction to other objects (particles).

9. Which state of matter has the lowest potential energy? Which state of matter has the highest?

   The particles in the gas state are very far apart, so they have the highest potential energy.

   The particles in the liquid state are quite close together. There is little space between the particles so liquids have moderate potential energy.

   The particles in the solid state are very close together. There is almost no space between the particles, so they have very low potential energy.

10. Compare the potential and kinetic energies of the following substances:

    a) a piece of ice at -28ºC and a piece of ice at -1ºC:

    - both substances are in the solid state, so they have essentially the same (very low) potential energy
    - the water molecules in the piece of ice at -28ºC are moving more slowly than the particles in the ice at -1ºC, so the ice at -28ºC has lower kinetic energy

    b) a bottle of water vapour at 25ºC and a bottle of liquid water at 25ºC

    - the bottle of water vapour is in the gas state so its particles are further apart and have higher potential energy than the water molecules in the liquid state, which are much closer together
    - both substances are at the same temperature, so their particles have the same average kinetic energy (they may have different forms of motion, but the amount of motion is the same)

    c) ammonia gas at 15ºC and ammonia liquid at -15ºC

    - the ammonia particles in the gas state are further apart so they have higher potential energy than the ammonia particles as a liquid, which are much closer together
    - the ammonia particles in the gas state are also at a higher temperature than the ammonia particles in the liquid state. Because they have a higher temperature, the ammonia particles in the gas state have higher average kinetic energy

11. Define pressure.

    Pressure is a measure of the force exerted over a certain area. Gases exert pressure on the walls of their container when the particles collide with the container's surface.

12. Convert between the following pressure units. Use the conversion factor method. Round your answer to the same number of significant digits as the original value.

    a) 2.25 atm to Torr: $2.25 \text{ atm} \times \frac{760 \text{ Torr}}{1 \text{ atm}} = 1710 \text{ Torr}$ (3 sig digs)

    b) 98.2 kPa to PSI: $98.2 \text{ kPa} \times \frac{15 \text{ PSI}}{101.3 \text{ kPa}} = 14.5 \text{ PSI}$ (3 sig digs)

    c) 32 PSI to atm: $32 \text{ PSI} \times \frac{1 \text{ atm}}{15 \text{ PSI}} = 2.1 \text{ atm}$ (2 sig digs)

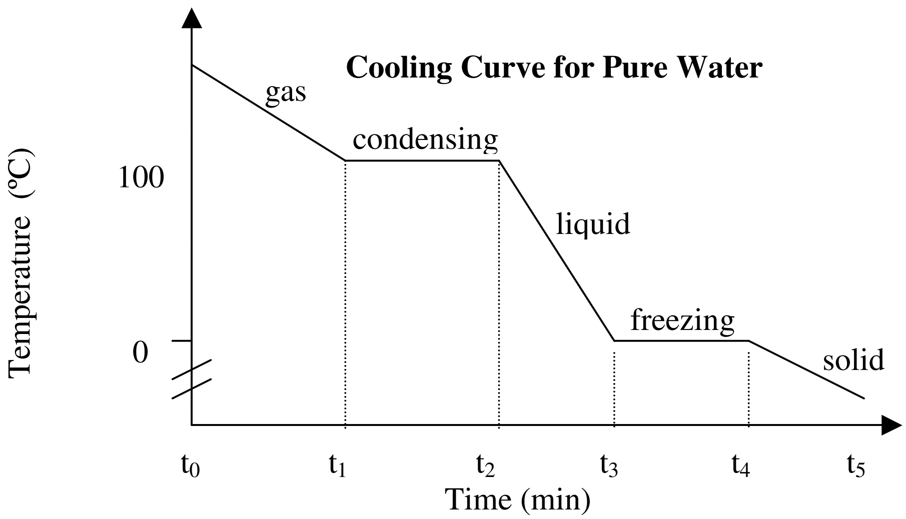
    d) 155.4 kPa to mmHg: $155.4 \text{ kPa} \times \frac{760 \text{ mmHg}}{101.3 \text{ kPa}} = 1166 \text{ mmHg}$ (4 sig digs)

Interpreting Energy Changes during Heating, Cooling and Changes of State

Key Points:

1. Temperature is a measure of the average **kinetic** energy of the particles in a substance.
2. When temperature is increasing, the motion of the particles in the substance is **increasing**.
3. When temperature is decreasing, the motion of the particles in the substance is **decreasing**.
4. The state of a substance determines the average **potential** energy of the particles in a substance.
5. In the solid state, the particles are very close together, so they have **low** potential energy.
6. In the liquid state, the particles are fairly close together, so they have **medium** potential energy.
7. In the gas state, the particles are very far apart, so they have **very high** potential energy.

When the temperature of a substance is changing, **kinetic** energy is changing and **potential** energy is constant. When the state of a substance is changing, **potential** energy is changing and **kinetic** energy is constant.



1. Refer to the cooling curve above, indicate if the following statements are **True or False**:

a) From t_1 to t_2, the motion of the particles is decreasing. **False**. Temperature is not changing.
b) From t_2 to t_3, the particles are getting closer together. **False**. State is not changing.
c) From t_0 to t_1, the motion of the particles is decreasing. **True**. Temperature is decreasing.
d) From t_3 to t_4, the potential energy of the particles is decreasing. **True**. The substance is turning solid.
e) From t_3 to t_4, the motion of the particles is increasing. **False**. Motion is constant (temp is constant).
f) From t_1 to t_2, the potential energy of the particles is constant. **False**. The substance is turning to liquid.

2. In regions on cooling curves when temperature is decreasing, what is happening to the:

a) motion of the particles: **decreasing** (decreasing temperature means that the particles are slowing down, so the average motion of particles decreases)
b) distance between the particles: **constant** (state is not changing so particles are no closer together)
c) kinetic energy of the particles: **decreasing** (temperature measures average kinetic energy)
d) potential energy of the particles: **constant** (state is not changing so particles are no closer together)
e) state of the particles: **constant** (when state changes, the temperature is constant)

3. In regions on cooling curves when temperature is constant, what is happening to the:

a) motion of the particles: **constant** (temperature measures the motion of particles, and temp is constant)
b) distance between particles: **decreasing** (in regions where temp is constant, potential energy changes)
c) kinetic energy of the particles: **constant** (temperature measures the average kinetic energy of particles)
d) potential energy of the particles: **decreasing** as the particles get closer together and change state
e) state of the particles: **changing** (in regions where temp is constant, state is changing)

The Kinetic Molecular Theory Applied to Gases

The Kinetic Molecular Theory is a set of statements which is used to explain the characteristics of the states of matter. The following additional statements apply specifically to the gaseous state.

1. Gases consist of small particles, either atoms or molecules depending on the substance, which are very far apart and their size is negligible (the particles themselves have essentially no volume).
2. Gas particles are in rapid and random, straight-line motion. The motion follows the normal laws of physics.
3. Collisions of the particles with the walls of their container or with other particles are PERFECTLY ELASTIC. This means that there is no loss of energy when particles collide.
4. There are essentially no attractive forces between gas particles.
5. The average kinetic energy of the particles is directly proportional to temperature. As the temperature of a gas is increased the particles move faster thereby increasing their kinetic (motion) energy.

To simplify the study of gases, scientists have defined an "**Ideal Gas**" as a gas in which:

1. Gas particles are so small that the particles themselves have no volume. This means that at absolute zero (0 K), when all motion stops, the volume occupied by the gas is zero.
2. The gas particles have zero attraction to each other (no inter-molecular attraction).

While neither of these assumptions is strictly true, they are acceptable approximations to predict the behaviour of gases under normal conditions of temperature and pressure.

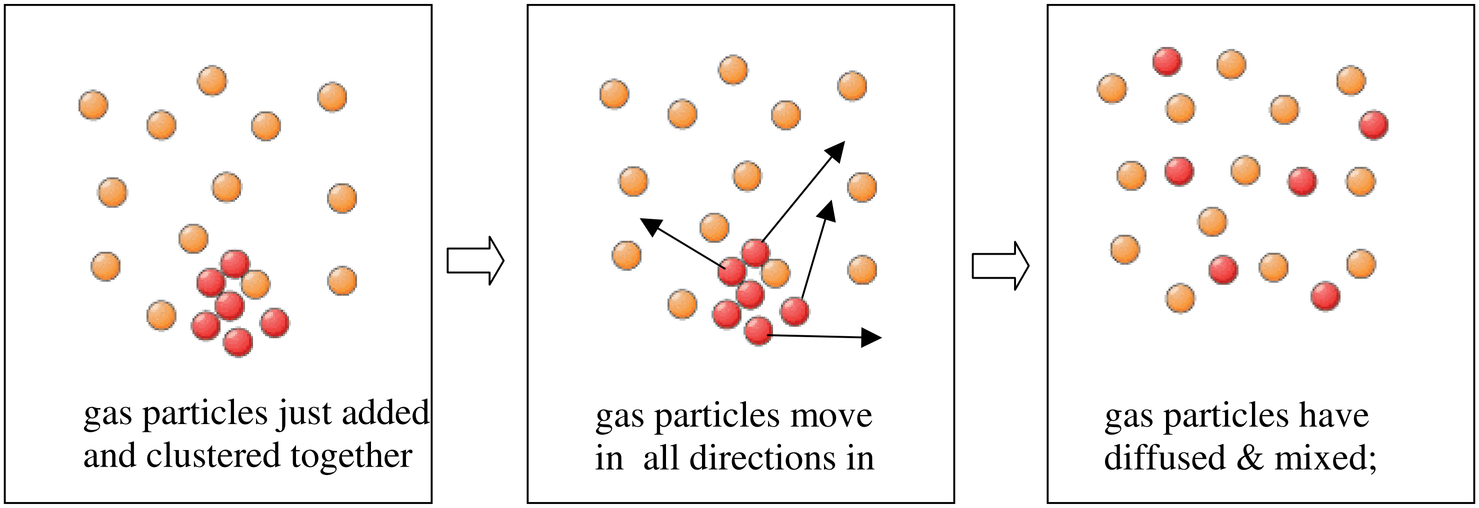
Questions:

1. What type(s) of molecular motion do particles display when they are in the gas state? Describe each type of motion.

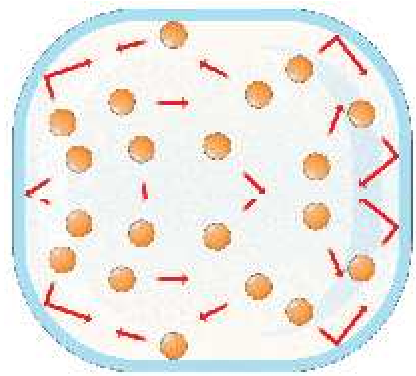
   Gas particles show vibration (motion back and forth along the chemical bonds), rotation (the atoms and molecules spin on a fixed axis) and translation (the molecules move from place to place).

2. Use the points of the Kinetic Molecular Theory to explain the following characteristics of gases:
   a) **Gases always fill their container**: the particles in the gas state move in rapid, random, straight line motion. They keep moving in a straight line until they hit something, either the wall of their container or another particle. Because they don't stop moving until they hit something, they will always spread out and fill their container.
   b) **Gases are easily compressed**: the particles in the gas state are very far apart and have essentially no attraction for one another. If pressure is exerted on the gas, the particles can be forced closer together and into a smaller space. If a gas is sufficiently compressed, it will eventually become a liquid as the particles are forced very close together.
   c) **Gases mix readily with other gases**: the particles in the gas state move constantly in rapid, random straight line motion. Also, the particles are very far apart. If two gases are mixed, the particles of both types of gases will move in straight lines, and move into the spaces between the particles of the other gas. In this way, the gases very quickly mix.
   d) **Gases diffuse**. For example, the smell of ammonia gas gradually spreads throughout a room. Gas particles move in rapid, random straight-line motion. A room is full of air, which is a mixture of gases. Ammonia gas particles will move out from their source into the air in straight lines until they hit something- either an "air" molecule or the wall of the room.

Diagram showing diffusion of gases**:**



e) **Gases exert pressure**: gas particles move freely in rapid, random straight-line motion until they hit something. When they hit the walls of their container, they bounce against it and then deflect off in another direction. Every time a gas particle hits the wall of the container, it pushes on it, which exerts pressure. All of the particles together can exert considerable pressure (force).



f) **The pressure exerted by a gas increases as the temperature increases**: when the temperature of a gas increases, the particles move more quickly. This means that they will hit the walls of their container harder, exerting more force. Because they are moving faster, they will also hit the walls more often. More collisions and harder collisions between the gas particles and the container mean that the pressure exerted by the gas will increase.

3. Students are sometimes asked to visualise gas particles as if they were 'billiard-balls' bouncing off each other and the sides of a pool table. Why is this not a completely accurate model of gas behaviour?

Gas particles are like billiard balls in that both particles and billiard balls have essentially no attraction between them, and if they hit each other or the sides of their container, they will bounce off and move in the other direction. However, gas particles are unlike billiard balls because the collisions of gas particles are perfectly elastic, so no energy is transferred to the walls of their container. This means that gas particles (at constant temperature) do not slow down with time, and they never stop moving. In contrast, when billiard balls roll across the table, collide with each other and collide with the sides of the table, they lose some of their kinetic energy to the billiard table and eventually slow down and stop moving.