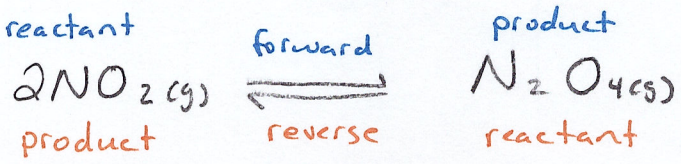
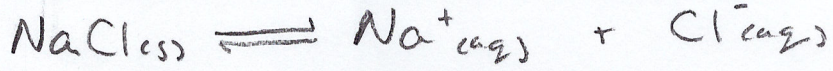
Reversible Reactions & Equilibrium

- Typically when we think of a chemical reaction, we think all the reactants get completely used up and are only left with new products
- However, many chemical reactions are *reversible* under the right conditions, which means the forward and the reverse reaction can occur
  - A double headed arrow indicates when a reaction is reversible
- Example:



Since the reaction continues in both directions (forward and reverse) at the same time, we never run out of either NO_2 or N_2O_4. NO_2 is continually being used to form N_2O_4, but at the same time N_2O_4 breaks down to form NO_2

- Another reversible reaction is dissolving salt in a beaker of water:



  - If more and more solid salt is added, eventually no more salt will be able to dissolve and the excess salt sits at the bottom of the beaker (the solution has reached the point of a *saturated solution*)
  - Has the dissolving reaction stopped? No!
  - The saturated solution has reached a point of **equilibrium**. Both the forward reaction, $NaCl_{(s)} \longrightarrow Na^+_{(aq)} + Cl^-_{(aq)}$ and the reverse reaction, $Na^+_{(aq)} + Cl^-_{(aq)} \longrightarrow NaCl_{(s)}$ occur at the *same rate*.
  - The solid NaCl dissolves to produce aqueous ions, but at the same rate and time, those aqueous ions recrystallized to form solid NaCl. Therefore, there are no observable or measurable changes in the system.

✳ • **Equilibrium** is the state at which the *rate* of the forward reaction *equals* the rate of the reverse reaction. At the point of equilibrium, no observable or measurable change can be made.
  - Equilibrium has nothing to do with equal amounts of reactants or products
  - The forward and reverse reactions continue at a molecular level even thought the reaction *appears* to have stopped at a macroscopic level!
  - In order for a reversible reaction to reach the point of equilibrium, the reaction must be carried out in a *closed system* (no additional reactants or produces can be added/removed) at constant temperature.

microscopic

observable with human eye

- EXAMPLES:
  - In a sealed aquarium, the liquid water and vapour water are at equilibrium as long as the temperature doesn't change
  - A carbonated soft drink is a closed system where carbon dioxide gas and dissolved carbon dioxide are in equilibrium. This equilibrium is distributed when the bottle is opened and a new equilibrium will be established

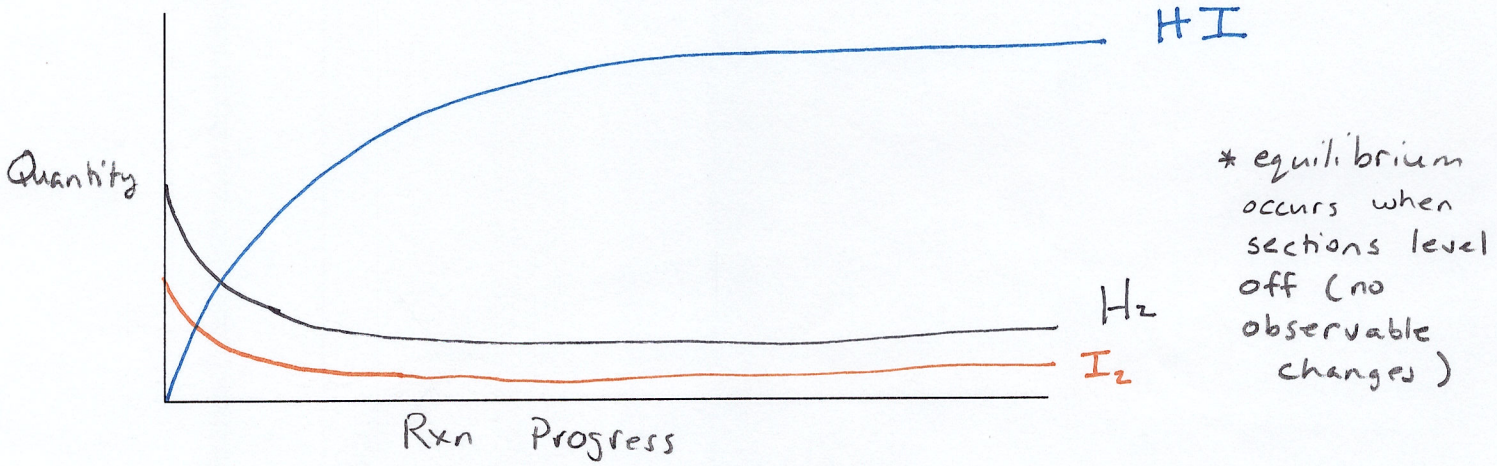
Demo this!

- Since a system at equilibrium can have different amount of reactants or products, a reaction at equilibrium can either *favour* the product or reactant side.
  - If more reactants remain than products, the reaction favours the reactants
  - If more products are produced, the reaction favours the product side

EXAMPLE: The reaction between hydrogen gas and iodine, $H_{2(g)} + I_{2(aq)} \longleftrightarrow 2HI_{(g)}$ came to equilibrium and the concentration of all species were measured. Hydrogen gas and iodine had a concentration of 0.022mol/L and hydrogen iodine had a concentration of 0.156mol/L.

  - The product side of the reaction is favoured
  - A Graphical Representation

REACTION OF HYDROGEN AND IODINE AT 448°C



  - If the product $HI_{(g)}$ was removed as it was formed, would the system reach equilibrium?

No, system is no longer a closed system.

*****Now try Practice Problems*****

Practice Problems: Reversible Reactions and Equilibrium

1. What is the difference between macroscopic and microscopic properties?
2. What must occur to create an equilibrium?
3. What is happening on the microscopic level during a dynamic equilibrium?
4. Write reversible reactions for each of the following situations (be sure to balance your equations):
    a. Hydrogen iodide gas (HI) decomposes into its elements.
    b. Hydrogen and nitrogen gases combine to form ammonia gas, NH_3

5. If the system represented by the following equation is found to be at equilibrium at a specific temperature, which of the following statements is true? Explain your answers.

$$H_2O_{(g)} + CO_{(g)} \leftrightarrow H_{2\,(g)} + CO_{2\,(g)}$$

    a. All species must be present in the same concentration.
    b. The rate of the forward reaction equals the rate of the reverse reaction.

6. For a chemical system at equilibrium:
    a. What are the observable characteristics?
    b. Why is the equilibrium considered "dynamic"?
    c. What is considered "equal" about the system?

7. A chemist places a mixture of $NO_{(g)}$ and $Br_{2(g)}$ in a closed flask. After a period of time, the flask contains a mixture of $NO_{(g)}$, $Br_{2(g)}$, and $NOBr_{(g)}$. Explain this observation.

8. When a damp towel is hung on a clothesline in fair weather, it will dry. The same towel left in a gym bag will remain damp.
    a. Using equilibrium principles to explain the difference.
    b. Is a running clothes dryer an open or closed system? Explain.

9. Is the following statement true or false? "If a chemical system at equilibrium in a closed container is heated, the system will remain at equilibrium." Explain.

10. Slush is a prominent feature of Canadian winters. Under what conditions do ice and water form an equilibrium mixture?

11. A sealed carbonated drink bottle contains a liquid with a space above it. The space contains carbon dioxide at a pressure of about 400 kPa.
    a. What changes are taking place at the molecular level?
    b. Which macroscopic properties are constant?

12. For each example, indicate whether the reactants or products are favoured.
    a. An excess of solid copper reacts with virtually all of the silver ions in a sample solution.
    b. When a solution containing calcium ions is mixed with a solution containing a large excess of sulphate ions, a precipitate forms, but test indicate that a small quantity of calcium ions remain in solution.
    c. When acetic acid is dissolved in water, the acetic acid molecules react with water molecules to from hydrogen ions and acetate ions. Careful pH testing shows that about 980 of every 1000 acetic acid molecules remain in their molecular form, at equilibrium.

Reversible Rxns : Equilibrium

1.) Macroscopic properties occur on large enough scale to be observed by the naked human eye.

Microscope properties occur on the molecular level.

2.) An equilibrium can occur in a closed system at a constant pressure and temperature.

3.) On the microscopic level during equilibrium, the forward and reverse rxn are occuring at the same rate.

4.) a.) $H_2 + I_2 \rightleftharpoons 2HI$
b.) $3H_2 + N_2 \rightleftharpoons 2NH_3$

5.) a.) False. At equilibrium the concentrations stay constant, but they do not need to be equal to one another.

b.) True. This is the definition of equilibrium.

6.) a.) At equilibrium, there are no macroscopic observations. The system appears to remain unchanged.

b.) Dynamic equilibrium because at a molecular level the forward and reverse rxn continue, but at equal rates

c.) The rates of the forward and reverse rxn are equal.

7.) The container is at equilibrium

$$2NO + Br_2 \rightleftharpoons 2NOBr$$

This explains why both products and reactants are present b/c both the forward & reverse rxn are taking place.

8.) a.) The towel on a clothes line is in an open system. The water in the towel will never be in equilibrium with the water vapour b/c the wind sweeps the water vapour away. Thus the water in the towel will eventually all evaporate. In the gym bag, this is a closed system and the water vapour will establish an equilibrium and the towel will remain damp.

b.) A clothes dryer is an open system b/c of the outside vent. This is why clothes dry in a dryer b/c an equilibrium b/w the water and water vapour can never be established.

9.) False. Changing the temperature will change the equilibrium.

10.) Slush will form at 0°C when water can freeze or melt. As long as the temperature remains at 0°C and no extra water or ice is added, the freezing and melting process will continue at the same rate, ∴ forming slush.

11.) a.) At a molecular level, gas is dissolving into the liquid and at the same rate, the gas is escaping out of the liquid.

b.) all macroscopic properties are held constant.

12.) a.) Products favoured
b.) Products favoured
c.) Reactants favoured.