CHAPTER 13 - __PROBLEM SHEET__ - REACTION RATES
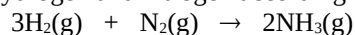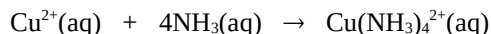
1.   Ammonia can be formed from hydrogen and nitrogen according to the following reaction:

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$

When ammonia is dissolved in water, it can react with copper ions to form the dark blue copper(II) tetrammine ion:

$$Cu^{2+}(aq) + 4NH_3(aq) \rightarrow Cu(NH_3)_4^{2+}(aq)$$

At room temperature, one of these reactions occurs rapidly and the other occurs very slowly. Which is the rapid reaction and which is the slow reaction?

2.   In an experiment, 1 g of granulated zinc is dissolved in 100 mL of 4 mol L^{-1} hydrochloric acid with the production
of   considerable quantities of heat. Which of the following actions will <u>decrease</u> the initial rate of production of
hydrogen?

   a) Heating the reaction mixture.

   b) Using 100 mL of 2 mol L^{-1} hydrochloric acid rather than 100 mL of 4 mol L^{-1} hydrochloric acid.

   c) Stirring the reaction mixture

   d) Adding a small volume of copper sulfate solution (acts as a catalyst)

   e) Using the same mass of zinc, but using powdered zinc.

   f) Using 5 g of the original granulated zinc instead of 1 g.

   g) Adding 100 mL of water to the original mixture.

3.   Titanium is extracted from its ore, ilmenite, a shiny black mineral present in granite. Ilmenite has the formula $FeTiO_3$.
The ore is mixed with coke (a source of carbon) and heated in an atmosphere of chlorine.

$$FeTiO_3(s) + 3C(s) + 3Cl_2(g) \rightarrow FeCl_2(s) + 3CO(g) + TiCl_4(g) \qquad \Delta H = -78 \text{ kJ mol}^{-1}$$
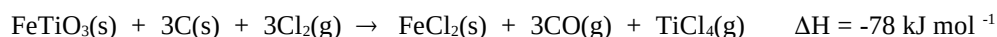
The reaction yields the volatile $TiCl_4$ which can isolated and reacted further to form titanium.

Which of the following will <u>increase</u> the rate of the reaction given above?

   a) Decreasing the temperature.

   b) Increasing the pressure of chlorine.

   c) Using large chunks of ilmenite and coke.

   d) Grinding the $FeTiO_3$ and C and mixing them thoroughly.

4.   Which of the following statements concerning the transition state in a reaction are correct?

The transition state (activated complex) in a reaction:

   a) is the product formed in the reaction

   b) is unstable

   c) can be isolated and stored in a container

   d) corresponds to a stage in the reaction at which bond-formation and bond-breaking is taking place

   e) has only a temporary existence

   f) is formed when a transition metal reacts

   g) is the highest energy state for the reacting system

5. Two of the following statements correctly define the term "activation energy of a reaction". Identify these TWO correct statements.

    The activation energy of a reaction

        a) is the energy that a reactant particle possesses.

        b) is equivalent to the temperature of a reaction mixture

        c) is the minimum energy that is required by colliding particles to result in a reaction

        d) is the kinetic energy possessed by the reactants.

        e) is the energy released in a chemical reaction

        f) is the difference between the energy of the products and the energy of the reactants

        g) is the energy generated when two reactant particles collide

   h) is the minimum energy that must be supplied by reactant particles before they can react.

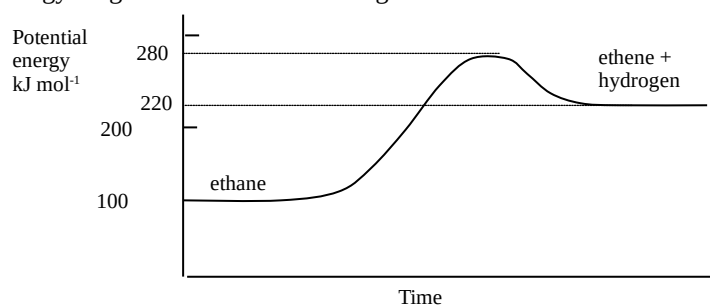6. Carbon monoxide and nitrogen dioxide react according to the following equation:

    $$CO + NO_2 \rightarrow CO_2 + NO \qquad \Delta H = -250 \text{ kJ mol}^{-1} \quad \text{Activation energy} = 150 \text{ kJ mol}^{-1}$$
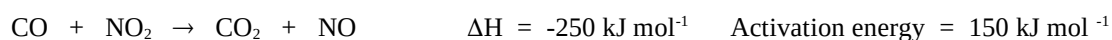
    Draw the potential energy diagram for this reaction. Choose your own scale for potential energy.
    Label the transition state.

Potential
energy
(kJ mol^{-1})

reaction coordinate
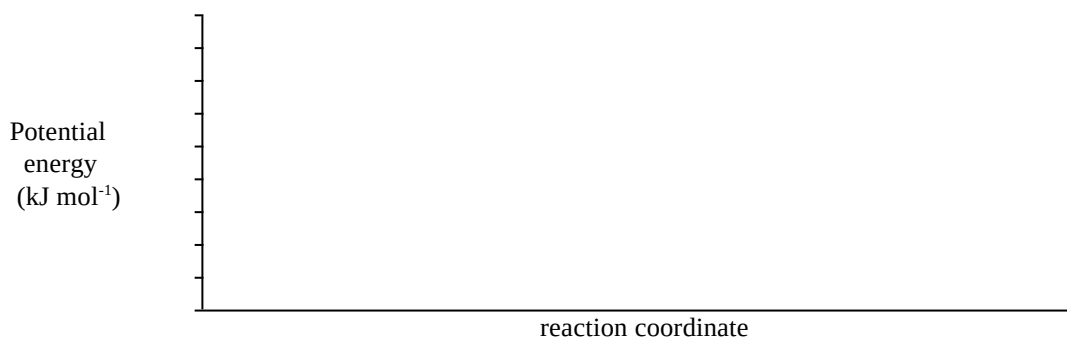
7. Ethene may be produced by heating ethane.   The reaction can be represented by the equation:
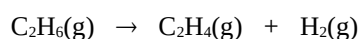
    $$C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)$$

    The potential energy diagram for this reaction is given below:

Potential
energy
kJ mol^{-1}

280

220

200

100

ethane

ethene +
hydrogen

Time

    Identify the following statements as true or false:

    a) The transition state for the reaction has a energy of 280 kJ.

    b) The reaction $C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)$ is exothermic.

    c) The heat of reaction for the reaction $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$ is - 120 kJ.

    d) The activation energy for the reaction $C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)$ is 280 kJ.

    e)   The enthalpy change, ΔH, for the reaction $C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)$ is +180 kJ

    f) The activation energy for the reaction $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$ is 60 kJ.

    g) When the reaction $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$ occurs, an increase in the temperature of the surroundings
        will result.

8.   According to the collision theory of reaction rates, which of the following are necessary prerequisites for a successful reaction?

        The reacting particles must:

          a) be heated to make them react

          b) collide in the presence of a catalyst

          c) be in the gaseous phase before a reaction will occur

          d) collide with the correct orientation

          e) collide with sufficient energy to supply the activation energy

          f) have large kinetic energies

9. Explanations based on the Collision Theory are given in boxes below:

EXPLANATION A	**EXPLANATION B**
Reactions involving breaking of strong covalent bonds tend to have higher activation energies and so are slower.	An increase in temperature, increases the number of particles with the required activation energy to react. Thus more collisions will be successful, resulting in a greater reaction rate

EXPLANATION C	**EXPLANATION D**
An increase in concentration or gas pressure will increase the rate of collisions, and hence the reaction rate.	A catalyst provides a pathway with a lower activation energy. Hence more particles will collide with the required (lower) activation energy to react.

EXPLANATION E
An increase in state of subdivision increases rate of collision between reactants, and hence reaction rate

Choose the correct explanations to explain the following observations:

a) For the reaction $H_2(g) + Br_2(g) \rightarrow 2HBr(g)$, if the pressure is increased (by decreasing the volume), then the rate of reaction increases.

b) To start a fire, small pieces of wood are used rather than logs of wood.

c) The reaction $2Ag(s) + Cl_2(g) \rightarrow 2AgCl(s)$ occurs much slower than the reaction $Ag^+(aq) + Cl^-(aq) \rightarrow$ AgCl(s).

  d) Concentrated hydrochloric acid is more dangerous than 0.1 mol L^{-1} hydrochloric acid.

e) Milk goes sour more quickly if it is left out of the refrigerator.

f) Hydrogen peroxide decomposes very slowly according to the equation $2H_2O_2 \rightarrow 2H_2O + O_2$. However, if a small amount of manganese dioxide is added to the hydrogen peroxide, it decomposes very rapidly.

10.   Complete the gaps in the following definition:

     A catalyst is an agent which i................................. the r.......................... of a chemical reaction by providing an

     alternative reaction   .... with a lower ....

     and are not p... c.................................... in the reaction.

11.   In a reaction between a solid X and a solution of Y, a gas is evolved. The reaction was performed three times with

the following quantities of reactants (X being in excess each time):

   i) 5 g of X and 25 mL of a 0.2 mol L^{-1} solution of Y

   ii) 10 g of X and 25 mL of a 0.2 mol L^{-1} solution of Y

   iii) 5 g of X and 25 mL of a 0.1 mol L^{-1} solution of Y

In each case the volume of gas liberated at various times after the start was noted. The graph drawn below has three

curves, A, B and C which summarise the three sets of results.

a) Which of the above experiments is responsible for each curve?

b) Draw the curves you would expect to obtain if the experiment were performed with the following quantities of reactants:

   iv) 5 g of X, 25 mL of a 0.1 mol L^{-1} solution of Y and 25 mL of water

   v) 5 g of X, 25 mL of a 0.1 mol L^{-1} solution of Y and a catalyst for this reaction

   vi)   10 g of X and 25 mL of a 0.2 mol L^{-1} solution of Y, performed at twice the temperature of ii)
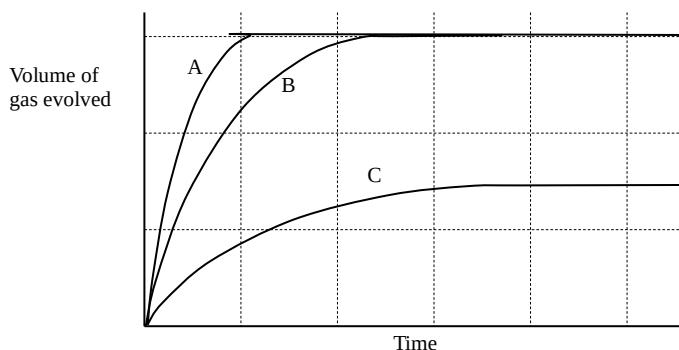
Old TEE questions

12   In the thermite process, a finely-ground mixture of aluminium powder and iron (III) oxide can react to produce white-hot molten iron. This mixture has first to be ignited with burning magnesium.

   (a)   On the axes below, draw a potential energy diagram for the reaction between aluminium and iron (III) oxide.

   (b)   Label the vertical coordinate.

   (c)   In the box below, write the equation for this reaction.
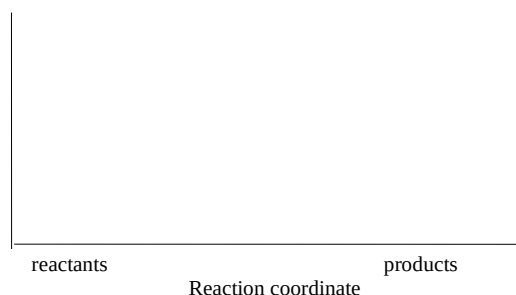
Equation:

13.   Explain the following.

	Explanation
Finely-chopped pieces of wood ignite faster than large lumps of wood	
Nitrogen reacts faster with hydrogen when a high pressure is used.	
Sulfur dioxide reacts faster with oxygen when a suitable catalyst is used.	

14. When white phosphorus, P_4, is left to stand in air, after a time it spontaneously ignites producing white fumes of tetraphosphorus decaoxide.
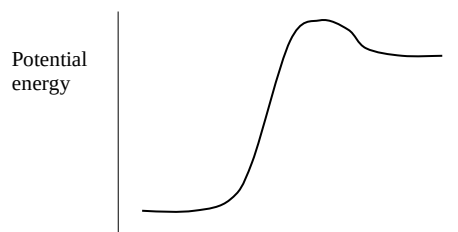
    (a)   On the axes below draw a potential energy diagram for the reaction.

    (b)   Label the vertical coordinate.

   (c)   Write the equation for the reaction in the box below.

reactants   products
Reaction coordinate
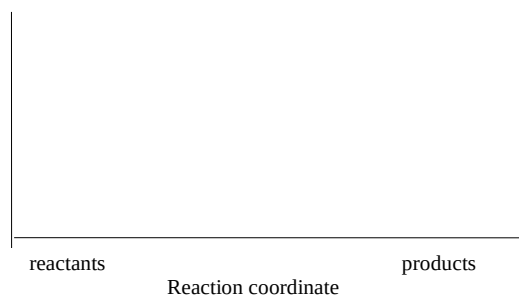
Equation: ⇌

15. For the reaction represented by the potential energy diagram below, which one of the following statements is **true**?

Potential
energy

    (a)   The activation energy for the forward reaction is smaller than the enthalpy change.
    (b)   The reaction mixture will get hot as the reaction proceeds.
    (c)   The value of ΔH is negative.
    (d)   The activation energy for the forward reaction is greater than that for the reverse reaction.
    (e)   The energy of the products is less than the energy of the reactants.

16. One step in the production of titanium metal from rutile (TiO_2) involves the following reaction at high temperature:

$$TiO_2(s) + 2 Cl_2(g) + 2 C(graphite) \rightarrow TiCl_4(g) + 2 CO(g)$$

    for this reaction   ΔH = - 77 kJ mol^{-1}.
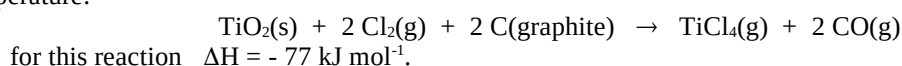
    Which of the following will increase the rate of reaction?

            I   Grinding the TiO_2 and C more intimately together.
            II   Increasing the temperature
            III Increasing the pressure

    (a)   I only   (b)   I and II only   (c)   I and III only
    (d)   III only   (e)   All of I, II and III

17. Hydrogen is commonly prepared in the laboratory by the reaction between zinc granules and dilute hydrochloric acid. The reaction is exothermic. If this reaction is performed using one mole of zinc and one mole of hydrochloric
    acid, which one of the following would **reduce** the rate of production of hydrogen?

    (a)   Increasing the temperature   (b)   Increasing the concentration of the hydrochloric acid.
    (c)   Adding water.   (d)   Increasing the amount of zinc present.
    (e)   Cutting the zinc into smaller pieces.

18. In an experiment, 2 g of magnesium shavings dissolve in 500 mL of 2 mol L^{-1} hydrochloric acid with the
     production of considerable quantities of heat. Which one of the following actions will NOT increase the initial
rate   of production of hydrogen?
     (a)   Using the same mass of magnesium but using larger pieces of the metal.
     (b)   Heating the reaction mixture.
     (c)   Using 500 mL of 5 mol L^{-1} acid instead of 500 mL of 2 mol L^{-1} acid.
     (d)   Stirring the reaction mixture.
     (e)   Using 10 g of the original magnesium shavings instead of 2 g.

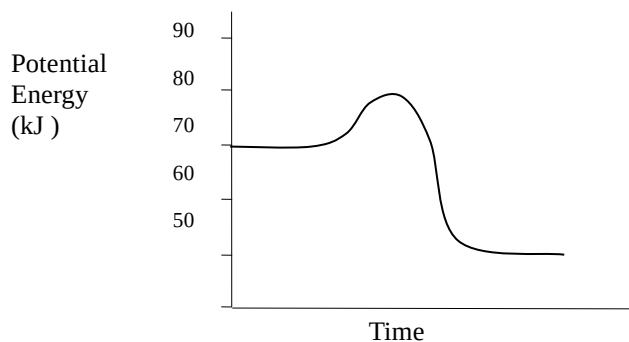19. Ethylene (ethene) and hydrogen chloride react according to the equation
$$C_2H_4(g) + HCl(g) \quad \rightleftharpoons \quad CH_3CH_2Cl(g) \; \Delta H = -70 \text{ kJ mol}^{-1}$$
$$\text{Activation energy} = 180 \text{ kJ mol}^{-1}$$
     On the axes below, draw a potential energy diagram for this reaction. Mark in your own choice of scale for
potential   energy.

Potential
energy
(kJ mol^{-1})
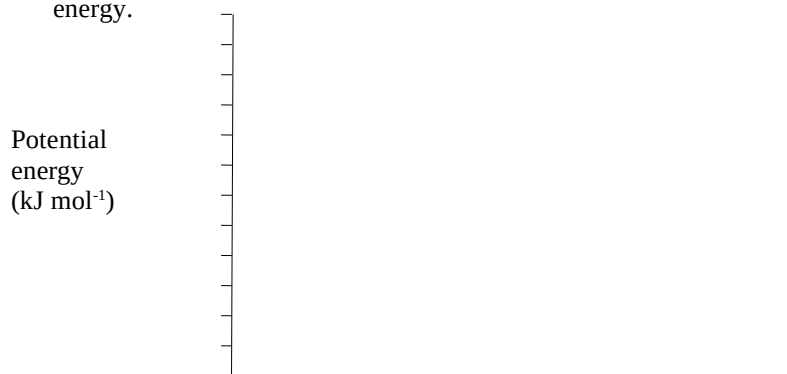
20. Below is the potential energy diagram for the reaction: $A(g) + B(g) \rightarrow AB(g)$

Potential
Energy
(kJ)

90
80
70
60
50

Time

     Which of the following statements is **TRUE**?

     (a) ΔH for this reaction is 20 kJ.   (b) ΔH for this reaction is -20 kJ.
     (c) ΔH for this reaction is -30 kJ.   (d)   The activation energy for this reaction is 20 kJ.
     (e)   The reaction endothermic.

21. Consider the reaction: $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

     Increasing the pressure of this system causes the rate of the reaction to increase. Which of the following
statements
     best explains this observation?

     (a)   The volume of the reactants in greater than that of the products.
     (b)   The number of reactant molecules with energies greater than the activation energy for the reaction will
increase.
     (c)   The total kinetic energy of the system will increase.
     (d)   The particles will collide more often.
     (e)   The average kinetic energy of the reactant molecules will increase.

22. For the chemical reaction: $A(aq) + B(s) \rightarrow C(g) + D(aq)$ $\Delta H = $ -50 kJ mol^{-1}

Which one of the following actions would increase the rate of the reaction?

(a)   Using the same mass of B but in larger lumps.   (b)   Increasing the pressure inside the reaction vessel.

(c)   Heating the reaction mixture.   (d)   Increasing the volume of the reaction mixture.

(e)   Decreasing [A(aq)].

23. Consider the following potential energy diagram for the reaction of hydrogen with iodine in the gas phase:

$$\tfrac{1}{2}H_2(g) + \tfrac{1}{2}I_2(g) \rightarrow HI(g)$$
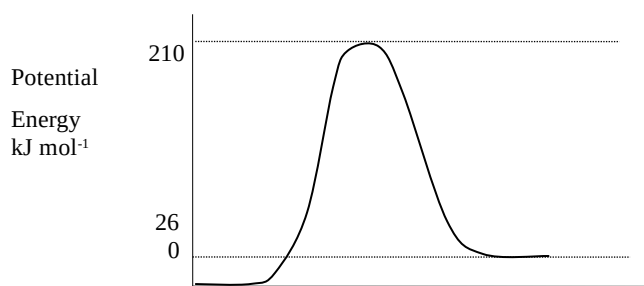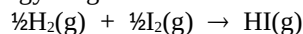
For the decomposition of hydrogen iodide (REVERSE of the above reaction) what are the values of activation energy

E_A and heat of reaction ΔH?

(a) $E_A = 210$ kJ mol^{-1}; $\Delta H = 26$ kJ mol^{-1} (b) $E_A = 184$ kJ mol^{-1}; $\Delta H = $ -26 kJ mol^{-1}
(c) $E_A = $ -184 kJ mol^{-1}; $\Delta H = $ -26 kJ mol^{-1} (d) $E_A = 184$ kJ mol^{-1}; $\Delta H = 26$ kJ mol^{-1}
(e) $E_A = 210$ kJ mol^{-1}; $\Delta H = $ -26 kJ mol^{-1}

ANSWERS

1. $3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$ is a slow reaction (because strong covalent bonds in the reactants need to be broken before the products can form. This means that the reaction would have a large activation energy, and so only a few particles would have sufficient energy to react. Thus the reaction would be slow.)

$Cu^{2+}(aq) + 4NH_3(aq) \rightarrow Cu(NH_3)_4^{2+}(aq)$ is a faster reaction (because no strong covalent bonds in the reactants need to be broken in the formation of the product. The particles need only to collide. This means the reaction will have a low activation energy and lots of particles will have this low energy. Thus, the reaction will be rapid.)

2. b) - concentration of reactant is less   g) - the water will decrease the concentration of the acid

3. b) - concentration of the gaseous reactant is increased
    d) - there will be a larger surface area for contact between the reactants

4. b), d), e), g)   5. c) and h)

6.
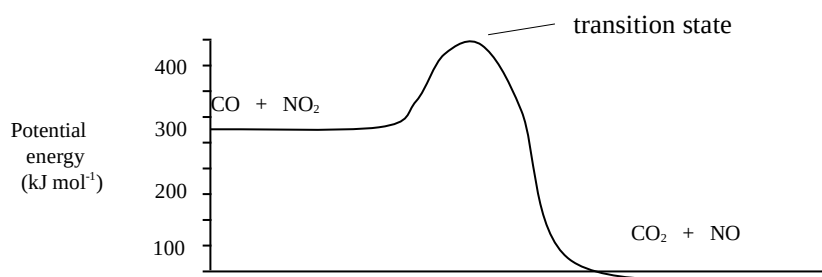
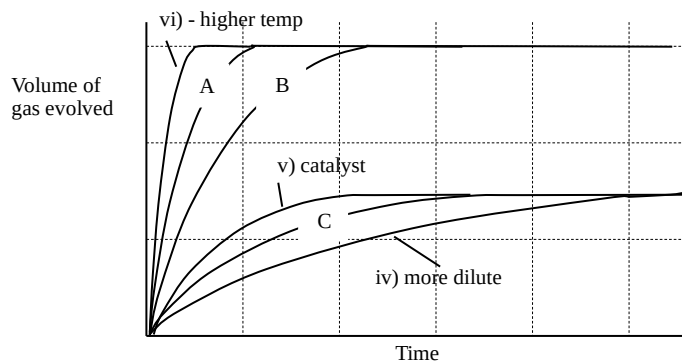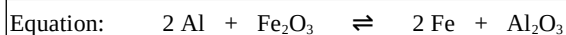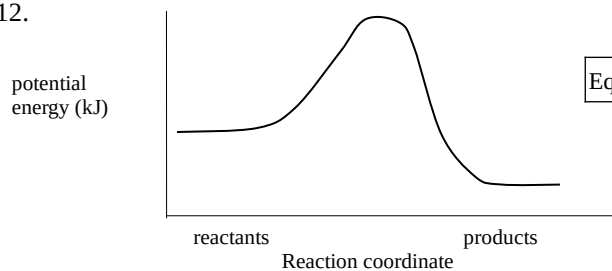7. a) True   b) False - it is endothermic   c) True   d) False
    e) False   f)   True   g) True

8. d),   e)

9. a) Explanation C   b) Explanation E   c) Explanation A
    d) Explanation C   e) Explanation B   f) Explanation   D

10. A catalyst is an agent which **increases** the **rate** of a chemical reaction by providing an alternative reaction **pathway**   with a lower **activation energy** and are not **permanently consumed** in the reaction.

11.   a) graph A - experiment ii)   graph B - experiment i)   graph C - experiment iii)
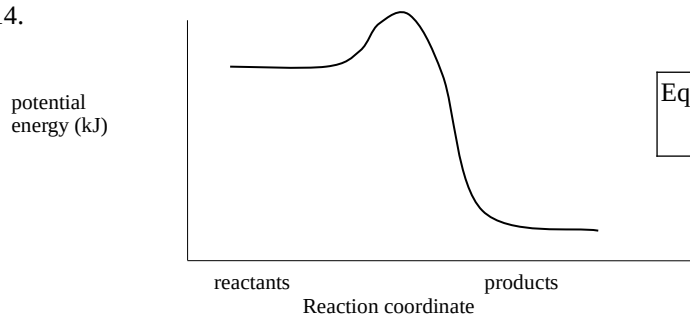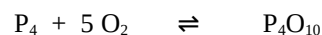
      b)

Volume of
gas evolved

vi) - higher temp

A   B

v) catalyst

C

iv) more dilute

Time

12.

potential
energy (kJ)

Equation: $2\ Al\ +\ Fe_2O_3\ \rightleftharpoons\ 2\ Fe\ +\ Al_2O_3$

reactants   products
Reaction coordinate

13.

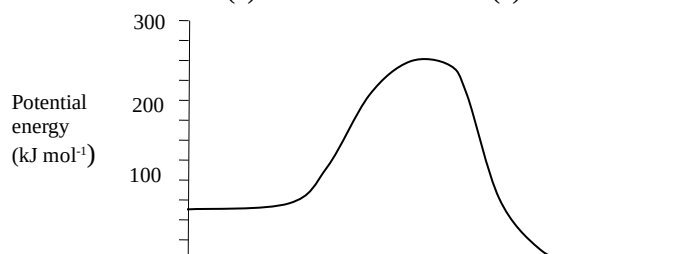|	Explanation
Finely-chopped pieces of wood ignite faster than large lumps of wood	Finely-chopped wood has a greater surface area which can be exposed to the air. Consequently, there will be a greater collision rate between the oxygen particles in the air and the wood particles, and so greater reaction rate.
Nitrogen reacts faster with hydrogen when a high pressure is used.	A high pressure will push the gas particles closer together (creating greater concentration) and so they will collide more often. This will result in an increase in reaction rate.
Sulfur dioxide reacts faster with oxygen when a suitable catalyst is used.	A catalyst increases the reaction rate by providing an alternative pathway with a lower activation energy. Consequently more particles will collide with sufficient activation energy required for reaction, in the presence of a catalyst.

14.

potential
energy (kJ)

Equation:

$P_4\ +\ 5\ O_2\ \rightleftharpoons\ P_4O_{10}$

reactants   products
Reaction coordinate

15. (d)   16. (e)   17. (c)   18. (a)

19.

Potential
energy
(kJ mol^{-1})

300

200

100

20.   (b)   21. (d)   22. (c)   23.   (b)
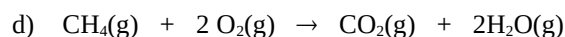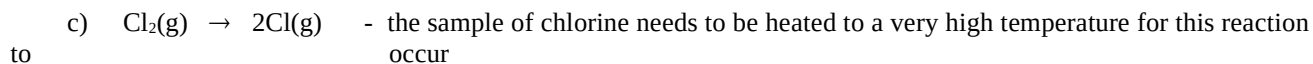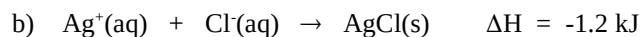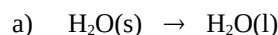
More Problems

24. Dinitrogen tetroxide is a colourless gas, nitrogen dioxide is a brown gas. Dinitrogen tetroxide reacts to form nitrogen dioxide according to the equation

$$N_2O_4(g) \rightarrow 2\ NO_2(g) \quad \Delta H = +57\ kJ, \quad \text{activation energy} = 69\ kJ\ mol^{-1}.$$
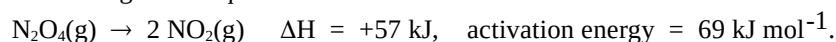
   a)   When dinitrogen tetroxide decomposes, would you expect the temperature of the surroundings to increase or decrease?

   b)   Assuming dinitrogen tetroxide has a potential energy of 50 kJ, sketch the potential energy diagram for the reaction, indicating clearly the enthalpy change and the activation energy.

25. Match up each of the following reactions with one of the potential energy diagrams shown below. Briefly justify your   decision in each case.

   a) $H_2O(s) \rightarrow H_2O(l)$

   b) $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s) \qquad \Delta H = -1.2\ kJ$

   c) $Cl_2(g) \rightarrow 2Cl(g)$ - the sample of chlorine needs to be heated to a very high temperature for this reaction to   occur

   d) $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$
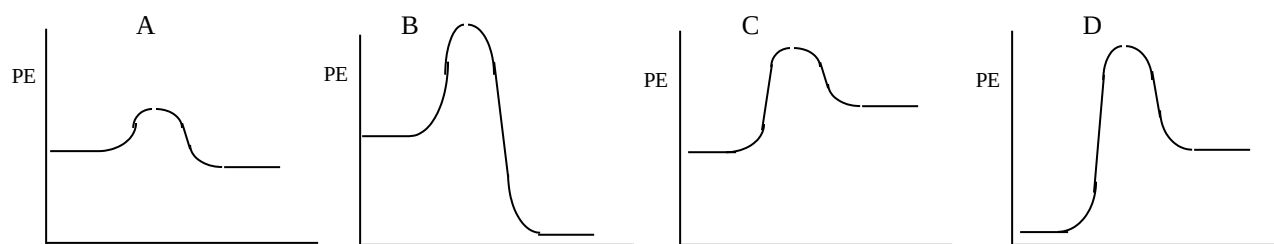
26. When dilute hydrochloric acid is added to a solution of sodium thiosulfate, a milky precipitate of sulfur is formed. The rate of reaction may change in any of these ways:
       A   the rate of reaction is decreased
       B   the rate of reaction is increased
       C   the rate of reaction is unchanged

   Choose from these three effects which one is appropriate to each of the following situations:

   a) the concentration of acid used is decreased

   b) the reaction mixture is stirred

   c) the solution of sodium thiosulfate is made from a finely ground powder instead of crystals

   d) the temperature is raised from 20°C to 30°C.

27. The rate of decomposition of hydrogen peroxide (to form oxygen) in the presence of manganese dioxide was studied   by measuring the mass of the reaction mixture at various tomes after mixing the hydrogen peroxide solution with   the powdered manganese dioxide in an open beaker. In the graphs below, curve A was obtained when

0.5 g of MnO_2 was added to 100 mL 2.0 mol L^{-1} hydrogen peroxide solution at 25ºC. Curve B was obtained when 0.5 g of MnO_2 was added to 100 mL of the same hydrogen peroxide solution, but at a temperature of 80ºC.

mass of
reaction
mixture
(g)

B

A

T

time (min)
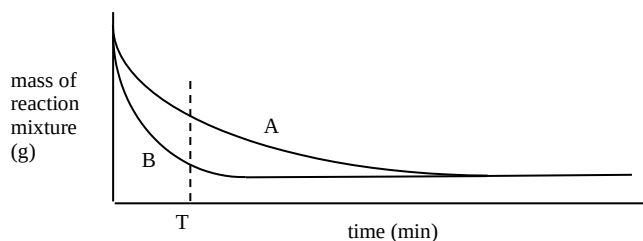
   Explain how you can use the curves to show that the rate of reaction A was slower at time T than the rate of
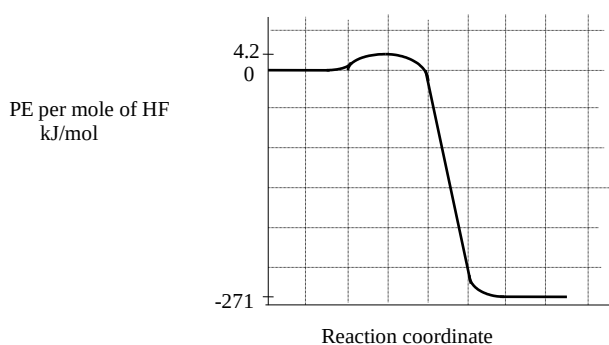   reaction B.

28. Explain, using the collision theory and/or potential energy diagrams, the following

   a) wood burns slower than paper (paper is made from wood)

   b) food cooks quicker in almost boiling oil than in boiling water (b.pt. of oil is about 250ºC)

   c) 5 mol L^{-1} hydrochloric acid is much more dangerous for students to use in practical work compared to 1 mol L^{-1}
          hydrochloric acid.

29. a)   Using the collision theory, explain why a mixture of methane (natural gas) and oxygen will not react unless it
       is first heated e.g. by lighting it with a match.

   b)   Why is it not necessary to continue to supply heat to "keep the reaction going"?

30. Examine the following potential energy diagram for a chemical reaction

60.0

40.0

Relative energy (kJ/mol)

20.0 reactants

0.0   products

Time
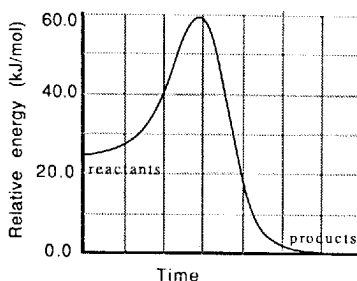
   a) Determine ΔH and the activation energy for the reaction.

   b) If a catalyst is added to the system, how will ΔH and the activation energy be affected?

   c) On the above axes, sketch the approximate potential energy diagram for the catalysed reaction.

31. Consider the following observations of a particular experiment:
       Observation I   When sucrose is mixed thoroughly with an oxidising agent, and heated strongly, no reaction is
                              observed.
       Observation II   When a drop of concentrated phosphoric acid is added to the sucrose mixture, a violent reaction
                              occurs releasing a large amount of heat and light energy.

Observation III   The amount of concentrated phosphoric acid remaining after the experiment is found to be the same as in the beginning.

a) What does observation I suggest about the activation energy for the reaction?

b) Explain how the concentrated phosphoric acid causes the violent reaction.

c) Is the reaction exothermic or endothermic?

d) Give two ways in which you could increase the rate of the reaction.

32. 1.0 g samples of magnesium carbonate are separately reacted with 10 mL samples of 2 mol L^{-1} hydrochloric acid at   15^{0}C, 20^{0}C and 25^{0}C. On the same axes, sketch (qualitatively) the graphs of volume of carbon dioxide formed versus time, for the probable results of each of the three experiments.

33. Hydrogen and fluorine react according to the equation $H_2(g) + F_2(g) \rightarrow 2HF(g)$. A potential energy diagram for this reaction is drawn below:

PE per mole of HF
kJ/mol

Reaction coordinate

a) What is ΔH for the reaction $H_2(g) + F_2(g) \rightarrow 2HF(g)$?
b) What is the activation energy for the reaction $H_2(g) + F_2(g) \rightarrow 2HF(g)$?
c) What is ΔH for the reaction $2HF(g) \rightarrow H_2(g) + F_2(g)$?
d) What is the activation energy for the reaction $2HF(g) \rightarrow H_2(g) + F_2(g)$?

34. A reaction time is being measured by mixing solutions of two reactants and then measuring the time taken for the mixed solution to reach a certain colour intensity. One of the products formed is coloured.
How will each of the following alter the reaction time?
   i) diluting the solutions with excess water
   ii) increasing the atmospheric pressure
   iii) heating the reaction mixture
   iv) adding a catalyst

35. Why is fine coal dust in a coal mine an explosive hazard? Explain your answer in terms of collision theory.

Homework

Write a paragraph explaining, in terms of the collision theory, what happens when two reactants react. In your answer, include an explanation of the concepts of 'activation energy' and 'transition state'. Use the following reaction if you wish to refer to a specific example in your answer.
$$NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g)$$