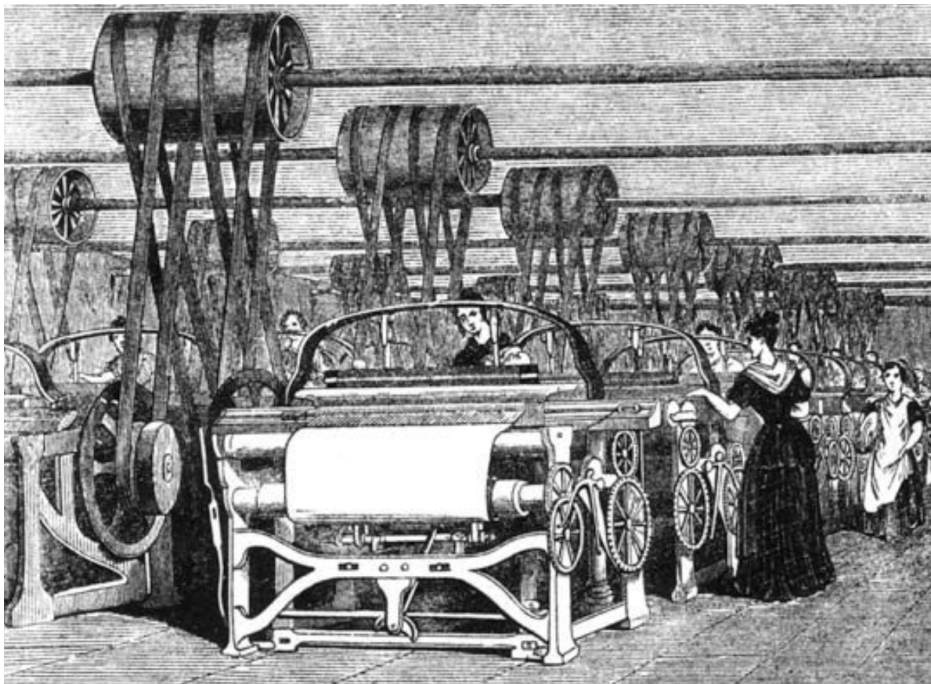# EX-WACE EXAM QUESTIONS

SCIENTIFIC METHODS

+

REACTION RATES & CHEMICAL EQUILIBRIUM

in

INDUSTRIAL PROCESSES

Questions 22 to 25 refer to the following information.

Some chemistry students were investigating the relationship between concentration and rate of reaction. In the investigation, different concentrations of hydrochloric acid were added to a sodium thiosulfate solution to produce solid sulfur. This reaction was represented by the following equation.

$$2\,H^+(aq) \quad + \quad S_2O_3^{2-}(aq) \quad \rightarrow \quad SO_2(g) \quad + \quad S(s) \quad + \quad H_2O(\ell)$$

A piece of paper with a cross drawn on it was placed under the reaction vessel. The time taken for the cross to disappear due to the formation of the precipitate was measured.

22. The independent variable was the

    (a) time taken for the cross to disappear.
    (b) total volume of the mixture.
    (c) rate of reaction.
    (d) concentration of hydrochloric acid.

23. The type of data collected and the source of data are best characterised as

    (a) qualitative and primary.
    (b) qualitative and secondary.
    (c) quantitative and primary.
    (d) quantitative and secondary.

24. When a number of laboratory groups pooled their data, one group's results were consistently higher than those of the others. This is an example of

    (a) a systematic error.
    (b) not enough trials.
    (c) a random error.
    (d) uncertainty.

25. One group chose to have its members take turns observing and timing the cross disappearing. This was poor methodology because

    (a) it could make the data invalid.
    (b) it introduced a possible systematic error.
    (c) more trials would be needed to produce better results.
    (d) the data would be less reliable.

End of Section One

See next page

Section One: Multiple-choice   **25% (25 Marks)**

Question No.	Answer
22	D
23	C
24	A
25	D

Question 30 (8 marks)

Carbonyl chloride, $COCl_2$, is a colourless, poisonous gas that is used in the production of insecticides and a variety of plastics. It is produced through the exothermic reaction between carbon monoxide and chlorine gases. Carbonyl chloride is a liquid below 8 °C at 100.0 kPa.

The following equation is used to represent the reaction.

$$CO(g) \quad + \quad Cl_2(g) \quad \leftrightharpoons \quad COCl_2(g) \qquad \Delta H < 0$$

(a) For this industrial process state the conditions that would optimise the: (2 marks)

rate of reaction _____

_____

yield _____

_____

(b) State **one** compromise in conditions that might be required to produce carbonyl chloride, $COCl_2$, in an industrial process. Explain the effect of this condition on the rate and yield and justify why this compromise is required. (6 marks)

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Question 30 **(8 marks)**

(a) For this industrial process state the conditions that would optimise the: (2 marks)
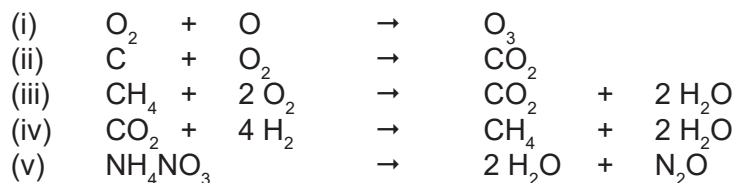rate of reaction
yield

Description	Marks
Rate: high temperature, high pressure, catalyst Note: At least two conditions must be given	1
Yield: low temperature, high pressure/maintain high concentration of reactants; removal of products Note: At least two conditions must be given	1
Total	2
Note: If one incorrect condition - no marks.	

(b) State **one** compromise in conditions that might be required to produce carbonyl chloride, $COCl_2$, in an industrial process. Explain the effect of this condition on the rate and yield and justify why this compromise is required. (6 marks)

Description	Marks
One condition requiring a compromise is the temperature at which the process occurs.	1
A high temperature is required to maximise the rate of reaction because a greater proportion of particles will: • be moving faster and so collide more frequently and • have sufficient energy (greater than the activation energy, Ea) resulting in a greater proportion of successful collisions.	1–2
A low temperature is required (to maximise the yield of $COCl_2$) because: • the reaction is exothermic in the forward direction, lowering the temperature favours the forward reaction • products are formed at a higher rate than reactants are formed.	1–2
Higher temperatures favour a higher rate but with a reduced yield while lower temperatures favour a higher yield but at a reduced rate. (A compromise of a moderate temperature is required to produce reasonable yield at a reasonable rate.)	1
Total	6

12. The United Nations Kyoto Protocol and the Intergovernmental Panel on Climate Change aim to secure a global commitment to reducing greenhouse gas emissions over the next few decades.

    Which of the following equations shows the production of a greenhouse gas?

    (i) O_2 + O $\rightarrow$ O_3
    (ii)   C + O_2 $\rightarrow$ CO_2
    (iii) CH_4 + $2 O_2$ $\rightarrow$ CO_2 + $2 H_2O$
    (iv) CO_2 + $4 H_2$ $\rightarrow$ CH_4 + $2 H_2O$
    (v) NH_4NO_3 $\rightarrow$ $2 H_2O$ + N_2O

    (a)   i and ii only
    (b)   ii and iii only
    (c)   iii, iv and v only
    (d)   i, ii, iii, iv and v

16. Chemists must act ethically when conducting research. Which of the following statements relate to **ethical** behaviour?

    (i)   Chemists calibrate all of their instruments with primary standards.
    (ii)   Chemists give due credit to all contributors to an investigation in their written reports.
    (iii)   Chemists record their experimental results accurately and without alteration to fit their prediction.
    (iv)   Chemists dispose of their waste materials carefully, especially those containing heavy metals.
    (v)   Chemists ensure that there is only one independent variable in every experiment they perform.
    (vi)   Chemists declare any conflict of interest relevant to their investigation.

    (a)   i, ii and iii only
    (b)   ii, iv and v only
    (c)   ii, iii, iv and vi only
    (d)   i, iii, iv, v and vi only

The following information relates to Questions 19, 20

A group of Year 12 Chemistry students wanted to know whether increasing ocean acidity increases the rate at which sea shells, $CaCO_3$, dissolve. They went to a beach to collect seawater and sea shells. In their school laboratory they crushed the sea shells and added 2.00 g of the resulting powder to five clean 250 mL beakers, each of which had been placed on top of its own electronic balance.

They split the seawater into five portions and bubbled carbon dioxide gas into four of the portions for different amounts of time. This gave the students 'natural' seawater plus four seawater samples of different pH. The various seawaters (150 mL portions) were then added to the beakers, with the weight of each beaker and its contents being recorded at timed intervals.

19.   Which one of the following proposes a suitable hypothesis for the investigation?

    (a)   As the seawater becomes more acidic, the sea shell powder will dissolve faster.
    (b)   The sea shell powder will dissolve fastest in the most acidic seawater.
    (c)   Adding carbon dioxide to seawater changes the pH of the seawater.
    (d)   More of the sea shell powder will dissolve as time progresses.

20.   Which one of the following pairs of statements on the validity and reliability of the investigation is correct?

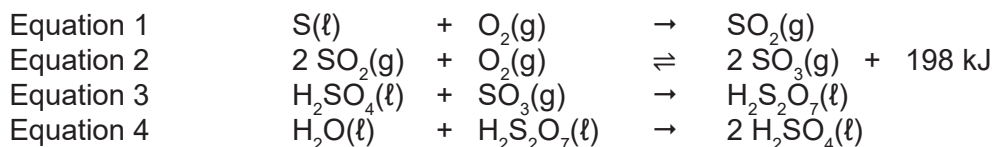|	**Validity**	**Reliability**
(a)	It is valid because the investigation allows them to determine if seawater pH affects the rate of sea shell dissolution.	It is reliable because the trials were performed in a laboratory.
(b)	It is not valid because the investigation was simulated in a laboratory and not performed in a real ocean.	It is not reliable because only one trial was performed at each different pH value.
(c)	It is not valid because the investigation was simulated in a laboratory and not performed in a real ocean.	It is reliable because trials were performed at five different pH values.
(d)	It is valid because the investigation allows them to determine if seawater pH affects the rate of sea shell dissolution.	Its reliability could be improved by conducting multiple trials at each different pH value.

Section One: Multiple-choice 25% (25 Marks)

Question No.	Answer
12	d
16	c
19	a
20	d

Question 29 (8 marks)

Sulfuric acid is a very useful chemical that is produced industrially by a multi-stepped process. These steps are summarised by the following equations.

Equation 1	$S(\ell)$	+ $O_2(g)$	$\rightarrow$	$SO_2(g)$	
Equation 2	$2\,SO_2(g)$	+ $O_2(g)$	$\rightleftharpoons$	$2\,SO_3(g)$	+ 198 kJ
Equation 3	$H_2SO_4(\ell)$	+ $SO_3(g)$	$\rightarrow$	$H_2S_2O_7(\ell)$	
Equation 4	$H_2O(\ell)$	+ $H_2S_2O_7(\ell)$	$\rightarrow$	$2\,H_2SO_4(\ell)$	

When dihydrogen sulfate, $H_2SO_4(\ell)$, is mixed with water, it produces sulfuric acid, $H_2SO_4(aq)$.

(a) Combine these equations to produce an overall equation for the production of dihydrogen sulfate, $H_2SO_4(\ell)$, from sulfur dioxide, $SO_2(g)$. (2 marks)

(b) Complete the following table by listing the advantages and disadvantages of using high temperatures and high pressures for the reaction represented by Equation 2 above. Consider yield, rate, cost and safety. (6 marks)

	Advantage/s	**Disadvantage/s**
High temperature		
High pressure		

See next page

Question 29 **(8 marks)**

(a) Combine these equations to produce an overall equation for the production of dihydrogen sulfate, $H_2SO_4(\ell)$, from sulfur dioxide, $SO_2(g)$. (2 marks)

Description	Marks
One mark for correct products and reactants	1
One mark for correct balancing	1
Total	2
Example of a two mark response: $2\ SO_2(g)\ +\ O_2(g)\ +\ 2\ H_2O(\ell)\ \rightleftharpoons\ 2\ H_2SO_4(\ell)$	

(b) Complete the following table by listing the advantages and disadvantages of using high temperatures and high pressures for the reaction represented by Equation 2 above. Consider yield, rate, cost and safety. (6 marks)

Description		Marks
High Temperature		
Advantage	increase rate	1
Disadvantages	two of: decrease yield, high energy cost **or** high safety hazards, (more) expensive	1–2
High Pressure		
Advantages	increase rate	1
	increase yield	1
Disadvantage	high cost (of construction and maintaining pressure) **or** high safety hazards	1
	Total	6
Note: • The answers may be expressed in different ways but must clearly indicate these understandings. • No explanation required.		

Question 38

One method for the production of methacrylic acid is by the following oxidation.

$$C_4H_8O \xrightarrow{\text{oxidation}} C_4H_6O_2$$

methylpropenol isomer   methacrylic acid
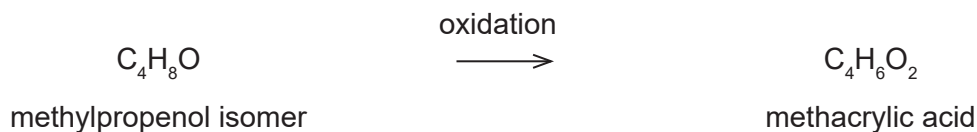
(d)   Suggest an assumption that **must** be made regarding the mole ratios of product to reactant for this reaction and then determine the mass of the methylpropenol isomer required to produce 1.50 tonne of methacrylic acid if the efficiency of this oxidation is 65%. (Note: 1 tonne = 1000 kg.)   (5 marks)

Assumption: _____

_____

Calculation: _____

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(d)   Suggest an assumption that **must** be made regarding mole ratios of product to reactant for this reaction and then determine the mass of the methylpropenol isomer required to produce 1.50 tonne of methacrylic acid if the efficiency of this oxidation is 65%. (Note: 1 tonne = 1000 kg.)   (5 marks)

Description	Marks
Assumption: $n(C_4H_8O)$ = $n(C_4H_6O_2)$	1
Calculation:	
$n(C_4H_6O_2)$ = $1.50 \times 10^6 / 86.088$ = 1.742×10^4 mol	1
$m(C_4H_8O)$ = $72.104 \times 1.742 \times 10^4$ = 1.256×10^6 g represents 65% efficiency	1
$m(C_4H_8O)$ = $100/65 \times 1.256 \times 10^6$ = 1.93×10^6 g represents 100% efficiency	1
Correct molar masses	1
Total	**5**

Question 36 **(17 marks)**

A scientist was given the task of investigating the concentration of dissolved heavy metals in abandoned open-cut mines that had filled with water to create small freshwater dams.

Using a map, the scientist identified 180 locations containing abandoned open-cut mines that had become freshwater dams. The scientist decided to randomly select locations to take water samples. The procedure for water sampling at each location was as follows:

1.	Take two samples using separate 100.0 mL bottles at a water depth of 0.50 m.
2.	Acidify each sample with a few drops of nitric acid solution to minimise heavy metal precipitation.
3.	Wait eight hours before measuring heavy metal concentration.
4.	Calculate the average concentration of a range of heavy metals, using two samples per location.

(a) Outline the difference between random and systematic errors. Give an example of each that might be encountered in this investigation. (4 marks)

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See next page

Water samples were collected from 59 of the 180 possible locations.

(b)   (i)   Calculate the sample size as a percentage of the testable locations.   (1 mark)

_____

       (ii)   Propose **two** reasons why samples were not collected from all locations.(2 marks)

One: _____

_____

Two: _____

_____

      (iii)   Predict the effect of using a smaller sample size on the reliability of the overall results. Justify your answer.   (2 marks)

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See next page

Question 36   **(17 marks)**

(a)   Outline the difference between random and systematic errors. Give an example of each that might be encountered in this investigation.   (4 marks)

Description	Marks
Random errors are fluctuations in measured data due to limitations of the measurement device/technique, they occur unpredictably and to varying extents throughout the experiment. Non-directional effect on results.	1
Examples • concentration of heavy metals may vary at depth • judgement made by the sample collector about depth • different collectors at different sites	1
Systematic errors are repeatable errors that occur due to faulty equipment or poor experiment design, they occur consistently to the same extent throughout the experiment. Results are skewed in one direction.	1
Examples • faulty timer • concentration of the nitric acid may not be exactly the same as labelled • water bottles and whether or not 100 mL is marked accurately on them (glassware uncertainty).	1
Total	**4**

Water samples were collected from 59 of the 180 possible locations.

(b)   (i)   Calculate the sample size as a percentage of the testable locations.   (1 mark)

Description	Marks
sample size = (59/180) x 100 = 32.8 %	1
Total	**1**

(ii)   Propose **two** reasons why samples were not collected from all locations.
                                                        (2 marks)

Description	Marks
• too expensive • too time consuming • accessibility • sample size deemed to be sufficient (statistical)	1–2
Total	**2**

Note: reason to be related to the context of the investigation

(iii)   Predict the effect of using a smaller sample size on the reliability of the overall results. Justify your answer.   (2 marks)

Description	Marks
Prediction: less reliable	1
Justification: • smaller sample size means less locations sampled which means less chance of collecting samples with the full range of heavy metal concentrations **or** • Increases the effect of random errors	1
Total	**2**

Question 38 **(18 marks)**

SpaceX is an American company that wants to send humans to Mars to explore the planet and establish a colony. One of the challenges of such a mission is finding reliable fuel sources away from Earth.

SpaceX plans to solve this problem by using the Sabatier reaction. The equation for the reaction is:

$$CO_2(g) + 4 H_2(g) \rightleftharpoons CH_4(g) + 2 H_2O(g) \qquad \Delta H = -165 \text{ kJ mol}^{-1}$$

The optimal conditions for this reaction are:
* temperature of 300 – 400 °C
* pressure of 200 – 300 kPa
* nickel catalyst.

The carbon dioxide would be obtained from the Martian atmosphere and the hydrogen from the hydrolysis of water extracted from either the Martian subsoil or atmosphere. The resulting methane could be used as rocket fuel while the water could be electrolysed to produce hydrogen and oxygen. The hydrogen could be fed back into the reaction vessel and the oxygen used for breathing apparatus.

(a)   With reference to rates of reaction, equilibrium and economic considerations, explain why the above conditions are considered optimal for the Sabatier reaction. In your response, address any compromises in conditions. (7 marks)

Question 38 (continued)

(b)   Predict the effect of each of the following changes on the methane yield in the Sabatier
        reaction.   (5 marks)

Imposed change	Effect on methane yield (circle your answer)		
a suitable catalyst is added	increase	decrease	no effect
the volume of the reaction vessel is increased	increase	decrease	no effect
the temperature is increased	increase	decrease	no effect
methane is removed through a special valve as soon as it forms	increase	decrease	no effect
the partial pressure of carbon dioxide is decreased	increase	decrease	no effect

Question 38 **(18 marks)**

(a) With reference to rates of reaction, equilibrium and economic considerations, explain why the above conditions are considered optimal for the Sabatier reaction. In your response, address any compromises in conditions. (7 marks)

Description	Marks
Temperature • high temperature gives a fast rate of reaction • reaction is exothermic so a low temperature increases the product yield • so temperature conditions to maximise rate and yield are opposite therefore a compromise is needed. • hence the moderate temperature of (300 – 400 °C) that is used	1–3
Pressure • high pressure increases the rate of the reaction • in this reaction high pressure increases the product yield	1–2
Economics • using high temperatures and pressures increases the operating costs (high energy requirements, cost of specialised equipment)	1
• use of catalyst which increases the reaction rate, means lower pressures and temperatures can be used to achieve reasonable reaction rates, improving the economics of the process	1
Total	7

(b) Predict the effect of each of the following changes on the methane yield in the Sabatier reaction. (5 marks)

Description		Marks
• a suitable catalyst is added	no effect	1
• the volume of the reaction vessel is increased	decrease	1
• the temperature is increased	decrease	1
• methane is removed through a special valve as soon as it forms	increase	1
• the partial pressure of carbon dioxide is decreased	decrease	1
	Total	5

Imposed change	Effect on methane yield (circle your answer)		
a suitable catalyst is added	increase	decrease	(no effect)
the volume of the reaction vessel is increased	increase	(decrease)	no effect
the temperature is increased	increase	(decrease)	no effect
methane is removed through a special valve as soon as it forms	(increase)	decrease	no effect
the partial pressure of carbon dioxide is decreased	increase	(decrease)	no effect