Reaction Rate

Spontaneity Versus Reaction Rate

* The conversion of diamond to graphite is “spontaneous” (it is self sustaining):

C(diamond) → C(graphite)

* Why is it NOT common to see diamond jewelry changing into graphite?
* What would be some ways to expedite this reaction?

Reaction \_\_\_\_\_\_\_

* Reaction rate is how \_\_\_\_\_\_\_ reactants are converted into products.
* *Reaction rate tells how the* \_\_\_\_\_\_\_ *of reactant or product change with time.*
* Reaction rates depend on “\_\_\_\_\_\_\_ energy”.
* Reaction rate is related to \_\_\_\_\_\_\_ (molecular \_\_\_\_\_\_\_ of reactants interacting).
* Theoretically, diamond can turn to graphite, but the reaction rate is \_\_\_.
* Reaction rate does \_\_\_\_\_\_\_ indicate the \_\_\_\_\_\_\_ of a reaction (how much product or reactant exists at equilibrium).

Collisions & Reaction Rate

* Reaction rate depends on the \_\_\_\_\_\_\_.

Collision Theory

* Every reaction begins with \_\_\_\_\_\_\_ of molecules or particles
* TWO Important parameters:
1. The \_\_\_\_\_\_\_ of collisions
* *Balloons stay “filled” because air molecules constantly collide against the sides of the balloon. Without sufficient collisions, the balloon will deflate.*
1. The \_\_\_\_\_\_\_ of the collisions
* Sufficient \_\_\_\_\_\_\_
	+ - *one may hit a billiard cue ball into another ball, but if the energy is insufficient, the ball will not go in the desired pocket.*
* Proper \_\_\_\_\_\_\_ of reactant particles
	+ - *One may have the correct key to the correct lock, but the key must be inserted right side up into the lock hole or it won’t work.*

\_\_\_\_\_\_\_ Collisions (\_\_\_\_\_\_\_ & \_\_\_\_\_\_\_)

* Energy to overcome the \_\_\_\_\_\_\_ energy barrier:
* comes from \_\_\_\_\_\_\_ \_\_\_\_\_\_\_ of colliding molecules
	+ kinetic \_\_\_\_\_\_\_ must be high enough
	+ collisions must be aligned adequately (\_\_\_\_\_\_\_)
	+ there must be enough collisions (\_\_\_\_\_\_\_)

Collision Theory explains activation energy and how chemical reactions happen.

* Every chemical \_\_\_\_\_\_\_ begins with a collision of \_\_\_\_\_\_\_, which produces an \_\_\_\_\_\_\_ state that is meta-stable and has enough energy to \_\_\_\_\_\_\_ the activation energy to form the products.
* Chemists use collision theory to figure out how to slow down the corrosion of steel and how to create fuels that burn more efficiently (speed up reaction).

Factors Affecting Reaction Rate

* Reactions require \_\_\_\_\_\_\_.
* There are many factors that affect the frequency and energy of collisions and thereby affect reaction rate
	+ S\_\_\_\_\_\_\_ area (particle size)
	+ C\_\_\_\_\_\_\_ of reactants
	+ T\_\_\_\_\_\_\_
	+ P\_\_\_\_\_\_\_
	+ C\_\_\_\_\_\_\_ or I\_\_\_\_\_\_\_

Effects of Surface \_\_\_\_\_\_\_ on Reaction Rate

* Reactions occur at \_\_\_\_\_\_\_.
* Increasing surface area increases the \_\_\_\_\_\_\_ of particle collisions.
* The easiest and most common way to increase the surface area of a solid is to break it into \_\_\_\_\_\_\_ pieces. Although its total \_\_\_\_\_\_\_ does not change, its surface area \_\_\_\_\_\_\_ significantly.
* Only atoms at the \_\_\_\_\_\_\_ of the metal are available for reaction.

Effect of Concentration on Reaction Rate

* The higher the \_\_\_\_\_\_\_ of reactants, the more \_\_\_\_\_\_\_ reactant molecules collide and the \_\_\_\_\_\_\_ the reaction proceeds to product(s).
* The concentration(\_\_\_\_\_\_\_ *of particles in a* \_\_\_\_\_\_\_ *volume*) affects the rate at which reactions occur.
* Cramming more particles into a fixed volume increases the concentration of reactants, and, thus, the \_\_\_\_\_\_\_ of \_\_\_\_\_\_\_.
* Concentration can increase by:
	+ \_\_\_\_\_\_\_ volume
	+ \_\_\_\_\_\_\_ more reactants

Effect of Pressure on Reaction Rate

* Reactions involving \_\_\_\_\_\_\_:
	+ Increasing pressure increases \_\_\_\_\_\_\_ and therefore, the \_\_\_\_\_\_\_ of collisions, which increases reaction rate.
	+ Solids & liquids are generally \_\_\_\_\_\_\_ to \_\_\_\_\_\_\_.
	+ Increasing pressure increases reaction rate if the \_\_\_\_\_\_\_ contain more moles of \_\_\_\_\_\_\_ than the \_\_\_\_\_\_\_.

Predict the effects of an increase in pressure for each of the following reactions.

N2(*g*) + 3H2(*g*) → 2NH3(*g*)

SnO2(*s*) + 2H2(*g*) → Sn(*s*) + 2H2O(*g*)

AgNO3(*aq*) + Cu(*s*) → Cu(NO3(*aq*) + Ag(*s*)

Na2CO3(*s*) + 2HCl(*aq*) → CO2(*g*) + H2O(*l*) + 2NaCl(*aq*)

Effect of Temperature on Reaction Rate

* Increasing \_\_\_\_\_\_\_ means that the average \_\_\_\_\_\_\_ \_\_\_\_\_\_\_ (KE) of the particles increases.
* Increasing the average KE (motion/energy) of the particles increases the \_\_\_\_\_\_\_ and \_\_\_\_\_\_\_ of collisions.
* General / Approximate Rule:
* Reaction rate will \_\_\_\_\_\_\_ for every +10º C
	+ *Applying a cover to a cooking pan increases the potential temperature and cooks food faster.*
	+ *A pressure cooker at 110º C will cook food twice as fast as a pot at 100º C.*
	+ Refrigeration \_\_\_\_\_\_\_ the temperature and \_\_\_\_\_\_\_ the rate of food spoilage.
	+ Food deteriorates four times as fast at room temperature (25º C) than in a refrigerator (5º C). Lower temperature reduces molecular \_\_\_\_\_\_\_ and \_\_\_\_\_\_\_ of motion, decreasing the \_\_\_\_\_\_\_ of \_\_\_\_\_\_\_ collisions.
	+ \_\_\_\_\_\_\_ temperature in essence \_\_\_\_\_\_\_ the activation energy of reaction.
	+ \_\_\_\_\_\_\_ Energy, EA, is the energy required to bring \_\_\_\_\_\_\_ to the point where they can \_\_\_\_\_\_\_ to form \_\_\_\_\_\_\_.
	+ In order for a reaction to occur between stable molecules (reactants), a certain amount of energy (Ea 🡪 \_\_\_\_\_\_\_ energy) must be applied to \_\_\_\_\_\_\_ the chemical bonds holding the reactant molecules together. *Like taking a* \_\_\_\_\_\_\_ \_\_\_\_\_\_\_ *to the top of the hill!*

Potential Energy Diagrams

* The \_\_\_\_\_\_\_ energy that \_\_\_\_\_\_\_ particles must have in order to react is called the activation energy, EA.
* Activation energy is needed for any reaction, but is \_\_\_\_\_\_\_ part of the heat or energy of reaction (∆H).

What are the major aspects involved in a chemical reaction?



Potential Energy Diagrams

(a) Activation Energy (EA) of the \_\_\_\_\_\_\_ reaction (*begins at PE of reactants up to the peak of the curve*)

(b) Activation Energy (EA) of the \_\_\_\_\_\_\_ reaction (*treat “products” as “reactants”*)

(c) +∆H (\_\_\_\_\_\_\_ of reaction)

*Overall, the forward reaction describes an* \_\_\_\_\_\_\_ *energy change (i.e. uphill).*

* When two reactant particles collide, they often form an \_\_\_\_\_\_\_ \_\_\_\_\_\_\_, which is an unstable, \_\_\_\_\_\_\_, arrangement of atoms that forms for a moment at the peak of the activation energy barrier.
* The activation-\_\_\_\_\_\_\_ \_\_\_\_\_\_\_ must be crossed before reactants are converted to products.
* EA is always \_\_\_\_\_\_\_ since energy must be added in to form the activated complex.

Potential Energy Diagrams for a reversible reaction

Reaction 1 shows (type of rxn)?



EA =

∆H =

Equation?



Reaction 2 shows (type of rxn)?

EA =

∆H =

Equation?

**C**\_\_\_\_\_\_\_

* Increasing the temperature is not always the best way to increase the rate of a reaction. Using a catalyst is often better.
* A catalyst is a substance that \_\_\_\_\_\_\_ the \_\_\_\_\_\_\_ of a reaction without being \_\_\_\_ \_\_\_ during the reaction. (*e.g. the “horse”*)
* Catalysts permit reactions to proceed along a lower energy path.

I\_\_\_\_\_\_\_

* Substances that \_\_\_\_\_\_\_ with the action of a catalyst. Some inhibitors work by reaction with, or “poisoning,” the catalyst itself.
* Thus, the inhibitor \_\_\_\_\_\_\_ the amount of catalyst available for a reaction and are often called “negative catalysts”.
* Reactions \_\_\_\_\_\_\_ or even stop when a catalyst is inhibited.

Reaction M\_\_\_\_\_\_\_

* Rates of reaction depend on reaction mechanism. An \_\_\_\_\_\_\_ reaction is a reaction in which reactants are converted to products in a \_\_\_\_\_\_\_ step. This type of reaction has only \_\_\_\_\_\_\_ activation-energy peak and one activated complex.
* \_\_\_\_\_\_\_ chemical reactions involve \_\_\_\_\_\_\_ steps (a path or sequence of steps) in which reacting molecules collide, rearrange, etc. and eventually form products.
* The series of elementary reactions or steps that take place during the course of a complex reaction is called a reaction \_\_\_\_\_\_\_.
* The reaction rate depends on the frequency of contact of the reactants in the \_\_\_\_\_\_\_ -\_\_\_\_\_\_\_ step, the \_\_\_\_\_\_\_ step.

Rate-Determining Step

* Usually there is one particular step in a reaction that is \_\_\_\_\_\_\_ than all the other steps.
* Therefore, the “rate determining step” (the slowest step) is most \_\_\_\_\_\_\_ for the rate of the overall reaction.

Many times one cannot determine the reaction mechanism using the overall chemical reaction:

NO2(g) + CO(g) → NO(g) + CO2(g)

Experiments have shown that the mechanism consists of the two steps shown below.

2NO2 + NO → 2NO + NO3 (slow)

NO3 + CO → NO2 + CO2 (fast)

Add these two reactions together:

A reaction between NO and H2 occurs in the following three-step process:

NO + NO → N2O2 (fast)

N2O2 + H2 → N2O + H2O (slow)

N2O + H2 → N2 + H2O (fast)

What is the rate determining step?

Write the balanced equation for the overall reaction.

Are there any intermediates? If so, state what they are.

R\_\_\_\_\_\_\_ Reactions

* Up until now, you may have assumed that any chemical equation we write represents a reaction that proceeds from reactants to products only.
	+ This is true of: 2H2 (g) + O2 (g) → 2H2O (g).
* In principle, however, almost all reactions are \_\_\_\_\_\_\_ to some extent under the right conditions.

Forward Reaction: CO2(aq) + H2O(l) → H2CO3(aq)

Reverse Reaction: H2CO3(aq) →CO2(aq) + H2O(l)

* *Reactions that can proceed in both directions (*\_\_\_\_\_\_\_ *and* \_\_\_\_\_\_\_*) use a double* \_\_\_\_\_\_\_ *system:*

*CO2(aq) + H2O(l)  H2CO3(aq)*

* *The* \_\_\_\_\_\_\_ *of each arrow is significant, indicating whether the forward or reverse reaction is favored.*

Chemical reactions do not proceed forever. We can classify reactions as follows:

* \_\_\_\_\_\_\_ reactions that go to completion:
	+ Explosions are nonreversible reactions and to go to completion.

CH4 + O2  🡪 CO2  +   2 H2O

* + When no reactants can be detected, you can say that the reaction has gone to completion, or is irreversible.
* \_\_\_\_ Reaction
	+ No products can be detected.
* \_\_\_\_\_\_\_
	+ Both reactants and products coexist.

Equilibrium

* Chemical equilibrium is the state in which both \_\_\_\_\_\_\_ and \_\_\_\_\_\_\_ are present in concentrations which have no further tendency to \_\_\_\_\_\_\_ with time.
* Usually, this state results when the \_\_\_\_\_\_\_ reaction proceeds at the \_\_\_\_\_\_\_ rate as the \_\_\_\_\_\_\_ reaction and concentrations of the reaction components no longer change.

Dynamic Equilibrium:

* a condition in a chemical system in which the rates of forward and reverse reactions are equal.
* Although the \_\_\_\_\_\_\_ of the forward and reverse reactions are equal at equilibrium, the \_\_\_\_\_\_\_ of the components usually are not.

Equilibrium C\_\_\_\_\_\_\_ 

* Chemists use an Equilibrium constant(*K*eq) to show the ratio of \_\_\_\_\_\_\_ concentrations to \_\_\_\_\_\_\_ concentrations at equilibrium.
* The equilibrium constant is determined using \_\_\_\_\_\_\_ concentrations and the stoichiometry of the reaction (\_\_\_\_\_\_\_ are used as superscripts).
* The \_\_\_\_\_\_\_ and \_\_\_\_\_\_\_ of a reaction can be predicted using the equilibrium constant, Keq.
* The size of the equilibrium constant, Keq, indicates whether reactants or products are more common at equilibrium.
	+ When \_\_\_\_\_\_\_, the equilibrium lies to the left (\_\_\_\_\_\_\_ are favored), meaning there are more \_\_\_\_\_\_\_ than products. Keq = 3.8 x 10-5
	+ When \_\_\_\_\_\_\_, the equilibrium lies to the \_\_\_\_\_\_\_ (\_\_\_\_\_\_\_ are favored), meaning there are more \_\_\_\_\_\_\_ than reactants. Keq = 3.1 x 107
	+ When \_\_\_\_\_\_\_, the reaction is at equilibrium, meaning there are \_\_\_\_\_\_\_ amount of products as reactants.

18B

S\_\_\_\_\_\_\_ to Chemical System

External changes called stresses can disrupt a chemical system at equilibrium.

Stresses include:

Change in \_\_\_\_\_\_\_

Change in \_\_\_\_\_\_\_

Change in \_\_\_\_\_\_\_

Le C\_\_\_\_\_\_\_’s Principle

* If a \_\_\_\_\_\_\_ is applied to a chemical system at equilibrium, the system will respond by \_\_\_\_\_\_\_ in a direction to counteract the stress and a new equilibrium will be established.
* Increasing Reactant Concentration shifts equilibrium to yield more \_\_\_\_\_\_\_ (\_\_\_\_\_\_\_ stress by favoring the \_\_\_\_\_\_\_ reaction).
* Increasing Product Concentration shifts equilibrium to yield more \_\_\_\_\_\_\_ (relieve \_\_\_\_\_\_\_ by favoring the \_\_\_\_\_\_\_ reaction).

Comlete the chart:

|  |  |  |
| --- | --- | --- |
| Change | Direction of equilibrium shift | Effect on Keq |
| Increase reactant concentration |  |  |
| Increase product concentration |  |  |
| Decrease reactant concentration |  |  |
| Decrease product concentration |  |  |

* Stressing the system with P\_\_\_\_\_\_\_ causes a shift reducing the amount of \_\_\_\_\_\_\_ molecules present that are colliding.

N2 (g) + 3H2 (g) ⇌ 2NH3 (g)

For the equilibrium system described by the equation above, how many moles of reactant and product gas are there?

\_\_ mol reactant molecules \_\_ mol product molecules

What will happen if pressure is increased?

Stressing the system by T\_\_\_\_\_\_\_ causes a shift in equilibrium based on how \_\_\_\_\_\_\_ flows

E\_\_\_\_\_\_\_ reaction \_\_\_\_\_\_\_ 🡪 \_\_\_\_\_\_\_ + \_\_\_\_\_\_\_

* \_\_\_\_\_\_\_ heat causes shift to \_\_\_\_\_\_\_ (*favors* \_\_\_\_\_\_\_ *reaction to relieve the stress of high energy products*)
* Removing heat causes shift to \_\_\_\_\_\_\_

E\_\_\_\_\_\_\_ reaction \_\_\_\_\_\_\_ + \_\_\_\_\_\_\_ 🡪 \_\_\_\_\_\_\_

* Adding heat causes shift to \_\_\_\_\_\_\_ (*favors* \_\_\_\_\_\_\_ *reaction to relieve the stress of high energy reactants*)
* Removing heat causes shift to \_\_\_\_\_\_\_

Real Life Application of Le Châtelier’s Principle

* During exercise, the [CO2] in the blood \_\_\_\_\_\_\_. This shifts the equilibrium in the direction of \_\_\_\_\_\_\_ acid, which breaks down to HCO3- and H+. The kidneys excrete extra H+.
* The increase in the level of CO2 also triggers an increase in the rate of breathing. With more breaths per minute, excess CO2 is \_\_\_\_\_\_\_ through the lungs.
* The removal of CO2 causes the equilibrium to \_\_\_\_\_\_\_ toward the \_\_\_\_\_\_\_, which reduces the amount of H2CO3 (aq) in the blood.

C\_\_\_\_\_\_\_ and Equilibrium

* Catalysts \_\_\_\_\_\_\_ the time it takes to establish equilibrium.
* However, they do \_\_\_ affect the amounts of reactants and products present at equilibrium.

Dissolving Solids

* Any finite quantity of \_\_\_\_\_\_\_ has a maximum amount of \_\_\_\_\_\_\_ it can dissolve at a given temperature and pressure.
	+ After the maximum quantity of solute is reached, a solution is said to be \_\_\_\_\_\_\_.
	+ Any solute not dissolved will \_\_\_\_\_\_\_ onto the bottom of the solution’s container.
* Some solids are only \_\_\_\_\_\_\_ **soluble** in a solvent.

The S\_\_\_\_\_\_\_ P\_\_\_\_\_\_\_ Constant

* When the “\_\_\_\_\_\_\_” compound silver chloride is mixed with water, a very \_\_\_\_\_\_\_ amount of silver chloride actually does dissolve in the water.
* An \_\_\_\_\_\_\_ is established between the solid and the dissolved ions in the saturated solution.
* However, since so little product is actually produced, and the reactant compound concentration does not \_\_\_\_\_\_\_ the equilibrium, we ignore it:

Solubility Product Constant

*K*sp = [A]*a* × [B]*b*

* Ksp represents the maximum extent that a solid that can be dissolved in solution.
* The \_\_\_\_\_\_\_ the numerical value of the solubility product constant, the lower the \_\_\_\_\_\_\_ of the compound. Therefore, less ions dissolve in solution.

|  |
| --- |
| ***K*sp at 25oC** |
| **Ionic compound** | ***K*sp** |
| CaSO4 | 2.4 × 10–5 |
| PbF2 | 3.6 × 10–8 |
| SrCO3 | 9.3 × 10–10 |
| ZnS | 3.0 × 10–23 |
| **Place the following compounds in order from MOST soluble to LEAST soluble at 25oC.** |  |

Example of using solubility product constants [Ref Table M]

CaSO4 (s) [Ksp = 2.4 x 10-5]

BaSO4 (s) [Ksp = 1.1 x 10-10]

Which is more soluble?

Which would precipitate out of solution first?

Ksp allows predictions to determine if a precipitate will form when two solutions are mixed …

AB (s) ⇌ A**+ (aq)** + B- (aq)

* if [A+][B-] > Ksp, the solution \_\_\_\_\_\_\_ precipitate. *K*sp < [A+] x [B–] … shows that the solution \_\_\_\_\_\_\_ dissolve the amount of ions present.
* if [A+][B-] < Ksp, \_\_\_ precipitate will form. *K*sp > [A+] x [B–] … shows that the solution **can** \_\_\_\_\_\_\_ more than the amount of \_\_\_\_\_\_\_ present.

Which ionic compound will precipitate out of solution first, BaSO4 (s) [Ksp = 1.1 x 10-10] or CaF2?

CaF2 is \_\_\_\_\_\_\_ soluble (10–11 < 10–10)and therefore, will \_\_\_\_\_\_\_ out first.

S\_\_\_\_\_\_\_ (\_\_\_\_\_\_\_ Energy): ∆G

Spontaneous Reactions

* Reactions that take place \_\_\_\_\_\_\_ exertion of outside forces.
* Ice melts when placed on a table (room temperature)
* Iron(III) Hydroxide (rust) forms on metals outdoors
* Spontaneity does \_\_\_\_ relate to RATE of Reaction
* The \_\_\_\_\_\_\_ energy of a system is a measure of the amount of usable energy (energy that can do work) in that system
* The concept of Free Energy provides a measure of how much usable energy is released (or consumed) when that reaction takes place.



Free energy depends on three main factors:

* + \_\_\_\_\_\_\_ in biology refers to energy stored in bonds, and the change in enthalpy is the difference in \_\_\_\_\_\_\_ energies between the products and the reactants.
	+ \_\_\_\_\_\_\_ is the change of the system during a reaction (becoming more or less \_\_\_\_\_\_\_).
	+ \_\_\_\_\_\_\_ (KE of the molecules in the system).
* \_\_\_\_\_\_\_ Reactions (-∆H) are \_\_\_\_\_\_\_, but not always, spontaneous at room temperature and 1 atm.
	+ *Fireworks displays are the result of highly favored, spontaneous reactions.*
* \_\_\_\_\_\_\_ Reactions (+∆H) are usually \_\_\_ spontaneous at room temperature and 1 atm. Chemical reactions that do NOT favor the formation of products are called \_\_\_\_\_\_\_.
* *Enthalpy is \_\_\_ a reliable indicator of spontaneity*.

Free Energy reflects the capacity of a substance to supply useful work in a reaction.

∆G rxn = ∑∆G products - ∑∆G reactants

* ∆G rxn = - the reaction is \_\_\_\_\_\_\_ and capable of producing useful work
* ∆G rxn = + the reaction is \_\_\_\_\_-spontaneous … work must be applied to the reaction. However, the \_\_\_\_\_\_\_ reaction would be spontaneous (∆ G rxn = -)
* ∆G rxn = 0 the reaction is at \_\_\_\_\_\_\_ … there is \_\_\_ driving force to make the reaction go forward or reverse

E\_\_\_\_\_\_\_ ∆S 🡪 2nd Law of Thermodynamics

* Entropy is the measure of “\_\_\_\_\_\_\_” or “randomness”
* ∆S rxn = - … \_\_\_\_\_\_\_ entropy … more “\_\_\_\_\_\_\_”
* ∆S rxn = + … \_\_\_\_\_\_\_ entropy … more “\_\_\_\_\_\_\_”
* *Beaker shatters when dropped*
* *Rivers become polluted*
* *Wilderness trails get littered*
* *Students don’t push in chairs*
* Entropy increases as \_\_\_\_\_\_\_ increases.
* Entropy increases in substances as they change phase from \_\_\_\_\_\_\_ to liquid to \_\_\_\_\_\_\_.
* Entropy increases when a substance is \_\_\_\_\_\_\_ into parts. For instance, entropy increases when an ionic compound \_\_\_\_\_\_\_ in water.
* Entropy tends to increase in chemical reactions in which the total \_\_\_\_\_\_\_ of \_\_\_\_\_\_\_ molecules is greater than the total number of \_\_\_\_\_\_\_ molecules.

Gibbs Free Energy Equation ∆G = ∆ H - T ∆S

* \_\_\_\_\_\_\_ Energy = \_\_\_\_\_\_\_ - (\_\_\_\_\_\_\_)(\_\_\_\_\_\_\_)
* Δ*H* is the change in \_\_\_\_\_\_\_
* Δ*S* is the change in \_\_\_\_\_\_\_
* *T* is the temperature in \_\_\_\_\_\_\_.
* The energy change for a chemical reaction (∆G) depends on:

a. breaking \_\_\_\_\_\_\_ and making bonds (∆H)

b. \_\_\_\_\_\_\_ (∆S)

c. absolute \_\_\_\_\_\_\_ (K)For the following reaction: C(s) + O2(*g*) 🡪 CO2(*g*)

* If ∆G is \_\_\_\_\_\_\_ (-), the reaction is \_\_\_\_\_\_\_
* If ∆G is \_\_\_\_\_\_\_ (+), the reaction is \_\_\_\_ spontaneous … the reverse reaction would be spontaneous

The entropy change, Δ*S*, is 3.0 J/mol·K. The enthalpy change, Δ*H,* is –394 kJ/mol with the system being at 298 K.

Will this reaction occur spontaneously? Describe all components.

∆G = ∆ H - T ∆S

Δ*G* = \_\_\_\_\_\_\_ kJ/mol – (\_\_\_\_\_\_\_ K)( \_\_\_\_\_\_\_ kJ/mol·K)

Δ*G* = \_\_\_\_\_\_\_ kJ/mol

*The reaction is* \_\_\_\_\_\_\_ *(as indicated by the –*Δ*G).*

\_\_\_\_\_\_\_*, constant* \_\_\_\_\_\_\_*, increased* \_\_\_\_\_\_\_ *(more* \_\_\_\_\_\_\_*)*