**UNIT I: REACTION KINETICS (REACTION RATES)**

**Introduction: How do Compounds React?**

* We have assumed thus far that ALL compounds having compatible \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ configurations, when placed together, will react - NOT TRUE!!
* Other factors contribute to a reaction proceeding: a) The right \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ for bonding.

b) The available \_\_\_\_\_\_\_\_\_\_\_\_\_\_ for bonding.

c) The \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ needed of each reactant.

* Once started, certain factors can increase the rate of a reaction.
* In this unit, we will be looking at factors ***initiating*** reactions, and factors that ***increase*** the rate of reaction.

1. **The Collision Theory of Reactions:**

Aside from having compatible electronic configurations, 2 reactants must meet the following conditions for a rxn to occur:

a) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_: The two compounds/atoms must collide with each other in a specific way.

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_: the atoms/compounds must have enough \_\_\_\_\_\_\_\_\_\_\_\_\_\_to overcome the \_\_\_\_\_\_\_\_\_\_ barrier of the rxn.
2. **The Collision:**

* When two compounds approach one another, not \_\_\_\_\_\_\_\_ of their atoms are necessarily electronically \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
* It is the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ atoms that must \_\_\_\_\_\_\_\_\_\_\_\_\_\_ into each other for rxn to occur.

*Example:* ethene + HCl ethyl chloride

**NOTE:** Possibility of a rxn with \_\_\_\_\_\_ or more reactants all being able to correctly align geometrically AND having the correct Ea is unlikely – These “complex” reactions tend to occur in 2 or more \_\_\_\_\_\_\_\_\_\_\_\_\_.

1. **Activation Energy (Ea)**

After the compounds have collided with favorable geometry, there may still be no reaction unless there is enough \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ energy called the **\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ energy.**

1. *E within bonds of a molecule* – **PE** – Directly relates to the **stability** of a molecule.

The lower the PE of a molecule, the more stable it is.

**Energy**

1. *E of the surroundings/environment* – provides **KE** to the molecule.

*Activation Energy (Ea):* the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ energy required for a rxn to occur.

Only those collisions meeting or exceeding the Ea will result in a reaction.

Ea is needed to \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ some of the reactant \_\_\_\_\_\_\_\_\_\_\_\_ in a rxn.

Graph of the Activation Energy of an Exothermic Reaction:

Graph of the Activation Energy of an Endothermic Reaction:

**WORKSHEET** – Drawing PE Energy Diagrams - #1-4

**The Maxwell – Boltzmann Distribution Curve:**

* This curve shows us the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of particles that possess the required \_\_\_\_\_\_\_for a rxn. to occur.
* The \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_ the curve measures the \_\_\_\_\_\_\_\_\_\_\_\_ number of \_\_\_\_\_\_\_\_\_\_\_\_\_ present.

**WORKSHEET:** Enthalpy/Energy Worksheet

**C. What is Enthalpy (ΔH)?**

* **Enthalpy (H):** the \_\_\_\_\_\_\_\_\_\_ content of a \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
* **System:** the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ in a reaction.
  + **Enthalpy of Reaction (ΔHrxn.):** the \_\_\_\_\_\_\_\_\_\_\_\_\_\_ between the enthalpies of the products and the enthalpies of the reactants.

**ΔHrxn = ΔHproducts**  **- ΔHreactants**

1. Exothermic: -ΔHrxn
2. Endothermic: + ΔHrxn

*Example:*

2 H2O(l)  2 H2 (g)  + O2 (g), ΔH = 88.0 kJ

CH4 (g) + O2 (g)  CO2 (g)  + 2 H2O (g), ΔH = -890.4kJ

* *The \_\_\_\_\_\_\_\_\_\_\_\_\_change in enthalpy of a multi-step rxn. can be calculated*:

*Example:*  The overall eqn for the synthesis of NO2 is as follows: N2 + 2 O2 2 NO2

The rxn. actually occurs in two distinct steps as follows:

a) N2 + O2 2 NO ΔH = 180kJ

b) 2 NO + O2 2 NO2  ΔH = -112kJ

Determine the overall ΔH for the rxn.

**Determining whether a Reaction is Exothermic or Endothermic;**

* 1. Metal + Acid:

Mg (s) + HCl(aq) → MgCl2(aq) + H2(g) + energy

* 1. Evaporation of Liquids:

CH3CH2OH(l) + energy → CH3CH2OH(g)

* 1. Combustion or Burning of Compounds:

C8H18 (g) + O2(g) → CO2(g) + H2O(g) + energy

* 1. Explosion:

C7H5N3O9(l)  + O2(g) → CO2(g) + N2(g) + H2O(g) + energy

**II. The Rate of Reaction:**

**Rate of Reaction:** the change in \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of a specific substance over \_\_\_\_\_\_\_\_\_\_\_\_\_\_.

**RATE = Δ property**

**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**Δ time**

The rate can be determined by monitoring changes in the following properties: a) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. \_\_\_\_\_\_\_\_\_\_\_\_ – if substance is \_\_\_\_\_\_\_.
2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

d) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

*Example:* Which of the following is not a unit for reaction rates?

A. mol/L.sec B. g/min. C. atm/year D. [ ]/ gram

*Example:* A solution contains 2.4 moles of HCO3-. After 30 sec., concentration of the bicarbonate ion is 1.0 mol. What is the rate of reaction?

*Example*: Consider the following reaction: N2 3H2 2NH3

The rate of formation of NH3 is 3.0 mL/min. What is the rate of consumption of H2?

**LAB: 11A** – Factors that Affect Reaction Rates

1. **Factors Affecting Rate of Reaction:**

There are 7 different factors that can increase or decrease the rate of a reaction:

a) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_: due to its \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ configurations, or its “nature”, some compounds will tend to react more slowly than others.

b) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_: as discussed previously.

c) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ f) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

d) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ g) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (if substance is a **gas**)

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. **Concentration of Reactants:**

*Fact*: The greater the concentration, the \_\_\_\_\_\_\_\_\_\_\_\_\_ the rate of reaction.

*Reason*: The more \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ available, the \_\_\_\_\_\_\_\_\_\_\_\_\_ the chances for \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

**NOTE:** If the rxn involves only one particle undergoing a \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ rxn, then \_\_\_\_\_\_\_\_\_\_\_\_ is \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, only activation energy is applicable.

*Applicable for*: Both \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ reactions.

***Homogenous****:* the \_\_\_\_\_\_\_\_\_\_\_of all the reactants are the \_\_\_\_\_\_\_\_ (eg. All reactants are aqueous.)

***Heterogeneous****:* the phases of the reactants are \_\_\_\_\_\_\_\_\_\_\_\_. (eg. One reactant is a solid and the

other is aqueous.)

*Inapplicable when*: a) A \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_is already working as fast as it can.

b) When the concentration of reactants in the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_is not increased.

*Example*: 2 H2O(l) + energy → 2 H2(g)  + O2(g)

Ways to **monitor** rate of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Ways to **increase** rate of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**NOTE:** Factors that CANNOT increase rate of reaction: 1) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

2) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

*Example*: NaCl(aq) + AgNO3(aq) → AgCl (s) + NaNO3(aq)

Ways to **monitor** rate of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Ways to **increase** rate of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**NOTE:** Rate CANNOT be monitored using the following methods:

1) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. **Temperature:**

*Fact*: The higher the temperature, the \_\_\_\_\_\_\_\_\_\_\_\_\_ the rate of reaction.

Rough estimate is that for every \_\_\_\_\_\_\_ increase, the rate \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

*Reason:* KMT states that the hotter the particles, the \_\_\_\_\_\_\_\_\_\_\_\_ they move. This results in greater possibility of \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

**MORE IMPORTANTLY!** The hotter the particles are, the more “\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_” they are and thus increasing the number of particles that will meet the required \_\_\_\_\_\_\_ for rxn to occur.

*Applicable for:* both homogenous and heterogeneous reactions.

**Graph of Distribution Curves between a Cool and Warmed Reaction:**

*Example*: KSCN(s) + NaOH(aq)  → NaSCN(aq) + KOH(aq)  + energy

Ways to monitor rate: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Ways to increase rate: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**NOTE:** Rate CANNOT be monitored using the following method:

1)\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. **Surface Area:**

*Fact:* The \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ the surface area, the faster the reaction.

*Applicable for*: ONLY \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ rxns, where one of the reactants must be a \_\_\_\_\_\_\_\_\_\_\_\_.

*Reason:* Solutions or liquids can only react with the \_\_\_\_\_\_\_\_\_\_\_\_\_ of a solid. The more “surfaces” of a solid exposed, the easier it is for the other reactant to \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ with, increasing possibility of a rxn.

*Example:* Catalytic converters in cars use an extremely fine layer of Pt, or Pd, plated onto a ceramic honeycomb structure to catalyze the conversion of NOx and COx to CO2 and N2.

*Example*: NaOH (s) + H2O(l) → Na+ (aq)  + OH-1(aq) + energy

Ways to monitor rate of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Ways to increase rate of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. **Catalysts:**

**Catalyst:** a chemical that \_\_\_\_\_\_\_\_\_\_\_\_\_ up a reaction, but is chemically \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ at the end of a reaction. Catalysts can be \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

*Fact:* Introduction of a catalyst will \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ increase the rate of reaction.

*Reason:* The catalyst provides an *\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ pathway* with a lower \_\_\_\_, for a reaction.

A catalyst does **\_\_\_\_\_\_\_\_** lower the overall Ea of a reaction.

Total amount of energy transferred, or \_\_\_\_\_\_\_, remains the same.

*Applicable for*: Heterogeneous and homogenous reactions

*Example*: 2 H2O2 (l)  MnO2 (cat) 2 H2O(l) + O2 (g)

***Uncatalyzed vs.Catalyzed Reaction:***

1. ***PE Graph b) Boltzman Distribution Graph***

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1. **Pressure:**

*Fact:* Applicable ONLY if one of the reactants is a \_\_\_\_\_\_\_\_\_\_. Increase in pressure will increase the rate of reaction.

*Reason:* By increasing the pressure on a system, you are also \_\_\_\_\_\_\_\_\_\_\_\_\_\_ its volume, thus increasing the system’s \_\_\_\_\_\_\_\_.

Particles packed into a \_\_\_\_\_\_\_\_\_\_\_ amount of space have a better the chance of successful \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

**NOTE:** For \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ reactions, pressure is irrelevant, only the Ea is applicable.

*Example*: C3H8(l) + 5 O2(g) → 3 CO2(g) + 4 H2O(l) + energy

Ways to monitor rate of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Ways to increase rate of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**WORKSHEET:** Factors Affecting Reaction Rates Worksheet

**LAB: 11B** – The Iodine Clock Reaction

1. **Reaction Mechanisms:**

**Reaction Mechanism:** Shows the *\_\_\_\_\_\_\_\_\_\_\_* involved in a reaction. Shows how the \_\_\_\_\_\_\_\_\_ are \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

*Example:* (CH3)3CBr + NaOH (CH3)3COH + NaBr (overall rxn.)

Steps Involved:

1) (CH3)3CBr + NaOH(aq)  *slow step* (CH3)3C+ + OH-(aq) + Na+1(aq) + Br-1(aq)

2) (CH3)3C+ + OH-(aq) + Na+(aq) + Br-1(aq) (CH3)3COH + NaBr(aq)

*fast step*

**Rate Determining Step:**  the \_\_\_\_\_\_\_\_\_\_\_\_\_ step in a reaction.

Gives us the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_ of reaction.

**Reaction Intermediate:** species that is \_\_\_\_\_\_\_\_\_\_\_\_\_ in one step and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ in the following step or steps.

**NOTE:** Changing [NaOH] will \_\_\_\_\_\_\_ affect the rate of the above rxn since NaOH is a reactant in the fast step.

*Example:*  For the following 3 step reaction, identify:



1. The Overall Reaction:
2. The reaction intermediate(s):
3. Catalyst (if any):

*Example*: Cl + O3 O2 + ClO (fast)

ClO + O Cl + O2 (slow)

a) The Overall Reaction:

b) The reaction intermediate(s):

1. Catalyst (if any):

*Example*: Overall Rxn: 2 NO + 2 H2 N2 + 2 H2O

Steps involved: 2 NO N2O­2

N2O2 + H2 N2O + H2O

\_\_\_\_\_\_\_\_ + H2 H2O + N2

Reaction Intermediate(s): \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Catalyst(s): \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

*Example:* CH4(g) + 4 S(s) → CS2(l) + 2 H2S(g). Determine the Hrxn given the reaction mechanism below:

1) C(s) + 2 H2(g) → CH4(g) H° = -74.8 kJ  
 2) C(s) + 2 S(s) → CS2(l) H° = +87.9 kJ  
 3) S(s) + H2(g) → H2S(g) H° = -20.6 kJ

***PE Graph for a Multi-Step Reaction:***

**WORKSHEETS:** \* Reaction Mechanism Worksheet

\* Reactions Rates Unit Review Worksheet