Unit 4: Kinetic Molecular Theory and Gas Laws
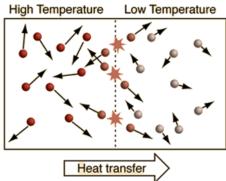
SC5. Obtain, evaluate, and communicate information about the Kinetic Molecular Theory to model atomic and molecular motion in chemical and physical processes.

SC5. a. Plan and carry out an investigation to calculate the amount of heat absorbed or released by chemical or physical processes. (Calculation of enthalpy, heat change, and Hess's Law are addressed in this element.)

The universe is composed of matter and energy. Chemistry is fundamentally the study of matter, and energy affects matter by doing work on the particles to change their motions and intermolecular forces. Temperature is a measure of these random motions, and it is commonly defined as "the average kinetic energy of the particles of the sample." Temperature changes often accompany physical and chemical changes of matter.
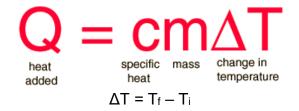

For physical changes:
As heat flows out of a substance, the temperature of the substance often decreases. As heat flows into a substance, the temperature often increases. (Not always…often. Sometimes heat flow affects intermolecular forces rather than motion. This will be discussed in SC5.b.) Heat is defined as the flow of energy due to a temperature difference.

The direction of the heat flow is predictable. It always flows from hot to cold until the particles reach the same average kinetic energy, or temperature. The flow of heat can be calculated in relationship to the temperature change it causes using the following equation:

$$Q = cm\Delta T$$

heat added — specific heat — mass — change in temperature

$$\Delta T = T_f - T_i$$

In chemical changes:

Chemists study the energy produced or absorbed in endothermic and exothermic reactions by measuring enthalpy change, ΔH. A principle, called Hess's Law, can be used to calculate the ΔH of a chemical reaction if the measurement cannot be made directly. Hess's law uses a series of known reactions and their enthalpy changes to build a goal reaction and calculate its enthalpy change. Basically, the known reactions can be reversed, multiplied or divided and then added together to give the goal reaction. If a known reaction is manipulated, then its ΔH value must be adjusted as well. Then, the adjusted ΔH values can be added together to produce an enthalpy change for the goal reaction.

Change in Reaction	Adjustment for ΔH
Reverse the reaction	Change the sign of ΔH
Multiply coefficients by a number	Multiple ΔH by the same number
Divide coefficients by a number	Divide ΔH by the same number

SC5. b. Construct an argument using a heating curve as evidence of the effects of energy and intermolecular forces on phase changes.

As heat flows into and out of a substance, phase changes can occur. Phase changes are common physical changes, and students often have a few misconceptions.
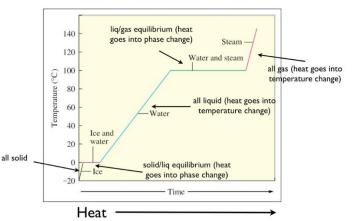
Review of Phase Changes:
Endothermic Phase Changes (energy is required):
- Melting (solid to liquid) – Solid particles experience strong intermolecular forces due to their close proximity to one another and slow motion. Melting is the process of weakening the intermolecular forces to allow for greater space and movement. Energy is required to weaken these intermolecular forces.
- Evaporation (liquid to gas) – Liquid particles experience some intermolecular forces due to their proximity to one another. Evaporation is the process of breaking the intermolecular forces to allow for much greater space and movement. Energy is required to break these intermolecular forces.
- Sublimation (solid to gas) - Solid particles experience strong intermolecular forces due to their close proximity to one another and slow motion. Sublimation is the process of breaking the intermolecular forces to allow for much greater space and movement. Energy is required to break these intermolecular forces.

Exothermic Phase Changes (energy is released):
- Freezing (liquid to solid) – Solid particles experience strong intermolecular forces due to their close proximity to one another and slow motion. Freezing is the process of allowing these intermolecular forces to grow in strength to reduce space and movement. Energy is released to allow these intermolecular forces to strengthen.
- Condensation (gas to liquid) – Liquid particles experience some intermolecular forces due to their proximity to one another. Condensation is the process of allowing the intermolecular forces to strengthen to reduce space and movement. Energy is released to allow these intermolecular forces to re-develop.
- Deposition (gas to solid) - Solid particles experience strong intermolecular forces due to their close proximity to one another and slow motion. Deposition is the process of forming the intermolecular forces to greatly reduce space and movement. Energy is released to allow these intermolecular forces to re-develop.

Heating curves are graphical representations of the temperature and phase changes associated with a flow of heat into a sample.

<u>Conceptual Observations and Explanations of the Water Heating Curve:</u>
- General observations:
  - The x-axis is labeled "Time," and it is not marked with specific values.
  - The y-axis is labeled "Temperature (°C)," and it is marked with specific temperatures.
  - The overall slope of the graph is positive. This means that the graph illustrates changes occurring when heat is ADDED to the sample.
  - The graph consists of 5 segments. Some segments are diagonal lines, and others are plateaus.

- Segment by Segment observations (from left to right):
  - -20°C to 0°C: The sample is a solid, and the particles are experiencing strong intermolecular forces. The temperature is initially -20°C, and it increases to 0°C. The kinetic energy of the particles must be increasing if the temperature is increasing.

  - At 0°C: The temperature is no longer changing. The temperature remains constant over a period of time. The melting point of water is 0°C. The heat being absorbed during this time period is being used to weaken intermolecular forces rather than to increase the kinetic energy of the particles. The sample is mainly solid at the beginning of this time, and it is mainly liquid at the end of this time.

  - 0°C to 100°C: The sample is a liquid, and the particles are experiencing some intermolecular forces. The temperature is initially 0°C, and it increases to 100°C. The kinetic energy of the particles must be increasing if the temperature is increasing.

  - At 100°C: The temperature is no longer changing. The temperature remains constant over a period of time. The boiling point of water is 100°C. The heat being absorbed during this time period is being used to break intermolecular forces rather than to increase the kinetic energy of the particles. The sample is mainly liquid at the beginning of this time, and it is mainly gas at the end of this time.

  - 100°C to 140°C: The sample is a gas, and the particles are experiencing no intermolecular forces. The temperature is initially 100°C, and it increases to 140°C. The kinetic energy of the particles must be increasing if the temperature is increasing.

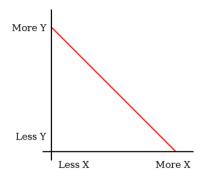<u>Quantitative Explanations of the Water Heating Curve:</u>
- General observations:
  - The overall slope of the graph is positive. This means that the graph illustrates changes occurring when heat is ADDED to the sample. Therefore, the Q values calculated for each segment and added together in the end should be (+) values.
  - TWO equations:
    - Diagonal Lines = Temperature changes occur: $Q = mc\Delta T$
    - Plateaus = Temperature does NOT change: $Q = (mol) \Delta H$

- Segment by Segment observations (from left to right):
  - ⁻20°C to 0°C (diagonal line): The temperature is initially ⁻20°C, and it increases to 0°C. Calculate the heat absorbed to cause this temperature change using $Q = mc\Delta T$. The ΔT is (final – initial): (0°C - ⁻20°C).

  - At 0°C: The temperature is no longer changing. Calculate the heat absorbed to weaken the intermolecular forces using $Q = (mol) \Delta H$. The molar enthalpy of fusion is used here, and it will be given as a constant.

- 0°C to 100°C: The temperature is initially 0°C, and it increases to 100°C. Calculate the heat absorbed to cause this temperature change using $Q = mc\Delta T$. The ΔT is (final – initial): (100°C - 0°C).

- At 100°C: The temperature is no longer changing. Calculate the heat absorbed to break the intermolecular forces using $Q = (mol)\ \Delta H$. The molar enthalpy of vaporization is used here, and it will be given as a constant.

- 100°C to 140°C: The temperature is initially 100°C, and it increases to 140°C. Calculate the heat absorbed to cause this temperature change using $Q = mc\Delta T$. The ΔT is (final – initial): (140°C - 100°C).

SC5. c. Develop and use models to quantitatively, conceptually, and graphically represent the relationships between pressure, volume, temperature, and number of moles of a gas.
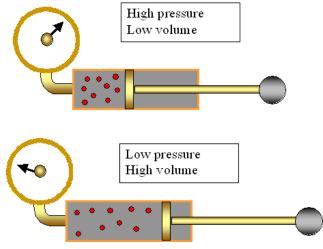
For our purposes, gas particles experience no intermolecular forces. With those forces absent, predictable relationships exist between variables that describe a particular gas sample.

Pressure and Volume Relationship:

The pressure of a gas is inversely proportional to its volume at constant temperature. Therefore, if the volume is large, then the pressure is small. When particles are required to exist in a smaller space, they are likely to collide with the walls of the container more often and exert a greater force, or pressure, on the container. Graphically, inverse relationships give negative slopes. Mathematically, inversely proportional variables are always arranged in the following format:
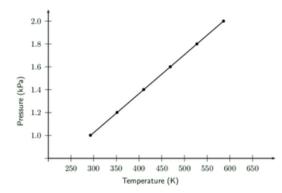
$$X_1Y_1 = X_2Y_2$$

As a result, the mathematical relationship between pressure and volume of a gas is: $P_1V_1 = P_2V_2$. The relationship is called Boyle's Law.
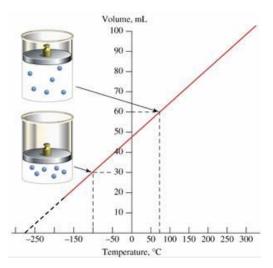
Pressure and Temperature Relationship:

Pressure and Kelvin temperature have a direct relationship. When temperature increases, the particles move more quickly and collide with the walls of their container more often and with greater energy. This results in a higher pressure.
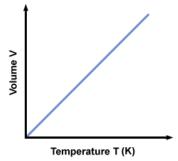
Graphically, direct relationships give positive slopes. Mathematically, directly proportional variables are always arranged in the following format:
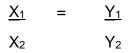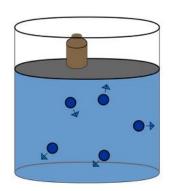

Temperature T   Temperature 3T

$$\frac{X_1}{X_2} = \frac{Y_1}{Y_2}$$

As a result, the mathematical relationship between pressure and Kelvin temperature, called Gay-Lussac's law, is $P_1/T_1 = P_2/T_2$.

Volume and Temperature Relationship:

Volume and Kelvin temperature have a direct relationship. When temperature increases, the particles move more quickly and collide with the walls of their container more often and with greater energy. This results in a larger volume if the container has flexible walls.
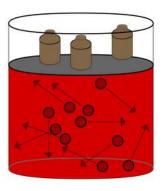

Graphically, direct relationships give positive slopes. Mathematically, directly proportional variables are always arranged in the following format:
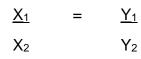
$$\frac{X_1}{X_2} = \frac{Y_1}{Y_2}$$

As a result, the mathematical relationship between volume and Kelvin temperature, called Charles's law, is $V_1/T_1 = V_2/T_2$.

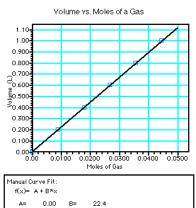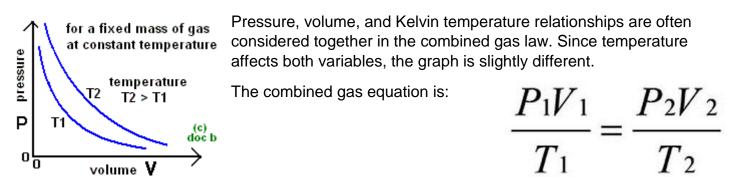## Number of Moles and Volume Relationship:

Volume and number of moles have a direct relationship. When the number of moles of gas increases, the volume holding the particles increases as well if the container has flexible walls.

Graphically, direct relationships give positive slopes. Mathematically, directly proportional variables are always arranged in the following format:
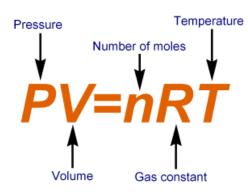
$$\frac{X_1}{X_2} = \frac{Y_1}{Y_2}$$

As a result, the mathematical relationship between moles of gas and volume, called Avogadro's law, is $V_1/n_1 = V_2/n_2$.

Combined Gas Law (Pressure, Volume, and Kelvin Temperature Relationship):

Pressure, volume, and Kelvin temperature relationships are often considered together in the combined gas law. Since temperature affects both variables, the graph is slightly different.

The combined gas equation is:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Ideal Gas Law:

Perhaps the most useful and significant of the gas laws is the ideal gas law, which includes the relationships between all of the variables.

The temperature must be in Kelvin, and the other variable units can be determined by the form of gas constant used. In most cases, the gas constant, R, will be 0.0821 L atm/ mol K.

Units	Numerical Value
L-atm/mol-K	0.08206
J/mol-K*	8.314
cal/mol-K	1.987
m^3-Pa/mol-K*	8.314
L-torr/mol-K	62.36

*SI unit