Questions

1 Consider the reaction between gaseous iodine and gaseous hydrogen.

$I_2(g) + H_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H^{\ominus} = -9 \text{ kJ}$

Why do some collisions between iodine and hydrogen not result in the formation of the product?

A. The I_2 and H_2 molecules do not have sufficient energy.

B. The system is in equilibrium.

C. The temperature of the system is too high.

D. The activation energy for this reaction is very low. [1]

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2 At 25 °C, 200 cm^3 of 1.0 mol dm^{-3} nitric acid is added to 5.0 g of magnesium powder. If the experiment is repeated using the same mass of magnesium powder, which conditions will result in the same initial reaction rate?

	Volume of HNO_3/ cm^3	Concentration of HNO_3/mol dm^{-3}	Temperature / °C
A.	200	2.0	25
B.	200	1.0	50
C.	100	2.0	25
D.	100	1.0	25

[1]

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3 Which of the following is an appropriate unit for rate of reaction?

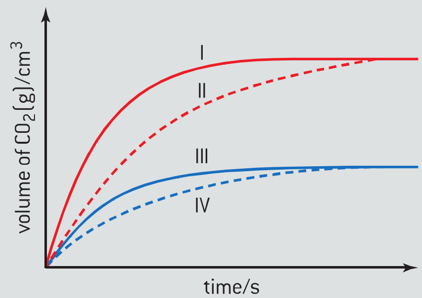
A. s

B. min

C. cm^3 s

D. mol dm^{-3} min^{-1}

4 Equal masses of powdered calcium carbonate were added to separate solutions of hydrochloric acid. The calcium carbonate was in excess. The volume of carbon dioxide produced was measured at regular intervals. Which curves in figure 20 best represent the evolution of carbon dioxide against time for the acid solutions shown in table 3?



▲ Figure 20

	25 cm^3 of 2 mol dm^{-3} HCl	50 cm^3 of 1 mol dm^{-3} HCl	25 cm^3 of 1 mol dm^{-3} HCl
A.	I	III	IV
B.	I	IV	III
C.	I	II	III
D.	II	I	III

▲ Table 3

[1]

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5 Hydrochloric acid is reacted with large pieces of calcium carbonate; the reaction is then repeated using calcium carbonate powder. How does this change affect the activation energy and the collision frequency?

	Activation energy	Collision frequency
A.	increases	increases
B.	stays constant	increases
C.	increases	stays constant
D.	stays constant	stays constant

[1]

IB, November 2009

6 Which factors can affect the rate of a chemical reaction?

I. The concentration of the reactants.

II. The temperature at which the reaction takes place.

III. The physical state of the reactants.

A. I and II only

B. I and III only

C. II and III only

D. I, II, and III

7 In an acid-catalysed hydrolysis reaction of ethyl ethanoate, the concentration of the ester changes from 1.50 mol dm^{-3} to 0.35 mol dm^{-3} in 3.5 min, at a given temperature, T_1. Which of the following statements are correct?

I. The average rate of the reaction is 0.33 mol dm^{-3} min^{-1}.

II. If the reaction is carried out at a higher temperature, T_2, the reaction rate will be greater.

III. The products of the reaction will be ethanoic acid and ethanol.

A. I and II only

B. I and III only

C. II and III only

D. I, II, and III

8 Factors that affect the rate of a chemical reaction include particle size, concentration of reactants, and the temperature of the reaction.

i) Define the term **rate of a chemical reaction**. [1]

ii) List the **three** characteristic properties of reactant particles that affect the rate of reaction as described by the collision theory. [3]

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9 a) A solution of hydrogen peroxide, H_2O_2, is added to a solution of sodium iodide, NaI, acidified with hydrochloric acid, HCl. The yellow colour of the iodine, I_2, can be used to determine the rate of reaction.

$$H_2O_2(aq) + 2NaI(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + I_2(aq) + 2H_2O(l)$$

The experiment is repeated with some changes to the reaction conditions. For each of the changes that follow, predict, stating a reason, its effect on the rate of reaction.

i) The concentration of H_2O_2 is increased at constant temperature. [2]

ii) The solution of NaI is prepared from a fine powder instead of from large crystals. [2]

b) Explain why the rate of a reaction increases when the temperature of the system increases. [3]

IB, November 2009

10 Models can prove vital in chemistry. Discuss the principles of the kinetic–molecular theory and the collision theory.

11 Design an appropriate experiment to measure the rate of reaction of a hydrolysis reaction (saponification) of the ester methyl ethanoate in an alkaline medium.

12 Design an appropriate experiment to measure the rate of reaction using the “clock reaction” technique involving the reaction of magnesium with dilute hydrochloric acid solution.

Topic 6 – Chemical kinetics

End of topic questions (page 177)

1. A; for a chemical reaction to occur between two reactant particles, a number of conditions must be fulfilled:

- the two particles must collide with each other, that is, there must be physical contact;
- the colliding particles must have the correct mutual orientations;
- the reactant particles must have sufficient kinetic energy to initiate the reaction;

Examining the alternatives, only A is plausible and is related to the third condition stated above.

2. C; checking the stoichiometry, 0.21 moles of Mg are reacting with 0.2 mol of HNO_3; referring to the balanced equation, it is determined that the HNO_3 is the limiting reagent; to achieve the same initial reaction rate, you will require the same number of mol of HNO_3;

3. D; the rate of reaction is defined as the change in concentration of reactants or products per unit time;

4. C; as calcium carbonate is in excess, it is the concentration and number of mol of HCl that will influence the initial rate of reaction; curves I and II demonstrate the fastest initial rates and produce twice the volume of carbon dioxide compared to curves III and IV; the reaction conditions in columns 1 and 2 both have 0.05 mol of HCl; however, column 1 has a smaller volume within which the reaction is taking place; this increases the probability of successful collisions; column 3 has half the number of mol of HCl when compared to columns 1 and 2; it is not possible to determine if column 3 represents curves III or IV; column 1 represents curve I and column 2 represents curve II;

5. B; in a heterogeneous reaction involving a gas (or a liquid) and a solid, the rate of reaction will increase if the surface area of the solid is increased by breaking the solid up into smaller pieces; the reason for this is that the reaction takes place only on the surface of the solid reactant; if a finely divided solid or powder is used, there will be an increase in the surface area and there will be a greater number of solid particles available for reaction; this will result in greater collision frequency; increasing the surface area of the solid reactant will not alter the activation energy of the reaction;

6. A; there are four factors that can increase the rate of a chemical reaction:

(i) increasing the temperature at which the reaction is conducted;

(ii) addition of a catalyst;

(iii) increasing the concentration of the reactants;

(iv) decreasing the particle size of reactants in the solid phase;

7. D; statement I: $average\ rate = \frac{\Delta C}{\Delta t} = \frac{1.50\text{–}0.35\ mol\ dm^{-3}}{3.5\ min} = 0.33\ mol\ dm^{-3}\ min$; statement II: with increasing temperature, the frequency of collisions will increase; there will be more successful collisions, since there are now more particles which have sufficient kinetic energy to overcome the activation energy barrier; statement III: esterification is a reversible reaction that occurs when a carboxylic acid and an alcohol are heated in the presence of a catalyst, normally concentrated sulfuric acid; acid – catalyzed hydrolysis is the reverse of esterification and results in the formation of a carboxylic acid and an alcohol;

8. **(i)** increase in concentration of product per unit time/decrease in concentration of reactant per unit time;

(ii) frequency of collisions; kinetic energy/speed of reactant particles; collision geometry/orientation;

9. **a)** **(i)** increases rate of reaction; molecules (of H_2O_2) collide more frequently/more collisions per unit time;

(ii) no effect/(solution) remains unchanged; solid NaI is not reacting/aqueous solution of NaI is reacting/surface area of NaI is not relevant in preparing the solution;

b) kinetic energy/speed of reacting molecules increases; frequency of collisions increases per unit time; greater proportion of molecules have energy greater than activation energy/E_a;

10. ***Discuss*** – *Offer a considered and balanced review that includes a range of arguments, factors or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence*. [Assessment Objective 3]

NOS 1.10. Models, some simple, some very complex, based on theoretical understanding, are developed to explain processes that may not be observable; computer-based mathematical models are used to make testable predictions, which can be especially useful when experimentation is not possible; models tested against experiments or data from observations may prove inadequate, in which case they may be modified or replaced by new models.

In the kinetic-molecular theory of gases, a sample of gas is modelled as consisting of a collection of particles moving at high velocities in random directions; the sizes of the particles are negligible; the particles collide with each other and with the walls of the container containing the gaseous sample; all the collisions are elastic; the pressure exerted by the gas results from collisions of its particles with the walls of the container; the three conditions that form the basis of collision theory are given in answer to question 1 above; the collision theory is a model that helps us understand why rates of chemical reactions depend on temperature; the model is based on the kinetic-molecular theory.

11. To design an appropriate experiment to measure the rate of reaction of a hydrolysis reaction (saponification) of the ester methyl ethanoate in an alkaline medium, we must first examine the chemical reaction ($CH_3COOCH_2CH_3 + NaOH \rightarrow CH_3COONa + CH_3CH_2OH$), which is second order as the rate of saponification is directly proportional to the concentration of the ester and the alkali; while the reaction proceeds, samples from the reaction mixture are taken periodically and analyzed using gas chromatography (GC), high performance liquid chromatography (HPLC), nuclear magnetic resonance (NMR), infrared spectroscopy (IR) or even mass spectroscopy (MS):

- GC will show individual peaks of all volatiles, including methanol, ethanoic acid and methyl ethanoate; these peaks can be individually integrated, and exact amounts/concentrations of all substances can be calculated using a calibration curve (made from standard samples of methanol, ethanoic acid and ester);
- HPLC will be very similar to GC;
- NMR will be problematic, but still possible, as the signals of CH_3 groups in CH_3OH, CH_3COOH and $CH_3C(O)OCH_3$ will all have slightly different chemical shifts(please note that we cannot look at OH groups, as the medium is aqueous, and all OH peaks will be too broad to detect);
- IR will show slightly different absorptions for the C=O groups in the acid and ester, and also very different absorptions in the fingerprint region; we will not be able to interpret those directly, but if we prepare a series of standard solutions containing known mixtures of CH_3OH, CH_3COOH and $CH_3C(O)OCH_3$, we'll be able to build a calibration curve or just match the spectra of the reaction mixture to the nearest standard;
- MS will be unclear unless we are using chemical ionization instead of electron impact, but similar to IR, it will be possible to interpret it using a calibration curve or just a series of standards;

When neither one of these techniques is available, we can still take samples of the reaction mixture and titrate with ethanoic acid; the saponification of the ester will partially consume the base [for example, $CH_3C(O)OCH_3 + KOH \rightarrow CH_3COOK + CH_3OH$]; the concentration of the remaining base can be compared with the initial concentration of this base, and the extent of the saponification calculated; the key here is to use the same acid (ethanoic) as the titrant, because if we use a strong acid, it will also react with both KOH and CH_3COOK, and thus will show about the same result regardless of the saponification extent, but also to use the correct indicator (phenolphthalein with pK_a 9.6 is the best), as the pH at the equivalence point will be greater than 7 (because CH_3COOK is a salt of a weak acid and a strong base); finally, if possible, use a colorimeter; the accuracy and precision of the experiment can be improved by taking multiple measurements, using different students and also by preparing standards with known concentrations of CH_3OH, CH_3COOH, $CH_3C(O)OCH_3$ and KOH (we have to titrate these standards as well and build a calibration curve showing the known concentration of KOH against the concentration of KOH determined by our titration – this will eliminate or reduce most systematic errors);

12. At the beginning of the reaction of Mg with dilute HCl, the addition an acid-base indicator will result in a color change when a certain percentage of HCl is consumed; from the *IB Data Booklet*, the most suitable indicators are methyl orange (pK_a 3.7, red to yellow), bromophenol blue (pK_a 4.2, yellow to blue), bromocresol green (pK_a 4.7, yellow to blue) and methyl red (pK_a 5.1), as other indicators will change color at too high a pH, which will not be achieved within a reasonable time during this reaction; the observed color of the reaction mixture will be accurate if a standard is used; start the experiment by preparing a buffer solution of pH = 4.0, add exactly the same amount of indicator to the flask and place both flasks (with HCl/Mg and standard) side by side on a white sheet of paper; when the colors of both flasks are the same, stop the timer and record the result; to eliminate random errors, repeat the experiment three times; to reduce systematic errors, ask different students to look at the color (as individual perceptions can vary).