O Level Pure Chemistry Structured

Speed of Reaction Test 2.0

Q1

Chemical Kinetics

Chemical kinetics is the study of the rate (or speed) of reactions and the factors that affect them.

In general, when the concentration of a reactant increases, the rate of the reaction increases. However, the rate of the reaction may not always be directly proportional to the concentration of each of the reactants in the reaction.

The rate of a reaction can be defined as the rate of increase in concentration of a product with time or the rate of decrease in concentration of a reactant with time.

Rate Law

The rate law or rate equation provides information on how the rate of a reaction depends on the concentration of all the reactants.

Consider the reaction: ***a A*** + ***b B*** → products

where ***a*** and ***b*** are the stoichiometric coefficients and ***A*** and ***B*** are the reactants.

The rate equation or rate law can be expressed as:

$$\text{Rate} = k\,[A]^m\,[B]^n$$

where **k** is a constant of proportionality in the rate equation.
m is the order of reaction with respect to reactant A
n is order of reaction with respect to reactant B

Order of reaction

The order of reaction with respect to a given reactant is defined as the power to which the concentration of that reactant is raised to in the rate equation.

A reaction is said to be zero order with respect to a particular reactant, e.g. A, if the rate of reaction does not depend on the concentration of A.

$\text{rate} \propto [A]^0$ where [A] represents the concentration of A

Hence, $\text{rate} = k\,[A]^0 = k$ where k is the proportionality constant

A reaction is said to be first order with respect to a particular reactant, e.g. B, if the rate of reaction is directly proportional to the concentration of B.

rate $\propto [B]^1$ where [B] represents the concentration of B

Hence, rate = $k [B]^1 = k [B]$ where k is the proportionality constant

A reaction is said to be second order with respect to a particular reactant, e.g. C, if the rate of reaction is directly proportional to the square of the concentration of C.

rate $\propto [C]^2$ where [C] represents the concentration of C

Hence, rate = $k [C]^2 = k [C]^2$ where k is the proportionality constant

Overall Order of a Reaction

The overall order of a reaction is the sum of the orders of reaction of all the reactants.

For example, if the rate equation for a reaction is

$$\textbf{Rate} = k [A]^m [B]^n$$

The overall order of the reaction is (**m** + **n**).

Hydrolysis of halogenoalkanes

Halogenoalkanes can react with aqueous sodium hydroxide upon warming to produce alcohols and the respective hydrogen halides. This is known as a hydrolysis reaction.

For example, $CH_3Br\ (aq) + NaOH\ (aq) \rightarrow CH_3OH\ (aq) + HBr\ (aq)$

The results of an investigation into the kinetics of this reaction are given below:

experiment number	$[CH_3Br]$ / mol dm^{-3}	[NaOH] / mol dm^{-3}	initial rate of reaction / mol dm^{-3} s^{-1}
1	0.10	0.20	0.001
2	0.20	0.10	0.001
3	0.20	0.20	0.002
4	0.30	0.20	0.003
5	0.60	0.40	0.012

The data collected in the table can then be analysed and processed to give information about the kinetics of the hydrolysis reaction between bromomethane and aqueous sodium hydroxide.

(a) Use the information in the table to deduce the order of reaction with respect to CH_3Br. Explain your reasoning.

[1]

(b) Use the information in the table to deduce the order of reaction with respect to NaOH. Explain your reasoning.

[1]

(c) What is the overall order of the reaction between bromomethane and aqueous sodium hydroxide?

....[1]

(d) Write an overall rate equation for the reaction between bromomethane and aqueous sodium hydroxide.

....[1]

(e) Determine the value and unit for the rate constant, k, in your rate equation in **(d)**.

....

....[1]

(f) The reactants and products for the reaction between bromomethane and aqueous sodium hydroxide are all colourless.

Describe a chemical test that can be carried out on the product(s) to confirm that the reaction has occurred. Include the observation(s) that would be made for a positive test.

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....[2]

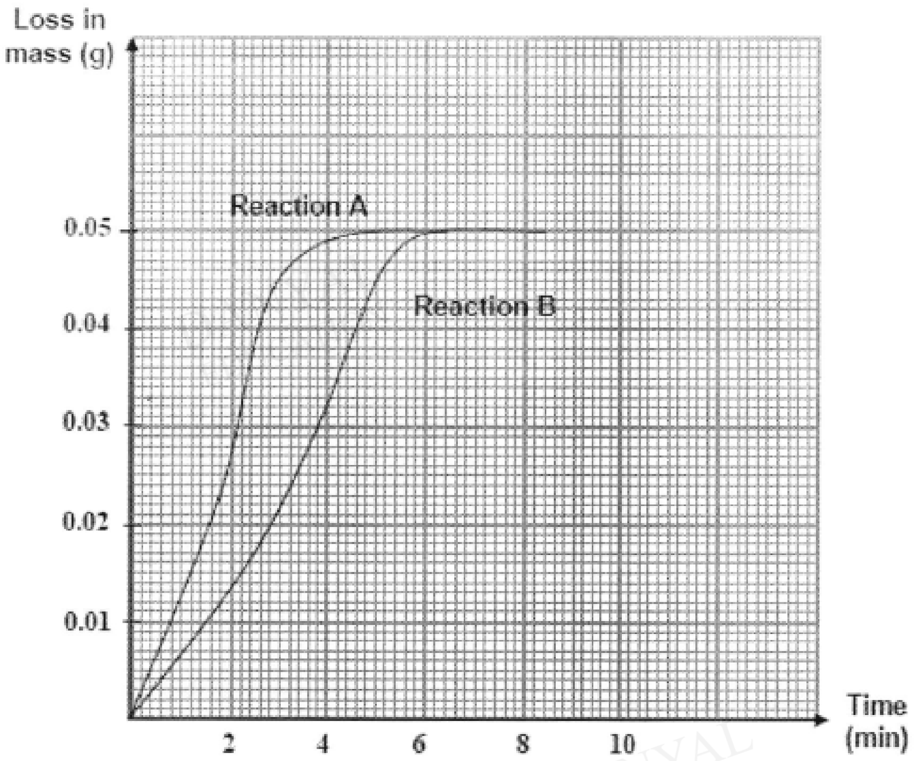
(g) A dibromoalkane W (M_r = 188), is warmed with excess aqueous sodium hydroxide to produce a diol X. The diol is then oxidised fully to a dicarboxylic acid Y. Under suitable conditions, diol X and dicarboxylic acid Y can react to form a polymer Z.

Deduce the identities of W, X, Y and Z.

[4]

Q2

The graphs below show the reaction of zinc with dilute nitric acid in two different reactions. The beaker and its contents were weighed every two minutes and the loss in mass was recorded.



(a) **(i)** In Reaction **A**, 1.625 g of large lumps of zinc was added to 250 cm^3 of dilute nitric acid of 0.500 mol/dm^3 in a beaker.
Explain the cause of the loss in mass.

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____ [1]

(ii) Determine the limiting reactant.
Show your working clearly. [2]

(b) In Reaction **B**, the reaction was repeated using 1.625 g of large lumps of zinc added to 250 cm^3 of dilute nitric acid of 0.500 mol/dm^3 in a beaker at a lower temperature.
All other conditions of the reaction remained the same.

Explain the difference in initial speed of reaction for reaction **B**.

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____ [2]

(c) A third reaction, Reaction **C**, is repeated with the addition of 50 cm^3 of aqueous copper(II) sulfate.

Two students predict the results of this experiment.

Student 1: 'The initial rate of reaction is **slower** as the aqueous copper(II) sulfate is an impurity.'

Student 2: 'The loss in mass is **lesser** as the aqueous copper(II) sulfate reacts with one of the reactants.'

Do you agree with the students?

Explain your reasoning.

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____ [3]

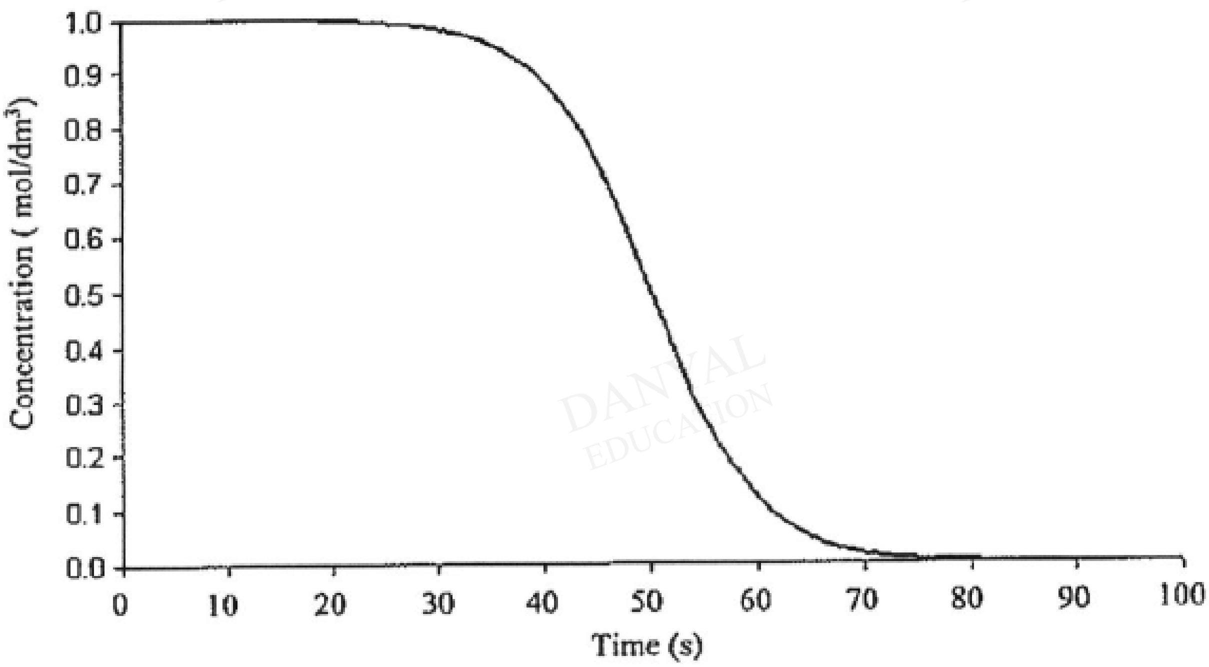
Q3

An autocatalytic reaction is one where the reaction is catalysed by one of its products. An example of an autocatalytic reaction is the reaction between acidified potassium manganate(VII) and oxalic acid, $H_2C_2O_4$. The ionic equation is as follows:

$$2MnO_4^-(aq) + 6H^+(aq) + 5H_2C_2O_4(aq) \rightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 10CO_2(g)$$

In this reaction, the Mn^{2+} ions act as the catalyst.

The graph for the changes in concentration of the oxalic acid over time when excess acidified potassium manganate(VII) solution was reacted with 1.0 mol/dm^3 of oxalic acid is as shown below:



(a) Explain how, in terms of activation energy and colliding particles, a catalyst speeds up the rate of reaction.

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.... [3]

(b) Explain why, in terms of colliding particles,

(i) the rate of reaction increases in the first 50 s,

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....[2]

(ii) the rate of reaction decreases after 50 s.

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....[2]

(c) Explain, in terms of oxidation state, why the reaction between acidified potassium manganate(VII) and oxalic acid is a redox reaction.

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....[2]

(d) State how one can tell that the reaction has completed.

....[1]

Q4

The molecules in a gas, at a fixed temperature, are in a state of constant random motion. However, not all molecules have the same speed. Some move faster than others. Fig. 9.1 shows the distribution of the number of molecules in a sample of gas having different molecular energies.

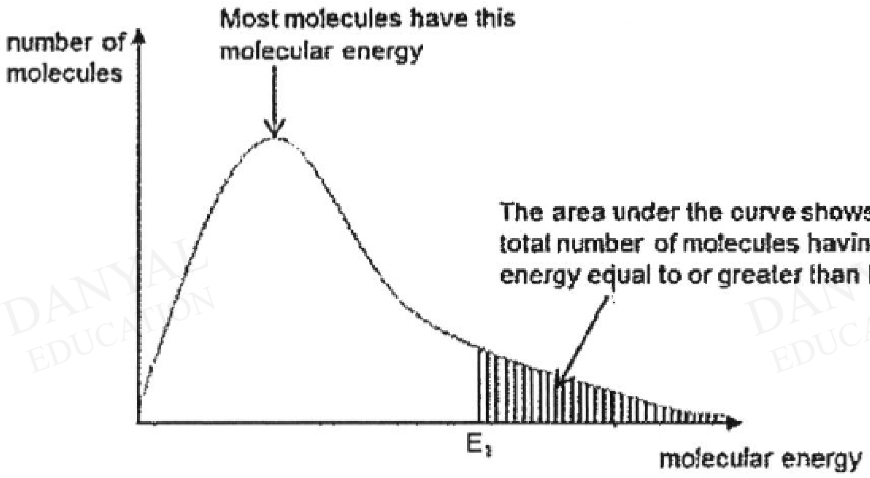

Fig. 9.1

(a) Describe the arrangement and movement of molecules in a gas.

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....[3]

Fig. 9.2 compares the distribution of molecular energies of a sample of gas at two different temperatures.

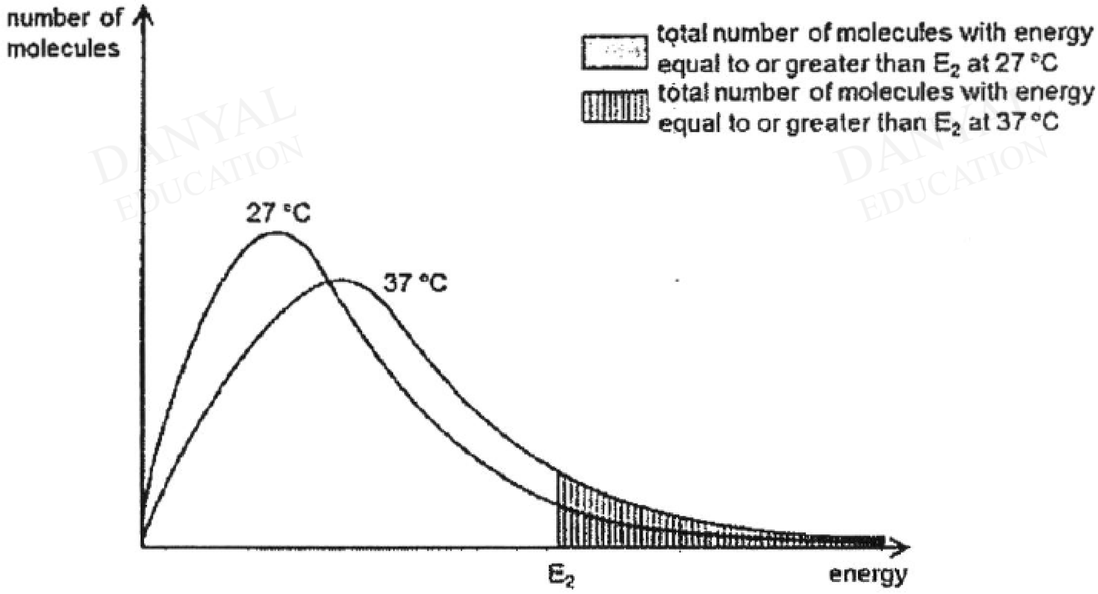

Fig. 9.2

(b) Use your knowledge about the behaviour of molecules to explain the difference in the area under the curve as seen in Fig. 9.2.

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....[2]

(c) The molecules of the sample of gas are able to react with one another in a chemical reaction. With reference to Fig. 9.2, if E_2 represents the activation energy of the reaction, then the total area under the curve shows the number of molecules of the gas that are able to react together. Hence, make use of the information provided in Fig. 9.2 to explain why the speed of a reaction increases when temperature increases.

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....[2]

(d) Catalysts are used to increase the speed of a reaction. Explain how catalysts are able to do so.

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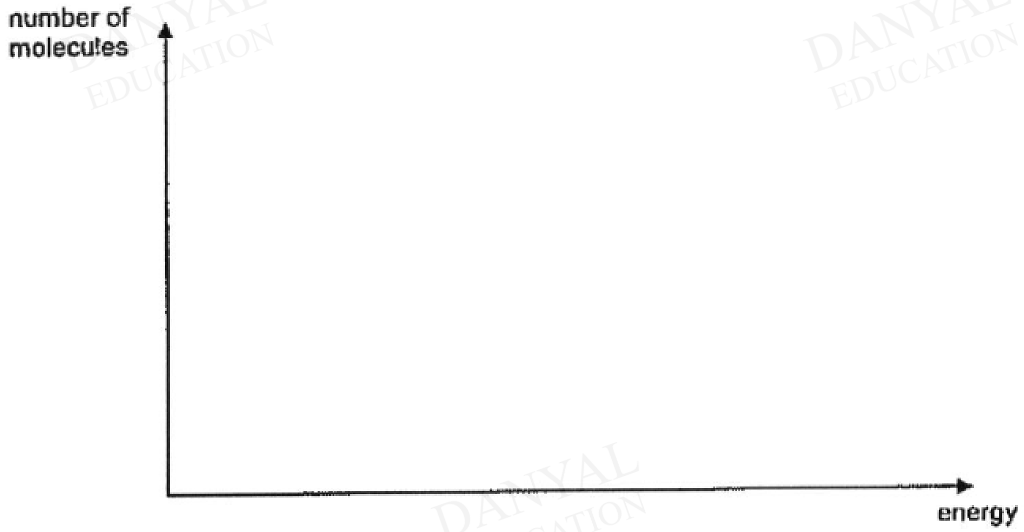
....[1]

(e) On the axes provided, sketch a graph similar to that in Fig. 9.2 to show the effect of a catalyst on the speed of a reaction. Label the graph clearly to show the catalysed and uncatalysed reactions. Provide an explanation for the graph that you have sketched.



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....[4]

Q5

Reactions that give iodine as one of the products are known as 'iodine clock'. One example of 'iodine clock' is the reaction of potassium iodate(V), KIO_3, with sodium sulfite, Na_2SO_3, in the presence of sulfuric acid, H_2SO_4, to produce iodine, I_2.

$$2IO_3^-(aq) + 5SO_3^{2-}(aq) + 2H^+(aq) \rightarrow I_2(aq) + 5SO_4^{2-}(aq) + H_2O(l)$$

In the presence of starch, the formation of a dark blue colour indicates that iodine is formed in the reaction.

A student investigated the effect of temperature on the initial rate of this reaction by changing the temperature of potassium iodate(V) solution and measuring the time taken for the colourless solution to turn dark blue. **Table 1** shows the student's results.

Table 1

temperature of potassium iodate(V) / °C	time for colourless solution to turn dark blue / s
25	32
30	27
35	24
40	23
45	20
50	18

The student then modified the experiment to find out how the concentration of sulfuric acid will affect the initial rate of the same reaction. Instead of varying the temperature, he varied the volume of 0.1 mol/dm³ sulfuric acid. The volume of sulfuric acid used determines its concentration. **Table 2** shows the student's results.

Table 2

volume of sulfuric acid / cm³	volume of water / cm³	time for colourless solution to turn dark blue / s
40	45	23
50	35	18
60	25	15
70	15	12

(a) Based on the information in **Table 1**,

(i) Deduce the effect of temperature of potassium iodate(V) solution on the initial rate of the 'iodine clock' reaction.

....

....[1]

(ii) Explain, in terms of particles, the effect deduced in a(i).

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....[2]

(b) (i) Deduce the relationship shown in **Table 2** and, hence, draw a conclusion about this experiment.

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....[2]

(ii) What is the role of sulfuric acid in the reaction?

....[1]

(c) Calculate the mass of iodine produced when 50 cm^3 of 2.0 g/dm^3 potassium iodate(V) and 25 cm^3 of 5.0 g/dm^3 sodium sulfite are used in the reaction.

[3]

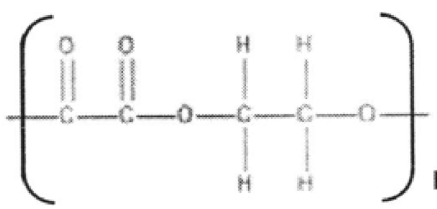
(d) Identify **one** variable not stated in the information given, which has to remain constant in both experiments, so that each experiment is a fair investigation.

....[1]

Answers

Speed of Reaction Test 2.0

Q1

(a)	Comparing experiments 1 and 3, when the concentration of CH_3Br is doubled, the rate of reaction is also doubled, hence the rate of reaction is directly proportional to $[CH_3Br]$. OR Comparing experiments 1 and 4, when the concentration of CH_3Br is triped, the rate of reaction is also tripled, hence the rate of reaction is directly proportional to $[CH_3Br]$. Order of reaction w.r.t CH_3Br = 1 [1] *reject order of reaction without logical reasoning.*
(b)	Comparing experiments 2 and 3, when the concentration of NaOH is doubled, the rate of reaction is also doubled, hence the rate of reaction is directly proportional to [NaOH]. Order of reaction w.r.t NaOH = 1 [1] *reject order of reaction without logical reasoning.*
(c)	Overall order = 1 + 1 = 2 [1]
(d)	Rate = k $[CH_3Br][NaOH]$ [1]
(e)	k = 0.05 $mol^{-1}dm^3s^{-1}$ 1 mark for both correct value and unit
(f)	Add a few drops of <u>acidified</u> aqueous silver nitrate [1] to the test solution. White precipitate formed [1]
(g)	W: dibromoethane / $Br(CH_2)_2Br$ [1] X: 1,2-ethane-diol / $OH(CH_2)_2OH$ [1] Y: ethanedioic acid / $(COOH)_2$ [1] Z:  n [1]

Q2

(a) (i) Hydrogen gas produced escapes from the reaction mixture. [1]

(ii) Loss in mass = mass of hydrogen = 0.05 g
No. of moles of hydrogen = 0.05/2 = 0.025
No. of moles of Zn required = 0.025
Actual no. of moles of Zn provided = 1.625/65 = 0.025
OR
No. of moles of acid used = 0.025× 2 = 0.05
Actual no. of moles of acid = 250/1000 × 0.500 = 0.125

[1] for working
The limiting reactant is Zn. [1] [2]

(b) As the temperature of the water decreases,
Nitric acid and Zn particles lose energy and move slower [;]
lesser reacting particles have energy equal or more than the activation energy[;]
1; to get first mark

leading to lowered frequency of effective collision between Zn and nitric acid. [1] [2]

(c) I disagree with student 1.
The initial rate of reaction is slower because adding 50 cm^3 of aqueous solution **decreases the concentration of H^+ ions in the solution** [1] thereby decreasing the rate of reaction.

I agree with student 2.
Zinc displaces copper from aqueous copper (II) sulfate. [;]
Lesser no. of moles of Zn is available for reaction with nitric acid.[;]
2; -[1] [3]
Hence lesser volume of hydrogen gas produced.[1]

Q3

a)
Catalyst provides an alternative pathway with a lower activation energy for the reaction to proceed;
More particles would have sufficient energy to overcome the activation energy;
This increases the frequency of effective collisions;

b)(i)
As the rate proceeds in the first 50s, the concentration of Mn^{2+} ions increases;
There would be more Mn^{2+} ions per unit volume of solution, resulting in increase in frequency of effective collisions;

b(ii)
As the rate proceeds after 50s, the concentration of oxalic acid decreases, so there would be less oxalic acid per unit volume of solution;
resulting in decrease in frequency of effective collisions;

c)
Potassium manganate(VII) is reduced as the oxidation state of Mn decreases from +7 to +2;
Oxalic acid is oxidised as the oxidation state of C increases from +3 to +4;

d)
No more effervescence/bubbles would be observed. (Reject: The solution will turn from purple to colourless)

Q4

(a) The molecules in a gas are arranged in a disorderly manner and very far apart from each other. [1]
The molecules are able to move at high speeds, [1] occupying every available space. [1]

(b) At a higher temperature, the molecules possess a greater amount of (kinetic) energy. [1]
Thus, more molecules will have the energy equal to or greater than E_2 at 37 °C compared to molecules at 27 °C. [1]

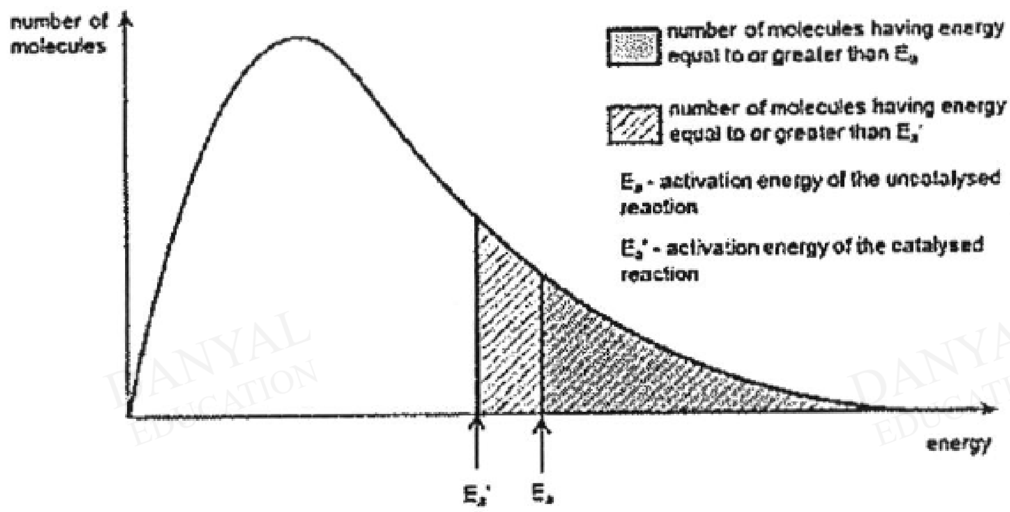
Must mention what Fig. 9.2 shows because this is not mentioned in the question.

(c) When temperature increases, there will be a greater number of molecules having the energy equal to or greater than the activation energy of the reaction. [1 mk pt] This is shown by the greater area under the curve when the temperature increases. [1 mk pt]
This results in more successful/effective collisions occurring, leading to a faster speed of reaction. [1 mk pt]

Reject ideas about faster speed resulting in more frequent collisions between molecules as students are required to make use of Fig. 9.2 to explain.

(d) Catalysts lower the activation energy of the reaction by providing an alternative pathway for the reaction. [1]

(e)



Activation energy for the catalysed reaction is lower than the activation energy of the uncatalysed reaction, ie. correct labelling of E_a' and E_a – [1]
More particles have the energy that is equal to or greater than Ea' compared to E_a, ie. the area under the curve is correctly shaded and labelled – [1]
Legend is provided – [1]

As a catalyst lowers the activation energy of the reaction, more particles are able to collide with the energy equal to or greater than the activation energy (E_a'). This is shown by the greater area shaded under the graph. [1]

Q5

(a)	(i)	As temperature increases, initial rate increases. OWTTE. Accept reverse.
	(ii)	As temperature increases, particles gain kinetic energy and move faster [1]. Frequency of effective collision increases, thus initial rate of reaction increases. [1] OWTTE. Accept reverse.
(b)	(i)	The concentration of acid increases when volume of acid increases // Concentration of acid is directly proportional to volume of acid [1] Accept reverse. Increase in the concentration of sulfuric acid increases the initial rate the reaction // rate at which iodine is produced. [1]
	(ii)	It acts as a catalyst // It speeds up the reaction // provides an acidic medium for reaction to occur [1]
(c)		mole of KIO_3 = 50/100 X [2 / (127+39+16X3)] = 0.0004672 mol mole of Na_2SO_3 needed to react fully = 0.004672/2 X 5 = 0.001168 mol mole of Na_2SO_3 used = 25/100 X [5 / (23X2+32+16X3)] = 0.0.000992 mol
		working [1] Limiting reactant = Na_2SO_3 mole of I_2 = 0.00992 / 5 = 0.0001984 mol [1] mass of I_2 = 0.0001984 X (127X2) = 0.05039 = 0.0504g [1]
(d)		concentration/ temperature/ volume of sodium sulfite // concentration/ volume of potassium iodate(V)// volume/ concentration of starch solution Reject temperature of distilled water// particle size