Lecture 15 CH131 Summer 1

Tuesday, June 18, 2019

- Complete: Effect of temperature on equilibrium
- Predicting direction of change
- Q algebra: Q (and so K) depends on how a reaction is written
- Disturbing equilibrium (Le Chatelier)

Begin ch 15: Acid-base equilibria

- The pH of water
- Weak acids and strong acids

Next lecture: Pure strong acid. Pure weak acid. Partially neutralized weak acid. Exactly neutralized weak acid. Neutralized weak acid with excess base. Practice with titration.

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[TP] The reaction $N_2(g) + 2\ H_2(g) \rightleftharpoons 2\ N_2H_4(l)$ is endothermic. What temperature range will result in the greatest amount of products? Hint: Sketch $\ln(K)$ vs $1/T$.

0%	1.	Very low T
100%	2.	Very high T
0%	3.	The amount will be the same at all T
0%	4.	More information needed

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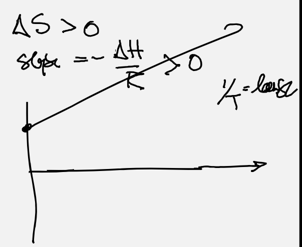
[Quiz] The reaction $N_2O_4(g) \rightleftharpoons 2\ NO_2(g)$ is exothermic. What temperature range will result in the greatest amount of products? Hint: Sketch $\ln(K)$ vs $1/T$.

92%	1.	Very low T
8%	2.	Very high T
0%	3.	The amount will be the same at all T
0%	4.	More information needed



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Predicting direction of change

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[TP] For the reaction

$$2\,A + B \rightarrow 2\,C$$

at a certain time the value of its reaction quotient is $Q = 7$. This means the value of the equilibrium constant for the reaction is ...

$K = ?$

- 0% 1. < 7
- 8% 2. 7
- 25% 3. > 7
- 67% 4. Further information needed

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[TP] The value of the equilibrium constant for the gas-phase reaction

$$2\,A + B \rightarrow C \text{ is } K = 10.$$

At a certain time the partial pressures are A, B and C are, respectively, 1 bar, 1 bar and 2 bar. The value of the reaction quotient is $Q =$ ...

- 67% 1. 2
- 25% 2. 10
- 8% 3. Further information needed

$$Q = \frac{C_{actual}}{A_{actual}^2 B_{actual}} = \frac{2}{(1)^2\,1} = 2$$

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[Quiz] The value of the equilibrium constant for the gas-phase reaction

$$2\,A + B \rightarrow C \text{ is } K = 10.$$

At a certain time the partial pressures are A, B and C are, respectively, 1 bar, 1 bar and 2 bar. Under these conditions, the value of the equilibrium constant is $K =$ ...

- 15% 1. 2
- 77% 2. 10
- 8% 3. Further information needed

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[TP] The value of the equilibrium constant for the gas-phase reaction

$$2\,A + B \rightarrow C \text{ is } K = 10.$$

At a certain time the partial pressures are A, B and C are, respectively, 0.2 bar, 1 bar and 4 bar. The value of the reaction quotient is $Q =$ ...

- 0% 1. 0.04
- 0% 2. 4
- 0% 3. 10
- 100% 4. 100
- 0% 5. None of the these

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[TP] The value of the equilibrium constant for the gas-phase reaction

$2\,A + B \rightarrow C$ is $K = 10$.

At a certain time the partial pressures are A, B and C are such that the value of the reaction quotient is $Q = 100$. As time passes, the value of Q will …

0% 1. increase

9% 2. stay the same

91% 3. decrease

$Q > K$, too much product

make more reactant

$Q = \frac{\text{products} \downarrow}{\text{reactants} \uparrow} \} \downarrow$

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[TP] The value of the equilibrium constant for the gas-phase reaction

$2\,A + B \rightarrow C$ is $K = 10$.

At a certain time the value of the reaction quotient is $Q = 6$. As time passes, the value of Q will …

100% 1. increase

0% 2. stay the same

0% 3. decrease

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The value of Q (and so K) depends on how a chemical reaction is written.

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Q depends on how a reaction is written

At a certain time, the value of the reaction quotient for the reaction

$2\,A + B \rightleftharpoons 2\,C$

is $Q_1 = 4.0$.

At the same time, what would be the value of Q be for the reaction

$4\,A + 2\,B \rightleftharpoons 4\,C$?

$Q_4 = (C)^4/((A)^4(B)^2) = (Q_1)^2 = 16$

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Q depends on how a reaction is written

At a certain time, the value of the reaction quotient for the reaction

$2\,\mathrm{A} + \mathrm{B} \rightleftharpoons 2\,\mathrm{C}$

is $Q_1 = 4.0$.

At the same time, what would be the value of Q be for the reaction

$2\,\mathrm{C} \rightleftharpoons 2\,\mathrm{A} + \mathrm{B}$?

$Q_2 = (\mathrm{A})^2(\mathrm{B})/(\mathrm{C})^2 = 1/Q_1 = 0.25$

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Q depends on how a reaction is written

At a certain time, here are the values of the reaction quotients for two different reactions,

$2\,\mathrm{A} \rightleftharpoons \mathrm{B},\quad Q_5 = (\mathrm{B})/(\mathrm{A})^2 = 2$

$\mathrm{C} \rightleftharpoons 3\,\mathrm{D},\quad Q_6 = (\mathrm{D})^3/(\mathrm{C}) = 5$

At the same time, what would be the value of Q be for the reaction

$2\,\mathrm{A} + \mathrm{C} \rightleftharpoons \mathrm{B} + 3\mathrm{D}$?

$Q_7 = (\mathrm{B})(\mathrm{D})^3/((\mathrm{A})^2(\mathrm{C})) = Q_5 \times Q_6 = 10$

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[TP] The value of the equilibrium constant for the reaction

$2\,\mathrm{A} + \mathrm{B} \rightleftharpoons \mathrm{C}$

is $K = 10$. The value of the equilibrium constant for the reaction

$6\,\mathrm{A} + 3\,\mathrm{B} \rightleftharpoons 3\,\mathrm{C}$

is …

0%	1.	10
23%	2.	30
0%	3.	100
77%	4.	1000
0%	5.	None of the above

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[TP] The value of the equilibrium constant for the reaction

$2\,\mathrm{A} + \mathrm{B} \rightleftharpoons \mathrm{C}$

is $K = 10$. The value of the equilibrium constant for the reaction

$2\,\mathrm{C} \rightleftharpoons 4\,\mathrm{A} + 2\,\mathrm{B}$

is …

0%	1.	−10
8%	2.	0.1
92%	3.	0.01
0%	4.	−0.001
0%	5.	None of the above

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[Quiz] The value of the equilibrium constant for the reaction

$2\ A \rightleftharpoons C$ is $K_1 = 4$

and that for the reaction

$D \rightleftharpoons C$ is $K_2 = 0.5$.

The value of the equilibrium constant for the reaction

$2\ A \rightleftharpoons D$ is $K_3 = \ldots$

- 0% 1. 2
- 0% 2. 4
- 15% 3. 6
- 85% 4. 8
- 0% 5. None of the above

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Disturbing equilibrium

Essential idea: A system at equilibrium responds to a disturbance by partially offsetting the disturbance.

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[TP] The reaction $3\ A(aq) \rightleftharpoons 2\ B(aq)$ is at equilibrium, with

$[A]_e = 0.10$ M and $[B]_e = 2.0$ M and so $K = 4000$.

Then 0.05 M of A is added.

At the moment of this change, the value of [A] will be …

- 0% 1. 0.05 M
- 0% 2. 0.10 M
- 100% 3. 0.15 M

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[TP] The reaction $3\ A(aq) \rightleftharpoons 2\ B(aq)$ is at equilibrium, with

$[A]_e = 0.10$ M and $[B]_e = 2.0$ M and so $K = 4000$.

Then 0.05 M of A is added.

At the moment of this change, the value of Q will be …

- 15% 1. > 4000
- 8% 2. = 4000
- 77% 3. < 4000

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[TP] The reaction 3 A(*aq*) ⇌ 2 B(*aq*) is at equilibrium, with
$[A]_e$ = 0.10 M and $[B]_e$ = 2.0 M and so K = 4000.
Then 0.05 M of A is added.
At the moment of this change, the system will …

100% 1. have too much reactant
0% 2. still be at equilibrium
0% 3. have too much product

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[TP] The reaction 3 A(*aq*) ⇌ 2 B(*aq*) is at equilibrium, with
$[A]_e$ = 0.10 M and $[B]_e$ = 2.0 M and so K = 4000.
Then 0.05 M of A is added.
After the system is once again at equilibrium, $[A]_e$ must be …

0% 1. < 0.10 M
0% 2. = 0.10 M
100% 3. > 0.10 M

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[Quiz] The reaction 3 A(*aq*) ⇌ 2 B(*aq*) is at equilibrium, with
$[A]_e$ = 0.10 M and $[B]_e$ = 2.0 M and so K = 4000.
Then 0.05 M of A is added.
After the system is once again at equilibrium, $[B]_e$ must be …

9% 1. < 2.0 M
0% 2. = 2.0 M
91% 3. > 2.0 M

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Disturbing equilibrium

Essential idea: A system at equilibrium responds to a disturbance by partially offsetting the disturbance.

This behavior is called Le Chatelier's principle.

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Practice: Problem 14.49

49. The equilibrium constant for the "water gas" reaction

$$C(s) + H_2O(g) \rightleftharpoons CO(g) + H_2(g)$$

is $K = 2.6$ at a temperature of 1000 K. Calculate the reaction quotient Q for each of the following conditions, and state which direction the reaction shifts in coming to equilibrium.

(a) $P_{H_2O} = 0.600$ atm; $P_{CO} = 1.525$ atm; $P_{H_2} = 0.805$ atm

(b) $P_{H_2O} = 0.724$ atm; $P_{CO} = 1.714$ atm; $P_{H_2} = 1.383$ atm

	C	+ $H_2O(g)$ ⇌	$CO(g)$ +	$H_2(g)$	Q
I	some	0.600	1.525	0.805	2.05 < K
C		−x	+x	+x	
E		0.600−x	1.525+x	0.805+x	

$K = 2.6 = \frac{(1.525+x)(0.805+x)}{0.600-x}$

I	0.724	1.714	1.383	3.27 > K
C	+x	−x	−x	

$Q = P_{CO}P_{H_2}/P_{H_2O}$

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Practice: Problem 14.52

52. At $T = 100°C$ the reaction

$$SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g)$$

has an equilibrium constant $K = 2.4$.

(a) Suppose the initial partial pressure of SO_2Cl_2 is 1.20 atm, and $P_{SO_2} = P_{Cl_2} = 0$. Calculate the reaction quotient Q and state whether the reaction proceeds to the right or to the left as equilibrium is approached.

(b) Calculate the partial pressures at equilibrium.

(c) If the volume of the system is then decreased, will there be net formation or net dissociation of SO_2Cl_2?

	SO_2Cl_2	SO_2	Cl_2	Q
I	1.20	0	0	0 < K
C	−x	+x	+x	
E	1.20−x	x	x	
	0.38	0.88	0.88	
NI	2*0.38	2*0.88	2*0.88	Q > K
C	+x	−x	−x	
E				

$pSO_2Cl_2 = 0.32$ atm, $pSO_2 = 0.88$ atm, $pCl_2 = 0.88$ atm

$\frac{P_{SO_2}P_{Cl_2}}{P_{SO_2Cl_2}} \rightarrow \frac{2P_{SO_2} \cdot 2P_{Cl_2}}{2P_{SO_2Cl_2}}$

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Begin ch15:

Acid-base equilibria in aqueous solutions

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The pH of water

Write down the chemical equilibrium that accounts for the pH of water.

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

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The pH of water

Write down the reaction quotient for the water autoionization equilibrium.

$Q = [H_3O^+][OH^-]$

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The pH of water

Pure water at 50 ºC is measured to have a pH of 6.63.

Write down the value of $[H_3O^+]$ at 50 ºC.

$[H_3O^+] = 10^{-6.63} = 2.34 \times 10^{-7}$ moles/liter

$pH \equiv -\log([H_3O^+]_e) = 6.63$

$10^{-pH} = [H_3O]_e = 10^{-6.63}$

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The pH of water

Pure water at 50 ºC is measured to have a pH of 6.63.

Write down the value of $[OH^-]$ at 50 ºC.

$[OH^-] = [H_3O^+] = 10^{-6.63} = 2.34 \times 10^{-7}$

50°C $H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

$10^{-6.63}$ M $10^{-6.63}$ M

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The pH of water

Pure water at 50 ºC is measured to have a pH of 6.63.

Write down the value of the reaction quotient of the water autoionization at equilibrium at at 50 ºC.

$Q_e = K_w = [H_3O^+]\,[OH^-] = (10^{-6.63})^2 = 5.48 \times 10^{-14}$

$= 10^{-2 \times pH} =$

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[TP] Pure water at 50 °C is measured to have a pH of 6.63. This means that at 50 °C water is ...

58% 1. acidic
25% 2. neutral
17% 3. basic

$[H_3O^+] = [OH^-]$

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[TP] Pure water at 10 °C has
$[H_3O^+] = 5.39 \times 10^{-8}$.
This means that at 10 °C water is ...

0% 1. acidic
90% 2. neutral
10% 3. basic

$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-$
50°C 2.34×10^{-7}
10°C 0.54×10^{-7}
25°C 1.01×10^{-7} ⇒ pH = 7

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[Quiz] The pH of pure water is different at different temperatures. This means that as temperature changes ...

23% 1. the relative amount of $H_3O^+(aq)$ and $OH^-(aq)$ in pure water change
0% 2. the acidity of pure water changes
46% 3. the value of the equilibrium constant changes
31% 4. All of the above
0% 5. None of the above

$\ln(K) = -\frac{\Delta H}{R}\frac{1}{T} + \frac{\Delta S}{R}$

$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

At 50°C $K_w = (10^{-6.63})(10^{-6.63})$
25°C $K_w = (10^{-7.00})(10^{-7.00})$

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Weak acids and strong acids

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What is an acid?

An acid makes $[H_3O^+] > [OH^-]$

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Strong acid equilibrium

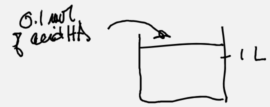
25°C

$c_a = 0.1$ M, $K_a = 1 \times 10^5$, $[H_3O^+] = 0.1$ M, % Yield?

$HA + H_2O \rightleftharpoons H_3O^+ + A^-$ Q < (K = 1×10^5)

I: 0.1 | 10^{-7} | 0

E: ≈ 0 | ≈ 0.1 | ≈ 0.1



% yield = actual $[H_3O^+]$ / most $[H_3O^+]$ = 0.1 / 0.1 · 100% = 100%

$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq)$

$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-$

$[H_3O^+] > [OH^-]$

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Weak acid equilibrium

$c_a = 0.1$ M, $K_a = 1 \times 10^{-5}$, $[H_3O^+] = 0.001$ M, % Yield?

25°C

$HA + H_2O \rightleftharpoons H_3O^+ + A^-$

I: 0.1 | 10^{-7} | 0

E: 0.1−0.001 ≈ 0.1 | 0.001 | 0.001

% yield = actual $[H_3O^+]$ / most $[H_3O^+]$ = 0.001 / 0.1 · 100% = 1%

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