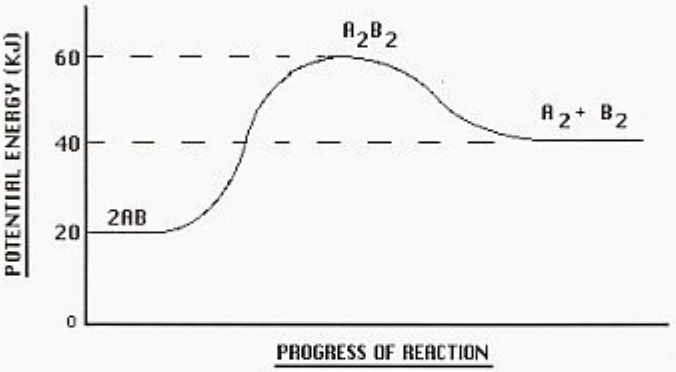
KEY

Chemistry 12
Review Sheet on Unit 2
Chemical Equilibrium

1. What two things are equal at ***equilibrium***?

the forward rate and the reverse rate

2. Consider the following *potential energy* diagram:



a) Which reaction, forward or reverse, will be affected *more* by an increase in temperature? forward

b) Write a thermochemical equation for the forward reaction using the numerical value for the heat.

Answer $2AB + 20\ KJ \rightarrow A_2 + B_2$

c) When the temperature is first raised, which reaction will increase *most* in rate, forward or reverse? forward

Explain why. it has a higher activation energy

d) If the rate of the forward reaction is *faster* than the reverse reaction for awhile, what will happen to the $[A_2]$ and $[B_2]$? they will increase

KEY

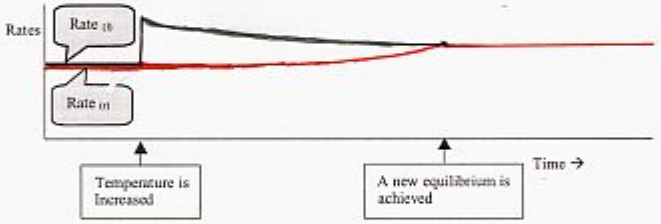
e) If the $[A_2]$ and $[B_2]$ increases, what will happen to the rate of the *reverse reaction*?
it will increase

f) When the reverse reaction rate *catches up* to the forward reaction rate, the system is again at equilibrium

g) Since, for awhile, *the rate of the forward reaction was faster than the rate of the reverse reaction*, there would be an *increase* in the concentrations of A_2 & B_2 and a *decrease* in the concentration of AB in the second equilibrium.

h) We can summarize by saying that the equilibrium has shifted to the RIGHT as a result of increasing the temperature.

i) Draw a graph showing the **rates** of the *forward* and *reverse* reactions vs. time summarizing what happens in 2(c) to 2(f).



3. Consider the reaction:

$$A_{2(g)} + B_{2(g)} \rightleftarrows 2C_{(g)}$$

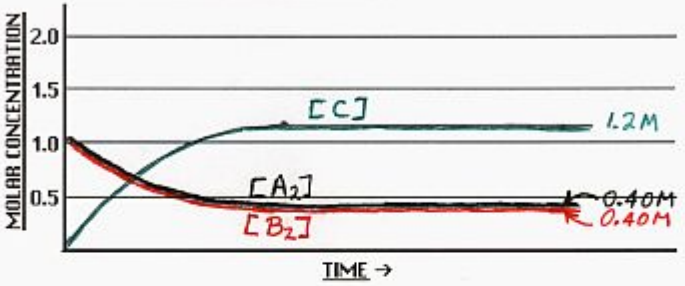
a) If one mole of A_2 and one mole of B_2 are placed in a 1.0 L container, an equilibrium is established in which $[A_2]$ and $[B_2] = 0.40$ M and $[C] = 1.2$ M. If 2.0 moles of C are placed into another 1.0 L container at the same temperature, what will the final concentrations of all the species be? (*HINT: This is <u>not</u> a calculation. It deals with how equilibrium can be approached from the left or from the right.*)

$[A_2] =$ 0.40 M $[B_2] =$ 0.40 M $[C] =$ 1.2 M

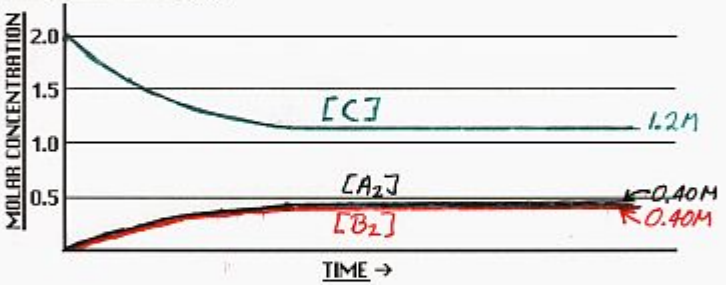
The same equilibrium can be approached from the reactants (A_2 & B_2) or from the products (2C)

KEY

b) Sketch ***two*** graphs showing each of the activities performed in 3a. The graphs are concentration vs. time.
(*Starting with 1 mole A_2 and 1 mole of B_2*)



(*Starting with 2 moles of C*)



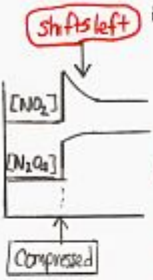
4. Give ***four*** characteristics of the ***equilibrium*** state.

1. forward rate = reverse rate
2. microscopic processes continue to occur (forward & reverse rx)
3. no macroscopic changes - system is closed - uniform temp.
4. equilm can be approached from reactants or products (left) (right)

KEY

5. Explain why the colour of NO_2 gas first gets **darker** and then gets *lighter* when compressed in a syringe. The equation is:

1 mog 2 mog
$N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)}$
colourless dark brown



when first compressed, both $[N_2O_4]$ and $[NO_2]$ increase (darker due to increased $[NO_2]$). To compensate, the reaction will shift left (less moles of gas) and $[NO_2]$ will gradually decrease (gets lighter)

6. Define ***enthalpy*** total energy (heat content) of a system

7. Define ***entropy*** disorder

8. For the reaction:

1 mog 0 mog
$ZnCl_{2(aq)} + H_{2(g)} \rightleftharpoons Zn_{(s)} + 2HCl_{(aq)}$ $\Delta H = +152$ kJ

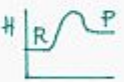
The tendency toward *minimum enthalpy* favours the reactants. The tendency toward *maximum entropy* favours the reactants

If the reactants are combined will the reaction *go to completion, not occur at all* or *reach a state of equilibrium*?

not occur at all

9. For the reaction:

0 mog 2 mog
$2NaHCO_{3(s)} + \text{heat} \rightleftharpoons Na_2SO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$



As this reaction proceeds right, enthalpy is increasing and entropy is increasing.

If the reactants are combined will the reaction *go to completion, not occur at all* or *reach a state of equilibrium*?

reach a state of equilibrium

KEY

10. For the reaction:

$$Cl_{2(aq)} + 25\ kJ \rightleftharpoons Cl_{2(g)}$$

The tendency toward *minimum enthalpy* favours the reactants. The tendency toward *maximum entropy* favours the products

If the reactants are combined will the reaction *go to completion, not occur at all* or *reach a state of equilibrium*? reach a state of equilibrium

11. For the reaction:

0 mog 1 mog

$$Na_{(s)} + H_2O_{(l)} \rightleftharpoons Na^+_{(aq)} + OH^-_{(aq)} + \tfrac{1}{2} H_{2(g)} + heat \quad \Delta H = -184\ kJ$$

Which way will the equilibrium shift when the following changes are made:

a) $NaCl_{(aq)}$ is added (Na^+ & Cl^-) — left

b) The pressure is increased — left

c) The $[OH^-]$ is decreased — right

d) The temperature is decreased — right

e) The volume of the container is decreased (P↑) — left

f) The solid sodium is chopped into smaller pieces.. — no shift

g) A catalyst is added — no shift

12. For the following reaction:

$$4NH_{3(g)} + 5O_{2(g)} + heat \rightleftharpoons 4NO_{(g)} + 6H_2O_{(g)}$$

Which way will the equilibrium shift (if any) when the following changes are made:

a) [NO] is decreased — right

b) $[O_2]$ is increased — right

c) $[NH_3]$ is increased — right

KEY

9 mog 10 mog

$$4NH_{3(g)} + 5O_{2(g)} + \text{heat} \rightleftarrows 4NO_{(g)} + 6H_2O_{(g)}$$

d) The temperature is decreased ..... left

e) The volume of the container is increased (P↓) ..... right

f) The total pressure is increased ..... left

g) Helium gas is added to increase the total pressure no shift

h) The temperature is increased ..... right

i) A catalyst is added ..... no shift

13. Discuss the ideal pressure and temperature conditions for achieving maximum yield of ammonia at a reasonable rate in the *Haber Process*:

4 mog 2 mog

$$N_{2(g)} + 3H_{2(g)} \rightleftarrows 2NH_{3(g)} + \text{heat}$$

Pressure should be (*high/low*) high and temperature should be (*high/low*) low, but still high enough to maintain a reasonable rate

Give reasons for your answer. High P & low temp. cause a shift RIGHT which results in more NH_3 at equilm. A high enough temp. assures a fast enough rate.

14. In an experiment at 423°C, the following concentrations were measured for the ***equilibrium*** system:

$$2HI_{(g)} \rightleftarrows H_{2(g)} + I_{2(g)}$$

$[HI] = 17.7 \times 10^{-3}$ M, $[H_2] = 1.83 \times 10^{-3}$ M and $[I_2] = 3.13 \times 10^{-3}$ M.

Calculate the *value* for the equilibrium constant (Keq) at 423°C .

$$K_{eq} = \frac{[H_2][I_2]}{[HI]^2} = \frac{(1.83\times10^{-3})(3.13\times10^{-3})}{(17.7\times10^{-3})^2} = 0.0183 \text{ or } 1.83\times10^{-2}$$

Answer $0.0183 (1.83\times10^{-2})$

KEY

15. If, at 423°C , the $[H_2]$ and $[I_2] = 4.8 \times 10^{-3}$ M, calculate the [HI]. Use Keq from question 14.

$K_{eq} = \frac{[H_2][I_2]}{[HI]^2}$ so $0.01828 = \frac{(4.8\times10^{-3})^2}{[HI]^2}$

$\sqrt{0.01828} = \frac{4.8\times10^{-3}}{[HI]}$

$[HI] = \frac{4.8\times10^{-3}}{\sqrt{0.01828}} = 0.0355\ M$

Answer $0.036M\ (3.6\times10^{-2}M)$

16. Given the equilibrium equation:

$$X_{2(g)} + 3Y_{2(g)} \rightleftarrows 2XY_{3(g)}$$

If 2.0 moles of X_2 and 2.0 moles of Y_2 are added to a 1.0 L container, an equilibrium is established in which the $[Y_2] = 0.80$ M. Find the following at equilibrium. (*Use a table.*)

-0.40 (1/3) -1.2 (3/3) $+0.80$

$X_2 + 3Y_2 \rightleftarrows 2XY_3$

	X_2	$3Y_2$	$2XY_3$
[I]	2.0	2.0	0
[C]	-0.40	-1.2	+0.80
[E]	1.6	0.80	0.80

$K_{eq} = \frac{[XY_3]^2}{[X_2][Y_2]^3}$

$= \frac{(0.80)^2}{(1.6)(0.80)^3}$

$= 0.78$

$[X_2] =$ 1.6M $[XY_3] =$ 0.80M Keq = 0.78

KEY

17. The equation: $A_{(g)} + B_{(g)} \rightleftarrows C_{(g)} + D_{(g)}$ has a Keq = *49* at 25°C.

If 1.0 mole of C and 1.0 mole of D are added to a 0.50 L container at 25°C, calculate the following *at equilibrium*: (*Use a table.*)

Initial [C] & [D] = $\frac{1.0 mol}{0.50 L}$ = 2.0M

Trial Keq = $\frac{[C][D]}{[A][B]} = \frac{(2.0)(2.0)}{0} = \infty$
Since $T_{keq} > keq$ rx. will shift LEFT

	A	+ B	⇌ C	+ D
[I]	0	0	2.0	2.0
[C]	+x	+x	−x	−x
[E]	x	x	2.0−x	2.0−x
[E]	0.25	0.25	2.0−0.25	2.0−0.25
[E]	0.25	0.25	1.75	1.75

$K_{eq} = 49 = \frac{[C][D]}{[A][B]}$

$49 = \frac{(2.0-x)^2}{x^2}$

$\sqrt{49} = 7.0 = \frac{2.0-x}{x}$

$7.0x = 2.0 - x$

$8.0x = 2.0$

$x = \frac{2.0}{8.0} = 0.25 M$

[A] = 0.25 M [B] = 0.25 M [C] = 1.8 M [D] = 1.8 M

18. In the equilibrium in question 17, what, if anything, would happen to the *value* of the equilibrium constant if the *temperature is increased*?

Answer If exo. Keq would decrease
If endo Keq would increase

Explain your answer. If temp. is increased, the equilm would shift toward the side without the heat term changing the Keq value accordingly

19. Write the *Keq expression* for the following reaction: (*Be careful of phases!*)

$2NaHCO_{3(s)} + \text{heat} \rightleftarrows Na_2SO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$

$K_{eq} = [CO_2][H_2O]$

KEY

20. The Keq for the reaction:

$2SO_{2(g)} + O_{2(g)} \rightleftarrows 2SO_{3(g)}$ is *85.0* at 25°C.

Using this information, calculate the Keq for the reaction :

$2SO_{3(g)} \rightleftarrows 2SO_{2(g)} + O_{2(g)}$ (reversed)

$Keq = \frac{1}{85.0} = 0.0118$

Answer 0.0118 or 1.18×10^{-2}

21. Consider the following equilibrium:

$2SO_{2(g)} + O_{2(g)} \rightleftarrows 2SO_{3(g)}$ Keq = *6.5* at a certain temperature

What will occur when 1.0 mol of SO_2, 1.0 mol of O_2, and 1.0 mol of SO_3 are placed in a 1.0 L container and allowed to reach equilibrium?

a) $[SO_2]$ will increase, $[SO_3]$ will increase.
b) $[SO_2]$ will increase, $[SO_3]$ will decrease.
c) $[SO_2]$ will decrease, $[SO_3]$ will increase.
d) $[SO_2]$ will decrease, $[SO_3]$ will decrease.

Trial $Keq = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{(1.0)^2}{(1.0)^2(1.0)}$

Trial Keq = 1.0 < Keq (6.5)

So rx. will shift to the RIGHT.
So $[SO_2]$ will decrease & $[SO_3]$ will increase

Answer C

Explain your answer. (see above)

22. Given the equilibrium:

$CO_{(g)} + H_2O_{(g)} \rightleftarrows CO_{2(g)} + H_{2(g)}$ + heat $\Delta H = -41$ kJ

Give 5 actions which could cause this equilibrium to shift to the ***left***:

1. decrease [CO]
2. decrease $[H_2O]$
3. increase $[CO_2]$
4. Increase $[H_2]$
5. Increase temperature

KEY

23. How does the addition of a *catalyst* affect the Keq for a system? no change

24. Choose the equilibrium which most *favours the reactants*.

a)	$NO + 1/2O_2 \rightleftarrows NO_2$	Keq = 4.4×10^{7}
b)	$CO + 1/2O_2 \rightleftarrows CO_2$	Keq = 4.0×10^{-3}
c)	$C + H_2O \rightleftarrows CO + H_2$	Keq = 3.1×10^{3}
d)	$NO + H_2O \rightleftarrows NO_2\ H_2$	Keq = 1.0×10^{-22}

smaller Keq favours reactants

25. Consider the following system: $2SO_{2(g)} + O_{2(g)} \rightleftarrows 2SO_{3(g)}$ + heat $\Delta H = -99$ kJ/mol
What are *four* things which could be done in order to increase the yield of SO_3?

1. increase pressure (decrease volume of container)
2. decrease temperature
3. add SO_2
4. add O_2

26. Given the equilibrium equation: $XY_{(g)}$ + *heat* $\rightleftarrows$ $X_{(g)} + Y_{(g)}$ (1 mol → 2 mol)

If initially, at equilibrium, the [XY] = 3.0 M, the [X] = 5.0 M and the [Y] = 6.0 M, draw a graph showing qualitatively what happens to the concentrations of each species as the following changes are made to the system:

Time I - The *temperature is decreased*.
Time II - Some $X_{(g)}$ is *removed from* the system
Time III - Some $XY_{(g)}$ is *added to* the system
Time IV - The *total pressure is increased*.