Neap:

CHEMISTRY VCE UNITS 3&4
DIAGNOSTIC TOPIC TESTS 2008

TEST 6: APPLICATIONS OF EQUILIBRIUM AND INDUSTRIAL PRODUCTION OF CHEMICALS

TOTAL 35 MARKS (45 MINUTES)

Student's Name: _____ Teacher's Name: _____

Directions to students

Write your name and your teacher's name in the spaces provided above.
Answer all questions in the spaces provided.

SECTION A: MULTIPLE-CHOICE QUESTIONS

Instructions for Section A

For each question in Section A, choose the response that is correct and circle your choice.
Choose the response that is **correct** or **best answers** the question.
A correct answer scores 1, an incorrect answer scores 0.
Marks will **not** be deducted for incorrect answers.
No marks will be given if more than one answer is completed for any question.

Question 1

HX is a strong, monoprotic acid. 100 mL of a 0.15 M HX solution is diluted to 150 mL.

The pH of the resulting solution is

A. 0.65
B. 0.82
C. 1.0
D. 1.3

Question 2

When the pH of a solution decreases from 11 to 9, the

A. concentration of the $H^+(aq)$ ion decreases by a factor of 100.
B. concentration of the $OH^-(aq)$ ion decreases by a factor of 100.
C. concentration of the $H^+(aq)$ ion decreases by a factor of 2.
D. concentration of the $OH^-(aq)$ ion decreases by a factor of 2.

Question 3

A dilemma for many industrial chemists is the conflict between the operating temperature required for maximum yield and the temperature required for maximum rate of reaction. Consider the two reactions below.

I $X(g) + 2Y(g) \rightleftharpoons 4Z(g) \quad \Delta H = +243 \text{ kJ mol}^{-1}$

II $2X(g) + 2Y(g) \rightleftharpoons 3Z(g) \quad \Delta H = -193 \text{ kJ mol}^{-1}$

For which of the two reactions listed would this dilemma occur?

A. I only

B. II only

C. I and II

D. neither I nor II

Question 4

Water ionises according to the equation shown below.

$$2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq) \quad \Delta H > 0 \quad K_w = 10^{-14} \text{ M}^2 \text{ at } 25°C$$

At 15°C, water will be

A. alkaline with a pH greater than 7.

B. neutral with a pH of 7.

C. neutral with a pH less than 7.

D. neutral with a pH greater than 7.

Question 5

The OCl^- ion hydrolyses in water according to the following equation.

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

When several drops of 1.0 M HCl are added to an equilibrium mixture of OCl^- in water, the

A. pH will increase.

B. reaction will move in the reverse direction to restore equilibrium.

C. pH will decrease and the reaction will move in the forward direction to restore equilibrium.

D. concentration of the OCl^- will increase.

Question 6

The pH of a 0.0500 M solution of $Ba(OH)_2$ solution at 25°C would be

A. 1.30

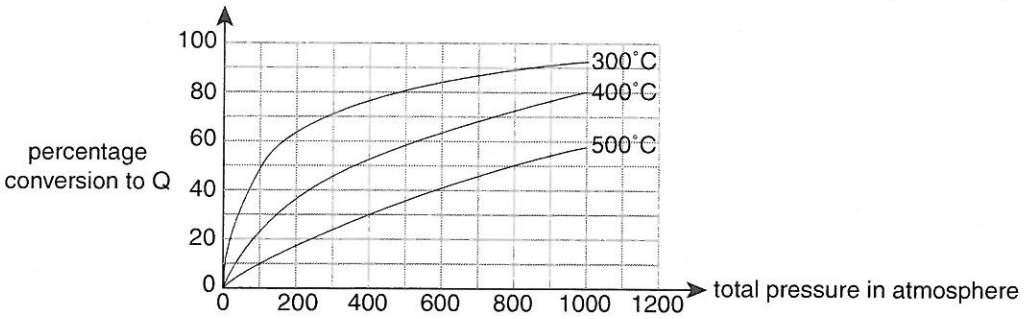
B. 12.0

C. 12.7

D. 13.0

Question 7

The industrial production of chemical Q from chemicals L and M proceeds in the presence of a catalyst. The graph below shows the variation in the equilibrium yield of Q with pressure over a range of temperatures.



Which of the following equations could represent the production process?

A. $2L(g) + 2M(g) \rightleftharpoons Q(g) \quad \Delta H < 0$

B. $2L(g) + M(g) \rightleftharpoons 4Q(g) \quad \Delta H < 0$

C. $L(g) + M(g) \rightleftharpoons 3Q(g) \quad \Delta H > 0$

D. $L(g) + 2M(g) \rightleftharpoons 2Q(g) \quad \Delta H > 0$

Question 8

Which of the following is most likely to be conducted by batch processing rather than continuous processing?

A. production of a new drug for preliminary testing of its pharmacological effects

B. production of fuels by fractional distillation of petroleum

C. production of iron from iron ore in a blast furnace

D. production of sulfuric acid, nitric acid and ammonia for fertiliser manufacture

Questions 9 and 10 refer to the following information.

Four reagent bottles (labelled **A** to **D**) each contain 250 mL of one of four different monoprotic acid solutions. The concentration and pH of each solution is shown below.

Solution	A	B	C	D
Concentration	0.010 M	0.010 M	0.030 M	0.030 M
pH	4.3	2.1	4.3	2.7

Question 9

Which solution contains the acid that is most completely ionised in water?

A. A

B. B

C. C

D. D

Question 10

Which solution contains the acid with the smallest acid ionisation constant, K_a?

A. A

B. B

C. C

D. D

SECTION B: SHORT-ANSWER QUESTIONS

Instructions for Section B

Answer **all** questions in the spaces provided.
To obtain full marks you should

- give simplified answers with an appropriate number of significant figures to all numerical questions; unsimplified answers will not be given full marks.
- show all working in your answers to numerical questions. No credit will be given for an incorrect answer unless it is accompanied by details of the working.
- make sure chemical equations are balanced and that the formulas for individual substances include an indication of state; for example $H_2(g)$; NaCl(s).

Question 1

Succinic acid ($C_4H_6O_4$) is a dioic acid produced during fermentation. It is a diprotic, organic acid, with a first acidity constant K_{a1} of 6.2×10^{-5}.

a. **i.** Draw a possible structure for succinic acid.

ii. Draw a possible structure for the ion formed when succinic acid is completely ionised.

1 + 1 = 2 marks

b. Write an expression for the second acidity constant, K_{a2}, for succinic acid.

1 mark

c. Would you expect the value of the second acidity constant for succinic acid, K_{a2}, to be greater than or less than 6.2×10^{-5}? Explain your choice.

2 marks
Total 5 marks

Question 2

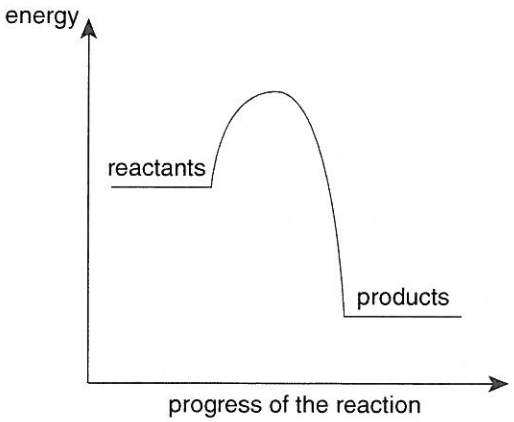
a. An equation which represents a reaction in the industrial production of 1,2-dichloroethane is shown below.

$$CH_2CH_2(g) + Cl_2(g) \rightleftharpoons CH_2ClCH_2Cl(g)$$

Iron(III) chloride solid can be used as a catalyst for the reaction.

i. Is the iron(III) chloride solid a **homogeneous** or **heterogeneous** catalyst when used in this industrial process? Explain your choice.

ii. The graph below shows the energy profile for this reaction.



On the graph, draw an energy profile for the catalysed reaction.

iii. State one factor which might limit the long-term viability of this industrial process.

2 + 1 + 1 = 4 marks

b. In 1998 Anastas and Warner developed twelve principles of green chemistry.

i. One principle is that of **minimising the energy requirements** of a chemical process.

Suggest one way in which this minimisation may be achieved in an industrial chemical production process.

ii. A second principle is the use of **renewable raw materials** whenever possible.

Give an example of the application of this principle in an industrial chemical production process.

1 + 1 = 2 marks

c. The **atom economy** of a reaction is an important consideration when designing industrial processes. Percent atom economy may be calculated using the following formula.

$$\%\text{ atom economy} = \frac{\text{total mass of desired products}}{\text{total mass of reactants}} \times \frac{100}{1}$$

i. Why is atom economy important when designing new industrial processes?

ii. Consider the following reaction which produces 1,2-dichloroethane.

$$CH_3CH_3(g) + 2Cl_2(g) \rightleftharpoons CH_2ClCH_2Cl(g) + 2HCl(g)$$

Determine the percentage atom economy for the reaction.

iii. Suggest two reasons why the reaction in part **c ii** may be less favourable for the industrial production of 1,2-dichloroethane than the reaction shown in part **a**.

1 + 1 + 2 = 4 marks
Total 10 marks

Question 3

Hypoiodous acid, HOI, has a K_a value of 2.29×10^{-11}.

a. Based on its K_a value, is hypoiodous acid a strong acid or a weak acid? Explain.

1 mark

b. Calculate the pH of a 0.10 M hypoiodous acid solution.

3 marks
Total 4 marks

Question 4

The following reactions occur during the manufacture of some chemicals of industrial importance. **Select one** of these reactions when answering the questions that follow.

I $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ (used in the production of ammonia)

II $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ (used in the production of nitric acid)

III $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ (used in the production of sulfuric acid)

IV $C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g)$ (used in the production of ethene)

Place the number (I to IV) of the reaction you have selected in the box below.

a. **i.** Theoretically, what conditions of pressure would increase the rate of this reaction?

_____

ii. Theoretically, what conditions of pressure would increase the yield of this reaction?

_____

iii. During the industrial production process, this reaction is conducted at particular pressure. What is this pressure?

_____

iv. Explain why the pressure listed in part **iii** is used.

_____

_____

1 + 1 + 1 + 1 = 4 marks

b. For the industrial process involving your selected reaction, briefly describe

i. **one** environmental consideration necessary during the industrial production.

_____

_____

ii. **one** safety consideration necessary during the industrial production.

_____

_____

1 + 1 = 2 marks
Total 6 marks

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TEST 6: APPLICATIONS OF EQUILIBRIUM AND INDUSTRIAL PRODUCTION OF CHEMICALS

SUGGESTED SOLUTIONS AND MARKING SCHEME

SECTION A: MULTIPLE-CHOICE QUESTIONS

Question 1 **C**

First calculate the concentration of the diluted acid solution.

$c_1V_1 = c_2V_2$

$$c_2 = \frac{c_1V_1}{V_2} = \frac{0.15 \times 100}{150} = 0.10 \text{ M}$$

For a strong, monoprotic acid $[H_3O^+] = [HX]$

$pH = -\log[H_3O^+] = -\log(0.10) = 1.0$

Note that **B** will be obtained if a student forgets to complete step 1 of the calculation.

Question 2 **B**

pH is a logarithmic scale, so a change of two pH units is a 10^2 change in hydrogen ion concentration (so **A** or **B** is correct). A decrease in pH represents an increase in acidity and a decrease in basicity (so **B** is the correct answer).

Question 3 **B**

The dilemma occurs for exothermic equilibrium reactions (reaction II), where a high temperature favours the rate, but a low temperature favours the yield. For endothermic equilibrium reactions, high temperatures favour both the rate and the yield, so there is no dilemma (so **A**, **C** and **D** are incorrect). For reaction I, high temperatures would be used, but the use of a catalyst might lower the required temperature and so lower operating costs.

Question 4 **D**

The reaction is endothermic. Decreasing the temperature will move the position of equilibrium to the left, and the value of the equilibrium constant will decrease. Fewer hydronium ions will be produced, leading to an increase in the pH to above 7 (which occurs at 25°C). The water remains neutral because the number of hydronium and hydroxide ions remains equal (so **A** is incorrect).

Question 5 **C**

The added H^+ ions will remove OH^- from the reaction mixture. The system will move forward to increase the concentration of OH^-. OCl^- concentration will therefore decrease (so **B** and **D** are incorrect). The final concentration of OH^- however will be lower than the starting concentration (since the change is not completely overcome), therefore the pH will be decreased.

Question 6 **D**

$Ba(OH)_2$ is a base, so the pH will be greater than 7 (so **A** is incorrect).

$[OH^-] = 2 \times [Ba(OH)_2] = 2 \times 0.0500 = 0.100$ M

$$[H_3O^+] = \frac{10^{-14}}{[OH^-]} = \frac{10^{-14}}{0.100} = 10^{-13.0} \text{ M}$$

$pH = -\log[H_3O^+] = -\log(10^{-13.0}) = 13.0$

Note that an answer of 12.7 (answer **C**) is obtained if a student forgets to double the $Ba(OH)_2$ concentration in step 1 of the calculation.

Question 7 **A**

The yield increases with increasing pressure, indicating that there are more moles of gaseous reactants than products, hence **A** and **D** are possible. The yield decreases with increasing temperature, indicating that this is an exothermic reaction (so **A** is correct and **D** is incorrect).

Question 8 **A**

A continuous process has a continual supply of reactants and it produces a continuous flow of products. This occurs in the case of production of iron, petroleum products, sulfuric acid, nitric acid and ammonia. Batch processing produces only a certain amount of product at a time. The process then stops, and later begins production of a new 'batch'. This would occur in the case of a drug trial.

Question 9 **B**

For complete ionisation of a monoprotic acid, $[H_3O^+] = [HX]$

For 0.010 M, $pH = -\log(0.010) = 2.0$

For 0.030 M, $pH = -\log(0.030) = 1.5$

B shows the pH nearest to that expected for complete ionisation.

A, C and D show pH values well above those expected for complete ionisation. These acids must therefore only be partially ionised.

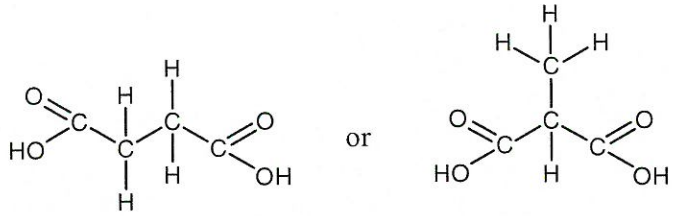
Question 10 **C**

B is the acid most completely ionised, and so it is the strongest acid. A and C have the same pH, but C is the more concentrated solution, therefore A is a stronger acid than C. C and D have the same concentration, but D has the lower pH, therefore D is a stronger acid than C. Therefore C is the weakest acid and so will have the smallest K_a value.

SECTION B: SHORT-ANSWER QUESTIONS

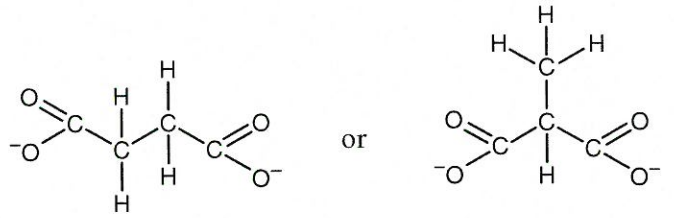
Question 1

a. i.



1 mark

ii.



1 mark

b. $K_{a2} = \dfrac{[H_3O^+][C_4H_4O_4^{2-}]}{[C_4H_5O_4^-]}$ 1 mark

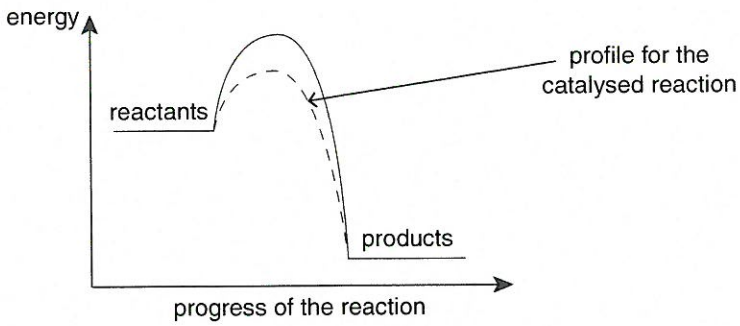
c. The second ionisation only occurs to a very small extent. 1 mark
Removal of a H^+ ion from the already negatively charged $C_4H_5O_4^-$ ion is difficult.
Therefore the value of K_{a2} is less than that of K_{a1}. 1 mark

Total 5 marks

Question 2

a. i. heterogeneous 1 mark
The state of the catalyst (solid) is different from that of the reactants and products (gases). 1 mark

ii.



1 mark

iii. The availability of the reactant ethene. It is sourced from non-renewable petroleum supplies. 1 mark

b. i. For example: the use of catalysts to increase the rate of reactions, and so reduce the need for additional heat (energy) to be provided. 1 mark

ii. For example: the generation of biodiesel from fats and oils, rather than the use of diesel from non-renewable petroleum. 1 mark

c. **i.** Atom economy is a measure of how many of the reactant atoms end up in the desired product. Atom economy should be as high as possible to avoid waste products, as these require the use of further energy (and expense) for their disposal. 1 mark

ii. mass of desired products = $(2 \times 12) + (4 \times 1) + (2 \times 35.5) = 99.0$
mass of reactants = $(2 \times 12) + (6 \times 1) + (4 \times 35.5) = 172$

$$\% \text{ atom economy} = \frac{99}{172} \times \frac{100}{1} = 58\%$$ 1 mark

iii. For example: The atom economy for the reaction in **a** is much higher (100%, as there is a single product). 1 mark
A mixture of chlorinated ethane products results from reaction of ethane with chlorine in the substitution reactions shown in part **c ii**. These products must be separated, involving more time and expense. 1 mark

Total 10 marks

Question 3

a. The low K_a value indicates a weak acid. 1 mark

b. $K_a = \dfrac{[OI^-][H_3O^+]}{[HOI]}$ 1 mark

Let $[H_3O^+] = x$

$[OI^-] = x$ and $[HOI] = 0.10 - x \approx 0.10$ (since x is very small for a weak acid)

$$K_a = 2.29 \times 10^{-11} = \frac{x^2}{0.10}$$ 1 mark

$$x^2 = 2.29 \times 10^{-12}$$

$$x = 1.51 \times 10^{-6}$$

$pH = -\log[H_3O^+] = -\log(1.51 \times 10^{-6}) = 5.8$ 1 mark

Total 4 marks

Question 4

a. **i.** **reaction I** – high pressure
reaction II – high pressure
reaction III – high pressure
reaction IV – high pressure 1 mark

ii. **reaction I** – high pressure
reaction II – low pressure
reaction III – high pressure
reaction IV – low pressure 1 mark

iii. **reaction I** – 200 atm
reaction II – 4–10 atm
reaction III – 1 atm
reaction IV – 1 atm or less 1 mark

iv. **reaction I** – The pressure is chosen as a compromise between the high pressure required for increased rate and yield, and the safer, less expensive lower pressure.
reaction II – The pressure is chosen as a compromise between the high pressure required for increased rate, and the safer, less expensive lower pressure that increases the yield slightly.
reaction III – The pressure is chosen as a compromise between the high pressure required for increased rate and yield, and the safer, less expensive lower pressure.
reaction IV – Low pressure (typically less than 1 atm) is used as this favours a greater yield. (The problems of working with gases at pressures below atmospheric are overcome by the use of steam as an inert dilutant.) 1 mark

b. **i.** **reaction I** – For example: Ammonia is toxic in the environment and so care is needed to contain spills.
reaction II – For example: NO and NO_2 may contribute to the formation of acid rain if leaked into the atmosphere.
reaction III – For example: SO_2 and SO_3 may contribute to the formation of acid rain if leaked into the atmosphere.
reaction IV – For example: Ethene is a highly flammable gas. Care is needed while transporting it. 1 mark

ii. **reaction I** – For example: Ammonia is irritating to the eyes and the respiratory system. Care is needed to ensure adequate ventilation.
reaction II – For example: Nitric acid is highly corrosive. Care is needed when handling.
reaction III – For example: Sulfuric acid is highly corrosive. Care is needed when handling.
reaction IV – For example: Ethene is an asphyxiant. Care is needed to ensure adequate ventilation. 1 mark

Total 6 marks