

## CHEMISTRY VCE UNITS 3&4 DIAGNOSTIC TOPIC TESTS 2008

### TEST 5: RATE, HEAT AND EQUILIBRIUM REACTIONS

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.

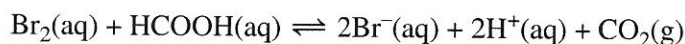
A correct answer scores 1, an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

No marks will be given if more than one answer is completed for any question.

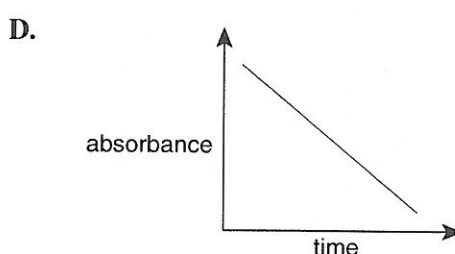
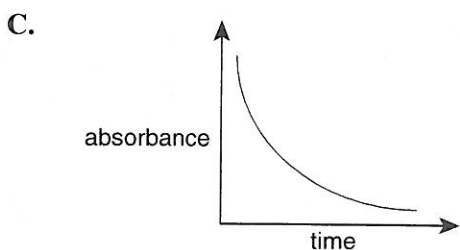
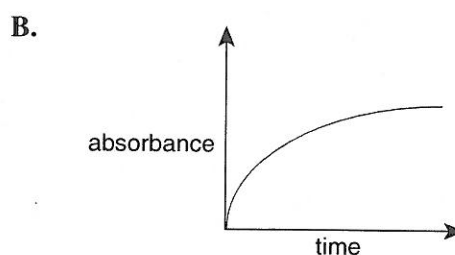
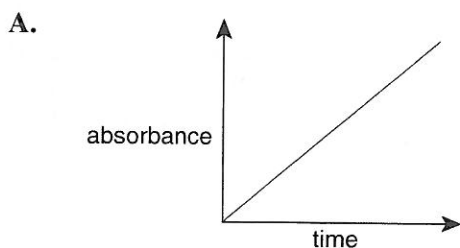
#### Question 1

Bromine reacts with methanoic acid according to the following equation.



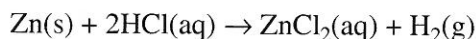
As the reaction proceeds to the right the characteristic red-brown colour of bromine fades. The decrease in colour intensity can be readily measured by using calorimeter.

Which of the following graphs most accurately represents the changes in colour intensity as the reaction proceeds?



### Question 2

Zinc metal reacts with dilute hydrochloric acid to produce a solution of zinc chloride and hydrogen gas according to the following equation.



Which of the following steps would be **least** likely to increase the rate of reaction?

- A. using powdered zinc rather than zinc granules
- B. increasing the gas pressure
- C. increasing the concentration of HCl
- D. employing a suitable catalyst

### Question 3

An increase in temperature generally favours a higher rate of reaction.

This is mainly because the reactant particles

- A. are moving faster and so collide more frequently.
- B. have more kinetic energy and so collide with more force.
- C. are more likely to collide with the correct orientation.
- D. collide more frequently with the sides of the container.

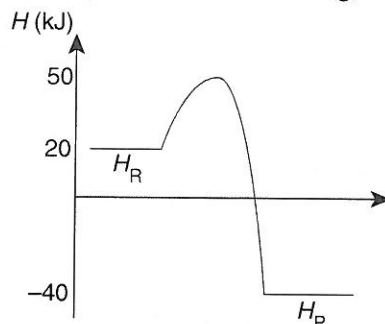
### Question 4

Which of the following statements is correct with respect to an endothermic chemical reaction?

- A. The activation energy is always greater than that of an exothermic reaction.
- B. As the reaction proceeds, energy is released into the surrounding environment.
- C. An increase in temperature always increases the rate of reaction.
- D. The amount of energy required to break the bonds in the reactants is greater than the amount of energy released as the products form.

Questions 5 and 6 refer to the following information.

The diagram below represents the heat change for the reaction  $A(g) + 2B(g) \rightarrow C(g)$ .



### Question 5

The enthalpy of reaction ( $\Delta H$ ) for  $3A(g) + 6B(g) \rightarrow 3C(g)$  is

- A.  $-180 \text{ kJ mol}^{-1}$
- B.  $-60 \text{ kJ mol}^{-1}$
- C.  $-20 \text{ kJ mol}^{-1}$
- D.  $+30 \text{ kJ mol}^{-1}$

### Question 6

The activation energy for the reaction  $2C(g) \rightarrow 2A(g) + 4B(g)$  is

- A.  $20 \text{ kJ mol}^{-1}$
- B.  $60 \text{ kJ mol}^{-1}$
- C.  $90 \text{ kJ mol}^{-1}$
- D.  $180 \text{ kJ mol}^{-1}$

### Question 7

Carbonyl fluoride decomposes as shown below.

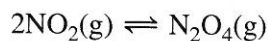


The magnitude of the equilibrium constant at 300 K for  $3\text{CO}_2(g) + 3\text{CF}_4(g) \rightleftharpoons 6\text{COF}_2(g)$  is

- A.  $3.72 \times 10^{-4}$
- B. 0.0240
- C. 41.7
- D. 2690

### Question 8

0.50 mol of  $\text{NO}_2$  is introduced into an evacuated 10 L vessel at 400 K. The  $\text{NO}_2$  is allowed to come to equilibrium according to the equation



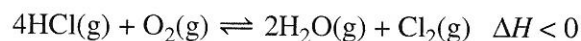
At equilibrium, 0.20 mol of  $\text{NO}_2$  remains.

The equilibrium constant for the reaction at this temperature is

- A.  $0.027 \text{ M}^{-1}$
- B.  $3.75 \text{ M}^{-1}$
- C.  $37.5 \text{ M}^{-1}$
- D.  $75 \text{ M}^{-1}$

**Question 9**

Consider the following reaction.



Which of the following steps would increase the yield of chlorine gas from this reaction?

- A. increasing the temperature
- B. adding an inert gas such as argon
- C. adding a suitable catalyst
- D. increasing the gas pressure

**Question 10**

For which of the following reactions would an increase in temperature and volume improve the yield of product?

- A.  $2\text{CO}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{CO}_2(\text{g}) \quad \Delta H = -564 \text{ kJ mol}^{-1}$
- B.  $\text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g}) \rightleftharpoons 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g}) \quad \Delta H = -2217 \text{ kJ mol}^{-1}$
- C.  $\text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \quad \Delta H = +125 \text{ kJ mol}^{-1}$
- D.  $\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \quad \Delta H = +868 \text{ kJ mol}^{-1}$

**SECTION B: SHORT-ANSWER QUESTIONS**

**Instructions for Section B**

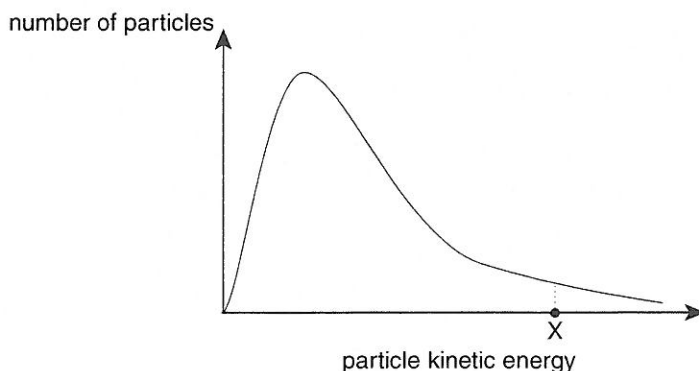
Answer **all** questions in the spaces provided.

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  $\text{H}_2(\text{g})$ ;  $\text{NaCl}(\text{s})$ .

**Question 1**

In order for a chemical reaction to proceed, particles must collide with sufficient energy and in the correct orientation. The graph below shows the range of average kinetic energies held by particles in a reaction mixture at a particular temperature.



a. i. What does point 'X' represent?

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ii. On the axes above, draw a new graph to represent the range of particle energies at a higher temperature.

iii. By referring to the graph that you drew in part ii, explain why even a small increase in temperature can result in a significant increase in reaction rate.

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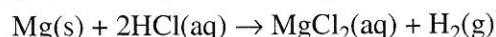
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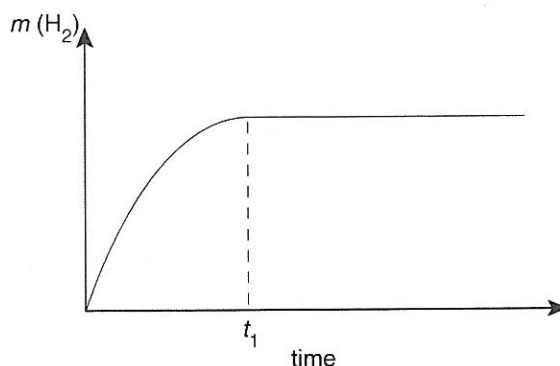
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1 + 1 + 1 = 3 marks

- b. A series of experiments are conducted in which the rate of reaction of magnesium with dilute hydrochloric acid is investigated. The equation that represents this reaction is



In the first experiment, 2.0 g of magnesium ribbon is dropped into a beaker containing 150 mL of 2.0 M hydrochloric acid. The mass of hydrogen gas produced is measured at regular intervals and the results are shown on the graph below.

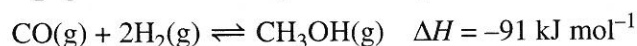


- i. At what time is the reaction proceeding at the greatest rate?  
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- ii. What event occurs at time  $t_1$ ?  
\_\_\_\_\_
- iii. The experiment is repeated using 1.0 g of powdered magnesium and the results are recorded. On the axes above, sketch the results of the second experiment.
- iv. State two ways (other than an increase in surface area of magnesium) by which the rate of this reaction could be increased.  
\_\_\_\_\_  
\_\_\_\_\_

1 + 1 + 2 + 1 = 5 marks  
Total 8 marks

### Question 2

Methanol is produced on an industrial scale by pumping a mixture of carbon monoxide and hydrogen gases over a catalyst comprising  $\text{Cr}_2\text{O}_3$  and  $\text{ZnO}$ . The equation to represent this reaction is



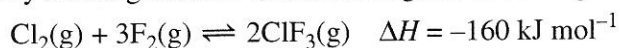
For the equilibrium above, complete the following table to show the effect on the equilibrium position and the equilibrium constant when each of the following changes are made to the conditions of the experiment.

Change in reaction conditions	Shift in equilibrium position (left, right or no change)	Change to equilibrium constant (decrease, increase or no change)
increased temperature		
continuous removal of methanol as it forms		
increased gas pressure		
removal of catalyst		

Total 4 marks

### Question 3

Chlorine trifluoride,  $\text{ClF}_3$ , is used in the electronics industry to clean electronic circuit boards during their manufacture. It is produced by reacting chlorine and fluorine gases according to the following equation.



- a. i. Write an equilibrium constant expression for this reaction.
- ii. A reaction mixture is allowed to reach equilibrium at  $400^\circ\text{C}$ . It is determined that the equilibrium concentrations are  $[\text{Cl}_2] = 0.173 \text{ M}$ ,  $[\text{F}_2] = 0.419 \text{ M}$  and  $[\text{ClF}_3] = 1.059 \text{ M}$ . Calculate the magnitude of the equilibrium constant at  $400^\circ\text{C}$ .

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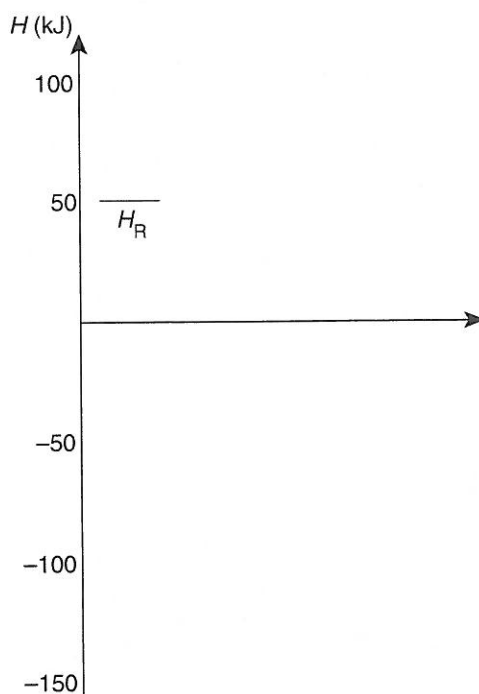


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1 + 1 = 2 marks

The activation energy for the forward reaction is  $40 \text{ kJ mol}^{-1}$ .

- b. Sketch an energy profile for the reaction on the set of axes below. Clearly mark the enthalpy of the products ( $H_P$ ), the change in enthalpy ( $\Delta H$ ) and the activation energy ( $E_A$ ) of the reaction.



2 marks

- c. For the reaction  $2\text{ClF}_3(\text{g}) \rightleftharpoons \text{Cl}_2(\text{g}) + 3\text{F}_2(\text{g})$ , determine
- i.  $\Delta H$ .

- ii.  $E_A$ .

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1 + 1 = 2 marks

- d. The manufacturers of chlorine trifluoride wish to maximise both the rate and the extent of the reaction as economically as possible. They decide to use higher temperatures, higher gas pressure and a suitable catalyst to achieve their aims.

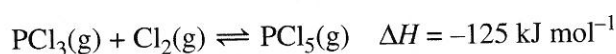
Complete the table below by indicating whether or not the changes introduced to the reaction conditions would be successful.

	Improvement in rate? (yes or no)	Improvement in extent? (yes or no)
increase in temperature		
increase in pressure		
addition of a catalyst		

3 marks  
Total 9 marks

#### Question 4

Phosphorus trichloride reacts with chlorine gas to produce phosphorus pentachloride according to the equation



At 250°C it has been determined that the equilibrium constant  $K = 0.041$ .

- a. At a certain temperature, 0.533 mol of  $\text{PCl}_3$  and 0.291 mol of  $\text{Cl}_2$  were introduced into an evacuated 4.00 L vessel. Once equilibrium was established, 60% of the  $\text{PCl}_3$  remained.

- i. Calculate the concentrations of all three gases in the container once equilibrium has been established.

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- ii. Calculate the equilibrium constant for the reaction at this temperature.

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2 + 1 = 3 marks

- b. Was the experiment carried out at a temperature higher or lower than 250°C? Explain your answer.

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1 mark  
Total 4 marks



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## CHEMISTRY VCE UNITS 3&4 DIAGNOSTIC TOPIC TESTS 2008

### TEST 5: RATE, HEAT AND EQUILIBRIUM REACTIONS

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#### SUGGESTED SOLUTIONS AND MARKING SCHEME

##### SECTION A: MULTIPLE-CHOICE QUESTIONS

###### Question 1      C

At the beginning of the reaction, the concentration of bromine (a reactant) is at its highest and so the colour intensity is also at a maximum. As the reaction proceeds most quickly initially and then slows as the concentration of reactants decreases, the loss of colour will not be linear, so **D** is incorrect. **A** and **B** both show low initial colour intensity, which is incorrect.

###### Question 2      B

The rate of a reaction is increased with increasing concentration of reactants, the use of a catalyst, higher temperatures and the use of a solid with high surface area, where applicable (so **A**, **C** and **D** are incorrect). In this reaction, the only gas is a product of the reaction (hydrogen) and so an increase in pressure would make it more difficult for it to be formed.

###### Question 3      B

An increase in temperature results in particles with significantly greater kinetic energy ( $E_K = \frac{1}{2}mv^2$ ). With more energy, the particles have more chance of overcoming the activation energy barrier required for the reaction to proceed. Particles will collide more frequently and therefore will collide with the correct orientation more often, but neither of these reasons is significant compared to the increase in energy, so **A** and **C** are incorrect. Colliding with the sides of the container is of no consequence (so **D** is incorrect).

###### Question 4      D

The energy given off as the products form is not as great as that which was absorbed to break the bonds in the reactants (the activation energy), so **D** is correct. The magnitude of the activation energy and the rate of the reaction are independent of whether the reaction is exothermic or endothermic (so **A** and **C** are incorrect). Endothermic reactions absorb energy from their surroundings (so **B** is incorrect).

**Question 5**      **A**

The enthalpy of reaction ( $\Delta H$ ) is defined as  $\Delta H = H_p - H_R$ . For the reaction shown in the diagram,  $\Delta H = -40 - 20 = -60 \text{ kJ mol}^{-1}$ . However, the question asks for  $\Delta H$  for this reaction multiplied by a factor of 3, so  $\Delta H = 3 \times -60 \text{ kJ mol}^{-1} = -180 \text{ kJ mol}^{-1}$ .

**Question 6**      **D**

The activation energy for the forward reaction as shown in the diagram is  $(50 - 20) = 30 \text{ kJ mol}^{-1}$ . The equation given is the reverse of this process multiplied by a factor of 2, and so is  $2 \times (50 - -40) = 2 \times 90 = 180 \text{ kJ mol}^{-1}$ .

**Question 7**      **A**

To obtain the desired equation from the one provided, it must be reversed and multiplied by a factor of 3. Thus, the  $K$  value is inverted and raised to the power of 3.

$$K' = \frac{1}{K^3} = \frac{1}{(13.9)^3} = 3.72 \times 10^{-4}$$

**Question 8**      **C**

When equilibrium is reached, 0.30 mol of  $\text{NO}_2$  has been consumed, as only 0.20 mol remains. From the equation, this means that the reaction has proceeded forward and  $\frac{1}{2} \times 0.3 = 0.15 \text{ mol}$  of  $\text{N}_2\text{O}_4$  has been formed. The equilibrium concentrations of  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$  are therefore 0.020 M and 0.015 M respectively.

$$K = \frac{[\text{N}_2\text{O}_4]}{[\text{NO}_2]^2} = \frac{0.015}{(0.020)^2} = 37.5 \text{ M}^{-1}$$

**Question 9**      **D**

To increase the yield of chlorine gas the reaction needs to proceed to the right. In this reaction there is 5 mol of gaseous reactants and 3 mol of gaseous products, so an increase in pressure causes the reaction to proceed to the side with less moles (so **D** is correct). The reaction is exothermic and so an increase in temperature will decrease yield (so **A** is incorrect). Adding an inert gas has no effect on the actual partial pressures of any of the gases and so has no effect on the position of equilibrium (so **B** is incorrect). A catalyst will increase the rate of reaction but has no effect on the yield (so **C** is incorrect).

**Question 10**      **C**

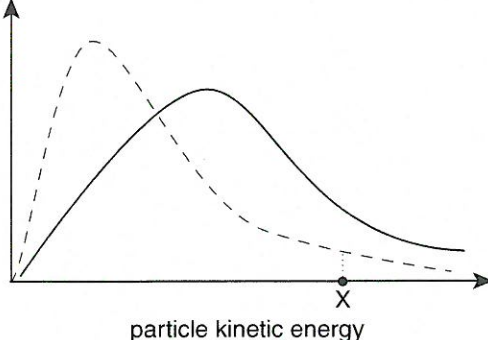
An increase in temperature will increase the yield for an endothermic reaction only (so **A** and **B** are incorrect). If the volume is increased the pressure decreases and the reaction will proceed to the side with the greater number of moles (so **C** is correct). The number of moles of reactants and products is the same in **D**, so a change in volume will have no effect.

**SECTION B: SHORT-ANSWER QUESTIONS**

**Question 1**

a. i. 'X' represents the activation energy barrier: the minimum amount of energy required for the reaction to proceed. 1 mark

ii. number of particles



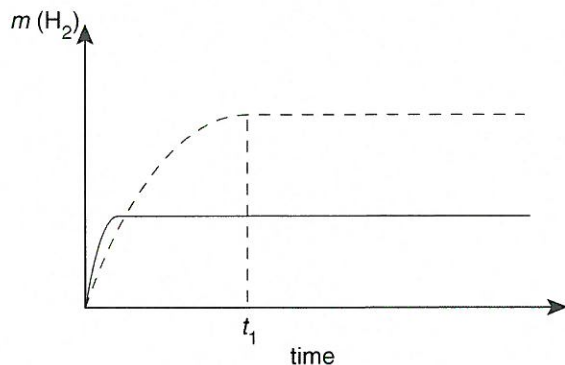
1 mark

iii. From the shape of the graph for the elevated temperature, it can be seen that a significantly greater proportion of particles now have sufficient energy to initiate reaction. Graphically, the area under the graph to the right of 'X' is much larger at the higher temperature. 1 mark

b. i. at the beginning of the reaction ( $t = 0$ ) 1 mark

ii. the reaction reached equilibrium 1 mark

iii.



*Powdered magnesium is used and so the rate of the reaction is much faster and the reaction reaches equilibrium more quickly. In this case only 1.0 g of magnesium is reacted and so the volume of hydrogen gas evolved is only half that of the initial experiment. Note that HCl is in excess in both cases.*

2 marks

*1 mark for graphing a greater rate of reaction*

*1 mark for graphing a smaller volume of hydrogen evolved*

iv. Any two of:

- increase the concentration of HCl
- increase the temperature of the solution
- use a suitable catalyst

1 mark

**Total 8 marks**



**Question 2**

Change in reaction conditions	Shift in equilibrium position	Change to equilibrium constant
increased temperature	left	decrease
continuous removal of methanol as it forms	right	no change
increased gas pressure	right	no change
removal of catalyst	no change	no change

An increase in temperature favours the endothermic process, so in this case the reaction proceeds backwards, or to the left. The equilibrium constant is affected by changes in temperature: as the reaction proceeds to form more reactant, the constant decreases.

The removal of a product (methanol) forces the reaction to proceed to the right to partly compensate according to Le Chatelier's principle. The constant will not be affected.

An increase in pressure will favour the side of the reaction with least moles, so in this case it proceeds to the right as the mole ratio is 3:1. Once again, the constant will not be affected.

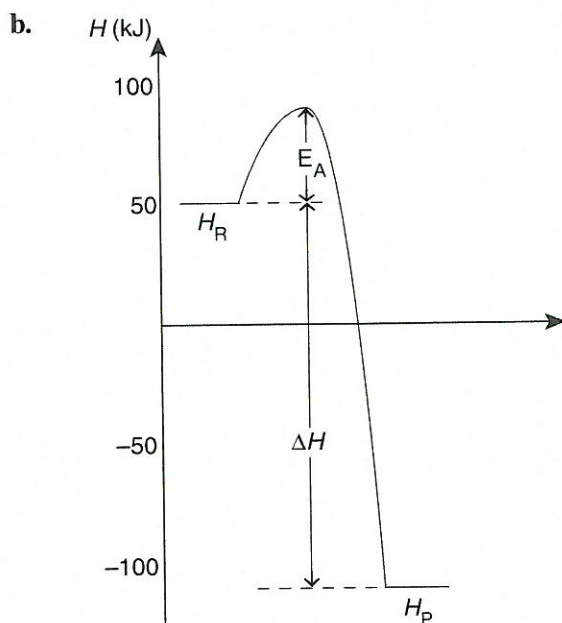
Catalysts have no effect on equilibrium position or constant; they affect only the rate of reaction.

4 marks  
 $\frac{1}{2}$  mark for each table cell correctly filled in  
Total 4 marks

**Question 3**

a. i.  $K = \frac{[\text{ClF}_3]^2}{[\text{Cl}_2][\text{F}_2]^3}$  1 mark

ii.  $K = \frac{[\text{ClF}_3]^2}{[\text{Cl}_2][\text{F}_2]^3} = \frac{(1.059)^2}{(0.173)(0.419)^3} = 88.1$  1 mark



2 marks  
 $\frac{1}{2}$  mark each for accurate labelling of  $H_P$ ,  $E_A$  and  $\Delta H$   
 $\frac{1}{2}$  mark for sketching all values accurately

- c. i.  $\Delta H = 50 - (-110) = +160 \text{ kJ mol}^{-1}$  1 mark  
 ii.  $E_A = 90 - (-110) = +200 \text{ kJ mol}^{-1}$  1 mark
- d.

	Improvement in rate?	Improvement in extent?
increase in temperature	yes	no
increase in pressure	yes	yes
addition of a catalyst	yes	no (no effect)

*An increase in temperature favours the endothermic process, so in this case the reaction proceeds backwards, or to the left. The reaction will proceed more quickly (as the particles have more energy) but the extent of reaction will be diminished.*

*An increase in pressure will favour the side of the reaction with least moles, so in this case it proceeds to the right as the mole ratio is 4:2, and extent increases. The increase in pressure also improves the rate, as particles are more likely to collide.*

*Catalysts have no effect on equilibrium position or constant; they affect only the rate of reaction. Catalysts lower the activation energy and so enhance rate.*

3 marks  
 $\frac{1}{2}$  mark for each table cell correctly filled in  
 Total 9 marks

#### Question 4

- a. i.

	Reactants		Products
mole ratio in the equation	$\text{PCl}_3$	$\text{Cl}_2$	$\text{PCl}_5$
$n_i$	0.533	0.291	0
change	-0.213	-0.213	+0.213
$n_{\text{eq}}$	0.320	0.078	0.213
$[\text{ ]}_{\text{eq}}, V = 4.00 \text{ L}$	0.0800	0.0195	0.0533

$$[\text{PCl}_3] = 0.0800 \text{ M}, [\text{Cl}_2] = 0.0195 \text{ M}, [\text{PCl}_5] = 0.0533 \text{ M}$$

2 marks  
 2 marks for all three correct concentrations  
 1 mark for recognising that the reactants decrease and the products increase in concentration

ii.  $K = \frac{[\text{PCl}_5]}{[\text{PCl}_3][\text{Cl}_2]} = \frac{0.0533}{0.0800 \times 0.0195} = 34.2 \text{ M}^{-1}$

*Note: A consequential mark should also be awarded to a student who correctly completes this step using incorrectly calculated concentration values from part i.*

1 mark

- b. The temperature was lower as the equilibrium constant increased for this exothermic equilibrium. A decrease in temperature favours the forward reaction for an exothermic process, resulting in a larger equilibrium constant.

1 mark  
 Total 4 marks