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Chemistry HL 2018-2020

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Acid-base, Equilibrium and before

Time Allowed: 65 min

1.

Which of the following will shift the position of equilibrium to the right in the Haber process?

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H^{\ominus} = -92.6\,kJ$$

I. Decreasing the concentration of $NH_3(g)$ ✓

II. Decreasing the temperature ✓

III. Increasing the pressure ✓

A. I and II only

B. I and III only

C. II and III only

(D.) I, II and III

2.

What are the conjugate acid–base pairs in the following reaction?

$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons OH^-(aq) + H_2CO_3(aq)$$

	Brønsted–Lowry acid	Brønsted–Lowry base	Conjugate acid	Conjugate base
A.	$HCO_3^-(aq)$	$H_2O(l)$	$H_2CO_3(aq)$	$OH^-(aq)$
B.	$H_2CO_3(aq)$	$OH^-(aq)$	$HCO_3^-(aq)$	$H_2O(l)$
(C.)	$H_2O(l)$	$HCO_3^-(aq)$	$H_2CO_3(aq)$	$OH^-(aq)$
D.	$H_2O(l)$	$HCO_3^-(aq)$	$OH^-(aq)$	$H_2CO_3(aq)$

✓

(2)

3.

Which group of three compounds contains only weak acids and bases?

A.	$Ba(OH)_2$	CH_3NH_2	CH_3COOH
B.	$CH_3CH_2CH_2COOH$	$CH_3CH_2NH_2$	HCOOH
C.	NH_3	HNO_3	CH_3CH_2COOH
D.	NH_3	NaOH	H_2CO_3

4.

What is the relationship between pK_a, pK_b and pK_w for a conjugate acid–base pair?

A. $pK_a = pK_w + pK_b$

B. $pK_a = pK_w - pK_b$

C. $pK_a \times pK_b = pK_w$

D. $\frac{pK_a}{pK_b} = pK_w$

$K_a \cdot K_b = \frac{[A^-][H^+]}{[HA]} \cdot \frac{[HA][OH^-]}{[A^-]} = K_w$

$-[\log K_a + \log K_b] = pK_w$

$pK_a + pK_b = pK_w$

5.

The table below shows data for the K_a and pK_b values for some acids and bases at 298 K.

Acid	K_a	Base	pK_b
HClO	2.9×10^{-8}	NH_3	4.75
$C_6H_5CH_2COOH$	4.9×10^{-5}	$C_6H_5NH_2$	9.13

Which two formulas represent the weakest acid and the weakest base in the table?

A. HClO and $C_6H_5NH_2$

B. $C_6H_5CH_2COOH$ and NH_3

C. $C_6H_5CH_2COOH$ and $C_6H_5NH_2$

D. HClO and NH_3

$K_a \downarrow = \frac{[A^-][H^+]\downarrow}{[HA]}$ $\quad K_b \downarrow = \frac{[HA][OH^-]\downarrow}{[A^-]}$

$pK_b \uparrow$

6.

Which pair of compounds could be used to make a buffer solution (assuming appropriate molar ratios)?

A. KCl and HCl

B. NaCl and HCl

C. $KHSO_4$ and H_2SO_4

D. CH_3COONa and CH_3COOH

7.

Which statements explain why a catalyst is used in the Contact process (shown below)?

$$SO_2(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$$

I. A catalyst lowers the activation energy.

II. A catalyst moves the position of equilibrium towards the product.

III. A catalyst allows the same rate to be achieved at a lower temperature.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

8.

Which statement is correct for a reversible reaction when $K_c >> 1$?

A. The reaction almost goes to completion.

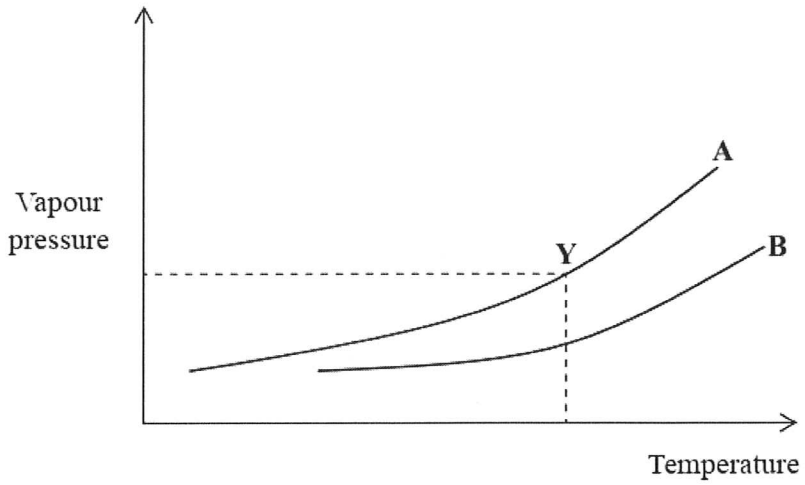
B. The reaction hardly occurs.

C. Equilibrium is reached in a very short time.

D. At equilibrium, the rate of the forward reaction is much higher than the rate of the backward reaction.

9.

The diagram represents the vapour pressure of two liquids, **A** and **B**, as temperature changes. **Y** is a point on the curve of liquid **A**.



Which statement can be made using the graph?

A. At the conditions of pressure and temperature at point **Y**, **A** is in the liquid phase and **B** in the gaseous phase.

B. At the conditions of pressure and temperature at point **Y**, both **A** and **B** are in the gaseous phase.

C. At the same pressure, **A** has a higher boiling point than **B**.

(D.) The intermolecular forces between the molecules of **B** are stronger than between the molecules of **A**.

10.

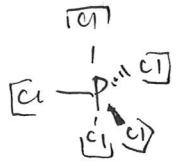
Which molecule is trigonal bipyramidal in shape?

A. PCl_3

B. $SiCl_4$

(C.) PCl_5

D. SF_6



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Section B

1.

(a) The following reaction is used in industry to obtain hydrogen from natural gas by partial oxidation with steam.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g) \qquad \Delta H^{\ominus} = +206\,kJ$$

(i) Describe the effect, if any, of each of the following changes on the equilibrium amount of hydrogen, giving a reason in each case. [4]

Increasing the pressure, at constant temperature:

2 portion of gas on the left; 4 portion on the right. To relieve stress caused by increased pressure, equilibrium shifts to the left ∴ the amount of hydrogen decreases.

Increasing the temperature, at constant pressure:

This is endothermic as $\Delta H > 0$. Adding heat is like adding reactant, which shifts equilibrium to the right, resulting in more hydrogen.

4

(ii) Discuss the effects of adding a solid catalyst to the mixture of methane and steam, at constant pressure and temperature. [3]

The catalyst has no effect on equilibrium. It decreases the activation energy of reactions of both directions, and helps to reach equilibrium faster.

3

(iii) Deduce the equilibrium constant expression, K_c, for the reaction. [1]

$$K_c = \frac{[H_2]^3 [CO]}{[CH_4][H_2O]}$$

1

8

(iv) Identify which of the changes in part (a) (i) will affect the value of K_c and whether the value will increase or decrease. [1]

increasing the temperature will cause Kc to increase.

1

(b) The equilibrium constant, K_c, for the reaction

$$CO(g) + H_2O(g) \rightleftharpoons H_2(g) + CO_2(g)$$

was found to be 10.0 at 420°C.

1.00 mol of CO(g) and 1.00 mol of $H_2O(g)$ are mixed in a 1.00 dm^3 container at 420°C. Calculate the equilibrium concentration of each component in the mixture, showing your working. [3]

[CO] = [H2O] = 1.00 mol / 1.00 L = 1M.

	CO	+	H2O	⇌	H2	+	CO2
	1		1		0		0
	-x		-x		+x		+x
	1-x		1-x		x		x

$K_c = \frac{x^2}{(1-x)^2} = 10$, $\frac{x}{1-x} = \sqrt{10}$, $x = \sqrt{10} - \sqrt{10}x$, $(1+\sqrt{10})x = \sqrt{10}$.

$x = 0.760$ $1-x = 0.240$

Therefore, at equilibrium, [CO] = [H2O] = 0.240 M,

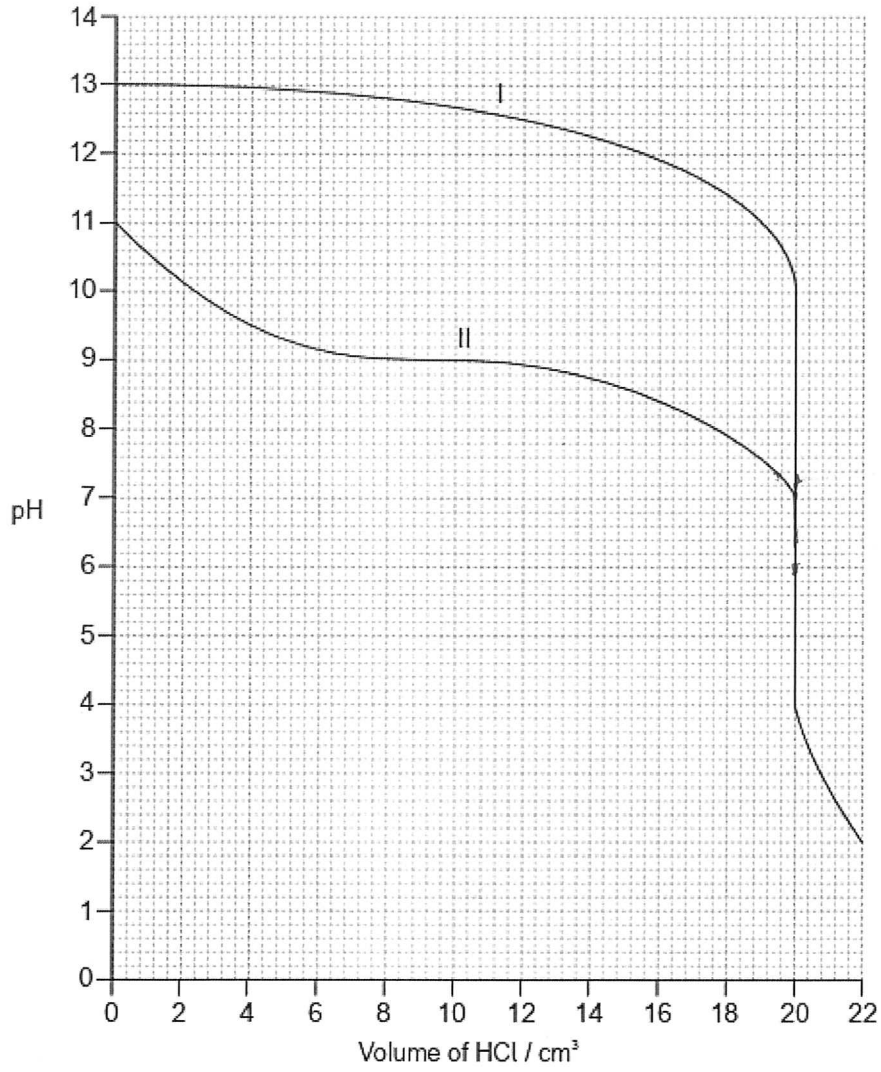
[H2] = [CO2] = 0.760 M.

3

4

2.

(a) 20.0 cm^3 aqueous solutions of two bases, each with a concentration of 0.100 mol dm^{-3} were separately titrated with 0.100 mol dm^{-3} hydrochloric acid, HCl(aq), and the following graph was obtained.



(i) Deduce the pH at the equivalence points for base I and base II. [2]

Base 1: (4+10)/2 = 7.

Base 2: (4+7)/2 = 5.5.

2

(ii) Suggest why the titration curve for base I is different from base II. [1]

Base I is strong base while base II is weak.

(iii) State the formulas of **two** possible bases which could be used as base I. [1]

NaOH, LiOH

(iv) Calculate, using data from the graph, the dissociation constant, K_b, of base II, showing your working. [3]

• At the beginning, $[A^-] = 0.1\ M$; at the equivalence point $[HA] = 0.1\ M$.
• Half way to the equivalence point, $[A^-] = [HA]$, (which is at $V = 10\ cm^3$). At that point, pH = 9.
• $pK_a = pH - \log\frac{[A^-]}{[HA]} = 9 - \log 1 = 9$ ... $pK_b = pK_w - pK_a = 5$.
∴ $K_b = 10^{-5}$

(v) Suggest an indicator that can be used for both titrations. [1]

Bromothymol blue (6.0-7.6) ✗
Not for II!

methyl red (4.4-6.2)

指示剂变色的范围必须完全在竖直的部分里.

5

Doesn't have to be equal.

(b) (i) State what is meant by the term buffer solution. [2]

Similar

Equal amount of weak conjugate acid and base in the solution, able to prevent dramatic change in pH when acid or base is added.

small amounts

1 只要写 conjugate acid & base 都在就好.

(ii) Calculate the pH of a solution prepared by mixing 40.0 cm^3 of 0.200 mol dm^{-3} NH_3 (aq) and 40.0 cm^3 of 0.100 mol dm^{-3} HCl (aq), showing your working. (pK_b NH_3 = 4.75 at 298 K) [3]

- $NH_3 + HCl \rightarrow NH_4Cl$
- After reaction, 1.25 M NH_3 and 1.25 M NH_4^+ present.
- $pH = pKa + \log \frac{[NH_3]}{[NH_4^+]} = pKa + \log 1 = pKa$
- $pKa = pKw - pK_b = 14 - 4.75 = 9.25$
- Therefore, pH = 9.25.

3

(c) The equations of two acid-base reactions are given below.

Reaction **A** $H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$

Reaction **B** $HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$

(i) Explain whether HCO_3^- (aq) behaves as an acid or a base in each of the reactions **A** and **B**. [2]

Reaction **A**:

~~acid~~

H_2CO_3 donates H^+ to form HCO_3^-, ~~conjugate~~ base. HCO_3^- accepts H^+, base (从 reverse reaction 的角度来看).

Reaction **B**:

~~base~~

~~Receives~~ Donates H^+, acid

2

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(ii) Deduce **two** conjugate acid-base pairs from reactions **A** and **B**. [2]

	Acid	Base
Conjugate acid-base pair 1	H_2CO_3	HCO_3^-
Conjugate acid-base pair 2	HCO_3^-	CO_3^{2-}

2

(d) Nitric acid, HNO_3, and nitrous acid, HNO_2, are described as strong and weak acids respectively.

(i) Distinguish between *strong* and *weak* acids. [1]

Strong acids dissociate into H_3O^+ and A^- completely, while weak acids only do that partially.

1

(ii) A 1.00 g sample of solid magnesium carbonate, $MgCO_3$, is added to separate solutions of HNO_3 and HNO_2 of the same concentration and temperature. State **one** similarity and **one** difference in the observations made in these reactions. [2]

Similarity:

Solid gradually disappears.

Difference:

For HNO_3, the rate of solid disappearing is higher than that for HNO_2.

2

(iii) A solution of HNO_3 has a pH of 1, while a solution of HNO_2 has a pH of 5. Determine the ratio of the hydrogen ion concentration in HNO_3:HNO_2. [1]

$[H^+] = 10^{-1}$ in HNO_3, $[H^+] = 10^{-5}$ in HNO_2.
$10^{-1} : 10^{-5} = 10^4 : 1$ in $HNO_3 : HNO_2$.

1

6