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Premium IB tuition — Physics, Chemistry, Maths

IB DIPLOMA CHEMISTRY · FIRST ASSESSMENT 2025

Reactivity 2
How Much, How Fast and How Far?

Paper 1 Style Practice · Paper 1A and Paper 1B

Medium to hard exam-style questions on Reactivity 2.1 – 2.3, with full worked solutions

Standard Level & Higher Level

Timing and marks

Higher Level: answer every question. Section A: 32 marks; Section B: 30 marks. Total **62 marks**. Suggested time **about 100 minutes** (48 min for Section A, 52 min for Section B).

Standard Level: omit the questions marked HL. Section A: 22 marks; Section B: 22 marks. Total **44 marks**. Suggested time **about 75 minutes**.

These timings use the same rate as the real examination (SL Paper 1: 55 marks in 1 h 30; HL Paper 1: 75 marks in 2 h). Reactivity 2 contains a large amount of additional higher level material (R2.2.6–2.2.13 and R2.3.5–2.3.7), so the HL paper is longer.

Inside this booklet

1. Section A — Paper 1A style: multiple-choice questions
2. Section B — Paper 1B style: data-based questions on experimental work
3. Answer key and worked solutions — Section A
4. Markscheme and worked solutions — Section B

Instructions

- Work under examination conditions: set a timer, and do not look at the solutions until you have finished.
- You need a **calculator** and a copy of the **IB Chemistry data booklet** (first assessment 2025). Where a question gives data, use those values. Molar volume of an ideal gas at STP (273 K, 100 kPa) = 22.7 $dm^3\ mol^{-1}$; R = 8.31 $J\ K^{-1}\ mol^{-1}$; $N_A = 6.02 \times 10^{23}\ mol^{-1}$.
- **Section A:** each question has one correct answer and is worth 1 mark. No marks are deducted for wrong answers, so answer every question. Record your answers in the grid at the end of Section A.
- **Section B:** write your answers in the spaces provided. Show your working in calculations. The marks for each part are shown in brackets.
- Questions tagged HL test Additional Higher Level material and are for HL students only.

Section A — Paper 1A style (multiple choice)

1. When this equation is balanced using the smallest whole numbers, what is the sum of the coefficients?

$$_Al(s) + _H_2SO_4(aq) \rightarrow _Al_2(SO_4)_3(aq) + _H_2(g)$$

A 6 **B** 7 **C** 9 **D** 11

2. What mass of magnesium oxide forms when 0.600 g of magnesium burns completely in oxygen? $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

A 0.995 g **B** 0.497 g **C** 0.600 g **D** 1.99 g

3. 20 cm^3 of propane is burned completely in 150 cm^3 of oxygen. All volumes are measured at the same room temperature and pressure, at which water is a liquid. What is the total volume of gas remaining? $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$

A 60 cm^3 **B** 110 cm^3 **C** 130 cm^3 **D** 190 cm^3

4. 25.0 cm^3 of 0.100 mol dm^{-3} sulfuric acid is exactly neutralized by 20.0 cm^3 of sodium hydroxide solution. What is the concentration of the sodium hydroxide? $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$

A 0.0800 mol dm^{-3} **B** 0.250 mol dm^{-3} **C** 0.125 mol dm^{-3} **D** 0.500 mol dm^{-3}

5. What volume of water must be added to 50.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid to dilute it to 0.500 mol dm^{-3}?

A 12.5 cm^3 **B** 100 cm^3 **C** 200 cm^3 **D** 150 cm^3

6. 2.70 g of aluminium is heated with 7.09 g of chlorine: $2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$. Which is the limiting reactant, and what is the maximum mass of aluminium chloride that can form? ($M(AlCl_3) = 133.33$ g mol^{-1})

	Limiting reactant	Maximum mass of $AlCl_3$
A	Al	13.3 g
B	Cl_2	8.89 g
C	Cl_2	13.3 g
D	Al	8.89 g

7. 12.0 g of ethanoic acid ($M = 60.06$ g mol^{-1}) is heated with excess ethanol and an acid catalyst, giving 11.0 g of ethyl ethanoate ($M = 88.12$ g mol^{-1}). What is the percentage yield? $CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$

A 62.5 % **B** 91.7 % **C** 37.5 % **D** 160 %

8. What is the atom economy for the production of ethanol by fermentation? $C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$ (M: $C_6H_{12}O_6$ 180.18; C_2H_5OH 46.08 g mol^{-1})

A 25.6 % **B** 100 % **C** 51.1 % **D** 48.9 %

9. Which units could be used for the rate of a reaction?

I. mol dm^{-3} s^{-1} II. cm^3 s^{-1} III. g s^{-1}

A I only **B** I and II only **C** II and III only **D** I, II and III

10. Which methods could be used to follow the rate of the reaction $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$?

I. measuring the loss of mass of the flask and contents II. collecting the gas in a gas syringe III. measuring the absorbance of the solution with a colorimeter

A I and II only **B** I and III only **C** II and III only **D** I, II and III

11. A graph of the volume of gas produced against time is plotted. A tangent drawn to the curve at $t = 0$ passes through (0 s, 0 cm^3) and (20 s, 60 cm^3). What is the initial rate of reaction?

A 1200 cm^3 s^{-1} **B** 0.33 cm^3 s^{-1} **C** 3.0 cm^3 s^{-1} **D** 60 cm^3 s^{-1}

12. What is the main reason why a 10 K rise in temperature greatly increases the rate of a reaction?

A The particles collide more frequently.

B A much greater proportion of collisions have energy greater than or equal to the activation energy.

C The activation energy decreases.

D The collisions are more likely to have the correct orientation.

13. How does the Maxwell–Boltzmann distribution for a fixed amount of gas change when the temperature is increased?

	Height of peak	Position of peak	Area under curve
A	higher	moves to lower energy	unchanged
B	lower	moves to higher energy	larger
C	higher	moves to higher energy	unchanged
D	lower	moves to higher energy	unchanged

14. Which statements about a catalyst are correct?

I. It provides an alternative reaction pathway with a lower activation energy. II. It makes the enthalpy change of the reaction more negative. III. It is chemically unchanged at the end of the reaction.

A I and III only **B** I and II only **C** II and III only **D** I, II and III

15. Zinc granules react with excess dilute hydrochloric acid. Which changes would increase the initial rate of reaction but **not** change the total volume of hydrogen produced?

I. using the same mass of zinc as a powder II. using the same volume of more concentrated acid III. using a larger mass of zinc granules

A I only **B** II only **C** I and II only **D** I, II and III

16. Which statement is correct for a reaction mixture at dynamic equilibrium?

A The concentrations of the reactants and products are equal.

B The rates of the forward and backward reactions are equal.

C The forward and backward reactions have stopped.

D It can be established in an open system.

17. What is the equilibrium constant expression for $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$?

A $K = [NH_3]^4[O_2]^5 / [NO]^4[H_2O]^6$ **B** $K = [NO][H_2O] / [NH_3][O_2]$

C $K = [NO]^4 / [NH_3]^4[O_2]^5$ **D** $K = [NO]^4[H_2O]^6 / [NH_3]^4[O_2]^5$

18. For $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, $K = 400$ at a certain temperature. What is K for $SO_3(g) \rightleftharpoons SO_2(g) + \frac{1}{2}O_2(g)$ at the same temperature?

A 0.0025 **B** 0.050 **C** 20 **D** −400

19. A reaction has $K = 1 \times 10^{-30}$ at 298 K. What can be deduced?

A At equilibrium the mixture consists almost entirely of reactants.

B At equilibrium the mixture consists almost entirely of products.

C The reaction is very slow.

D The forward reaction is endothermic.

20. For which equilibrium does an increase in pressure shift the position of equilibrium to the right?

A $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ **B** $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

C $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ **D** $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

21. The forward reaction of an equilibrium is exothermic. What happens when the temperature is increased?

	Position of equilibrium	Value of *K*
A	shifts to the right	increases
B	shifts to the right	unchanged
C	shifts to the left	unchanged
D	shifts to the left	decreases

22. What is the effect of adding a catalyst to a reaction mixture that has not yet reached equilibrium?

	Position of equilibrium	Value of *K*	Time taken to reach equilibrium
A	unchanged	unchanged	shorter
B	shifts to the right	increases	shorter
C	unchanged	increases	shorter
D	unchanged	unchanged	unchanged

23. HL The initial rate of P + Q → products was measured.

Experiment	[P] / mol dm^{-3}	[Q] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.10	0.10	2.0×10^{-4}
2	0.20	0.10	8.0×10^{-4}
3	0.20	0.20	8.0×10^{-4}

What is the rate equation?

A rate = k[P][Q] **B** rate = k[P]^2 **C** rate = k[P]^2[Q] **D** rate = k[P][Q]^2

24. HL What are the units of k for a reaction with rate = k[A]^2[B]?

A s^{-1} **B** mol dm^{-3} s^{-1} **C** mol^{-2} dm^6 s^{-1} **D** mol^{-1} dm^3 s^{-1}

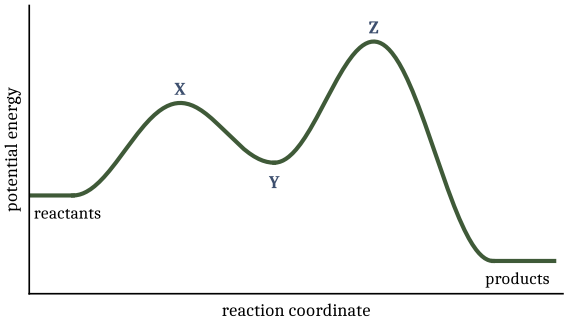
25. HL A proposed mechanism for $NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g)$ is:

step 1 (slow): $NO_2 + NO_2 \rightarrow NO_3 + NO$ step 2 (fast): $NO_3 + CO \rightarrow NO_2 + CO_2$

Which rate equation is consistent with this mechanism?

A rate = $k[NO_2]^2$ **B** rate = $k[NO_2][CO]$ **C** rate = $k[NO_3][CO]$ **D** rate = $k[NO_2]^2[CO]$

26. HL Which statement about the reaction shown in this energy profile is correct?



A X is an intermediate.

B The first step is the rate-determining step.

C The overall reaction is endothermic.

D Y is an intermediate, and the second step is the rate-determining step.

27. HL A first-order reaction has a half-life of 20 s. What fraction of the reactant remains after 60 s?

A 1/3 **B** 1/8 **C** 1/4 **D** 1/6

28. HL A graph of $\ln k$ against $1/T$ is a straight line with a gradient of -6.00×10^3 K. What is the activation energy?

A 722 J mol^{-1} **B** 6.00 kJ mol^{-1} **C** 49.9 kJ mol^{-1} **D** 4.99×10^4 kJ mol^{-1}

29. HL For $N_2O_4(g) \rightleftharpoons 2NO_2(g)$, $K = 0.50$ at a certain temperature. A mixture contains $[N_2O_4] = 0.20$ mol dm^{-3} and $[NO_2] = 0.40$ mol dm^{-3}. What is the reaction quotient, Q, and what happens next?

	Q	Direction of net reaction
A	2.0	to the left
B	0.80	to the right
C	2.0	to the right
D	0.80	to the left

30. HL A reaction has $K = 1.0 \times 10^{-3}$ at 298 K. What is $\Delta G^\ominus$?

A +17.1 kJ mol^{-1} **B** −17.1 kJ mol^{-1} **C** +7.43 kJ mol^{-1} **D** +0.0171 kJ mol^{-1}

31. HL 1.00 mol of $H_2(g)$ and 1.00 mol of $I_2(g)$ are placed in a 1.00 dm^3 flask. At equilibrium the flask contains 1.60 mol of HI(g). What is K for $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$?

A 1.6 **B** 8.0 **C** 64 **D** 16

32. HL Which changes increase the value of the rate constant, k, for a reaction?

I. increasing the temperature II. adding a catalyst III. increasing the concentration of a reactant

A I only **B** I and II only **C** II and III only **D** I, II and III

Answer grid — Section A

Q		Q		Q		Q	
1		9		17		25	
2		10		18		26	
3		11		19		27	
4		12		20		28	
5		13		21		29	
6		14		22		30	
7		15		23		31	
8		16		24		32	

Section A total: SL 22 marks (Questions 1–22); HL 32 marks.

Section B — Paper 1B style (data-based questions on experimental work)

Question 1 Calcium carbonate in eggshell by back titration (8 marks)

A student added 0.500 g of powdered eggshell to 50.0 cm^3 of 0.200 mol dm^{-3} hydrochloric acid, an excess. When the fizzing had stopped, the mixture was transferred to a 250.0 cm^3 volumetric flask and made up to the mark with distilled water. 25.0 cm^3 portions were titrated with 0.0100 mol dm^{-3} sodium hydroxide solution using phenolphthalein indicator.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g) \qquad HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Titration	Rough	1	2	3
Final burette reading / cm^3	21.40	20.85	41.05	20.75
Initial burette reading / cm^3	0.50	0.55	20.85	0.50
Titre / cm^3	20.90	20.30	20.20	20.25

(a) Explain why a back titration is used, rather than titrating the eggshell directly with acid. **[1]**

(b) Calculate the mean titre, stating which titres you used. **[1]**

(c) Calculate the amount, in mol, of hydrochloric acid that remained unreacted in the 250.0 cm^3 flask. **[2]**

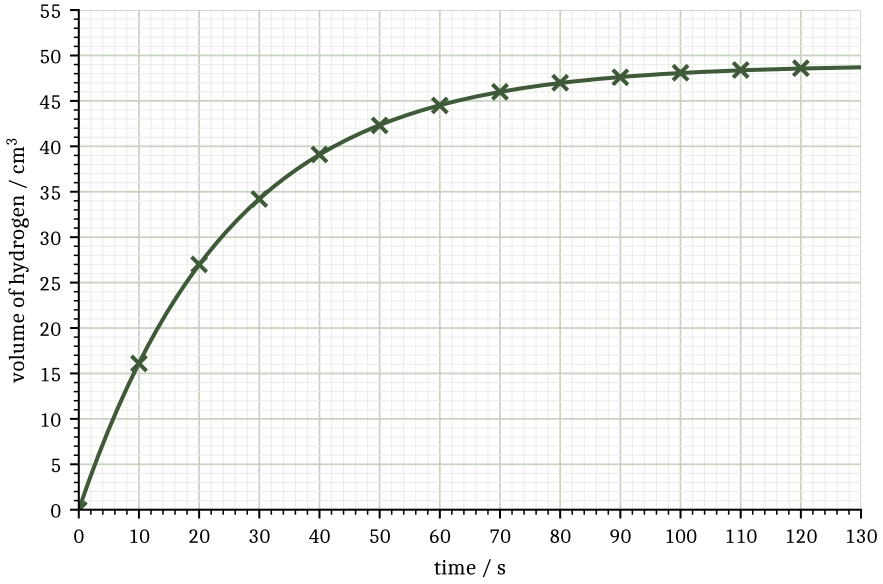
(d) Calculate the percentage by mass of calcium carbonate in the eggshell. **[2]**

(e) The calculation assumes that calcium carbonate is the only substance in the eggshell that reacts with the acid. Eggshell also contains a small amount of magnesium carbonate. State and explain the effect of this on the calculated percentage, and suggest one other source of error in the method. **[2]**

Question 2 The rate of reaction of magnesium with hydrochloric acid (8 marks)

A 0.0480 g piece of magnesium ribbon was added to 50.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid in a conical flask connected to a gas syringe. The volume of hydrogen was recorded every 10 s. The gas was measured at 298 K and 100 kPa, where the molar volume of a gas is 24.8 dm^3 mol^{-1}.

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$



(a) Show that the magnesium is the limiting reactant, and calculate the maximum volume of hydrogen that can be produced. **[2]**

(b) Draw a tangent to the curve at $t = 0$ and use it to determine the initial rate of reaction, in cm^3 s^{-1}. **[2]**

(c) Explain, using collision theory, why the gradient of the curve decreases as the reaction proceeds. **[2]**

(d) The experiment is repeated with the same mass of magnesium ribbon and 50.0 cm^3 of 0.500 mol dm^{-3} hydrochloric acid. Sketch, on the graph above, the curve you would expect, and explain its final volume. **[2]**

Question 3 Determining an equilibrium constant by titration (6 marks)

A student mixed 0.100 mol of ethanoic acid and 0.100 mol of ethanol with a small amount of concentrated hydrochloric acid as a catalyst. The flask was stoppered and left at 298 K for one week. The whole mixture was then titrated with 1.00 mol dm^{-3} sodium hydroxide solution: 38.50 cm^3 was required. In a separate experiment, the same amount of the hydrochloric acid catalyst alone required 4.50 cm^3 of the sodium hydroxide solution.

$$CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$$

(a) Explain why the flask was stoppered and left for one week before titrating. **[1]**

(b) Calculate the amount, in mol, of ethanoic acid present at equilibrium. **[1]**

(c) Deduce the equilibrium amounts of ethanol, ethyl ethanoate and water. **[1]**

(d) Calculate the value of K, and explain why the total volume of the mixture is not needed. **[2]**

(e) The catalyst was added as an aqueous solution. State how ignoring the water added with the catalyst affects the calculated value of K. **[1]**

HL Question 4 Initial rates and activation energy (8 marks)

The reaction $2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(g)$ was studied at 298 K. The initial rate of each experiment was found from the gradient, at $t = 0$, of a graph of total pressure against time.

Experiment	$[H_2]$ / mol dm^{-3}	[NO] / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.010	0.010	2.0×10^{-5}
2	0.020	0.010	4.0×10^{-5}
3	0.010	0.020	8.0×10^{-5}
4	0.030	0.030	?

(a) Deduce the order of reaction with respect to H_2 and with respect to NO, giving your reasoning. **[2]**

(b) Write the rate equation and calculate the value of the rate constant, *k*, with its units. **[2]**

(c) Calculate the initial rate in experiment 4. **[1]**

(d) Suggest why this reaction is unlikely to take place in a single step. **[1]**

(e) At 308 K, the rate constant is 40 (same units). Calculate the activation energy, in kJ mol^{-1}, using section 1 of the data booklet. **[2]**

Section B total: SL 22 marks (Questions 1–3); HL 30 marks.

End of questions

Answer key — Section A

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	**C**	9	**D**	17	**D**	25	**A**
2	**A**	10	**A**	18	**B**	26	**D**
3	**B**	11	**C**	19	**A**	27	**B**
4	**B**	12	**B**	20	**C**	28	**C**
5	**D**	13	**D**	21	**D**	29	**D**
6	**B**	14	**A**	22	**A**	30	**A**
7	**A**	15	**C**	23	**B**	31	**C**
8	**C**	16	**B**	24	**C**	32	**B**

Worked solutions — Section A

1. C. $2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2$: 2 + 3 + 1 + 3 = 9. The coefficient 1 counts in the sum.

2. A. $n(Mg) = 0.600/24.31 = 0.02468$ mol = $n(MgO)$; 0.02468 × 40.31 = 0.995 g. B uses a 2 : 1 ratio; C assumes mass is unchanged.

3. B. 20 cm^3 C_3H_8 uses 100 cm^3 O_2 and makes 60 cm^3 CO_2. Remaining: 50 cm^3 O_2 + 60 cm^3 CO_2 = 110 cm^3. D counts the water as a gas; A forgets the excess oxygen.

4. B. $n(H_2SO_4) = 0.100 \times 0.0250 = 2.50 \times 10^{-3}$ mol; $n(NaOH) = 5.00 \times 10^{-3}$ mol; $c = 5.00 \times 10^{-3}/0.0200 = 0.250$ mol dm^{-3}. C ignores the 1 : 2 ratio.

5. D. $c_1V_1 = c_2V_2$: $V_2 = 2.00 \times 50.0/0.500 = 200$ cm^3, so add 200 − 50.0 = 150 cm^3. C is the final volume, not the volume added.

6. B. $n(Al) = 0.100$ mol and $n(Cl_2) = 0.100$ mol; 0.100 mol Al needs 0.150 mol Cl_2, so Cl_2 is limiting. $n(AlCl_3) = ⅔ \times 0.100 = 0.0667$ mol = 8.89 g. A and C use the amount of Al.

7. A. Theoretical: 12.0/60.06 = 0.1998 mol → 0.1998 × 88.12 = 17.6 g; yield = 11.0/17.6 × 100 = 62.5 %. B compares masses of different substances; D is inverted.

8. C. Atom economy = 2 × 46.08/180.18 × 100 = 51.1 %. A forgets the coefficient 2; D is the percentage of waste (CO_2).

9. D. Rate is the change in any measurable quantity (concentration, volume of gas, mass) per unit time.

10. A. CO_2 escapes, so the mass falls, and the gas can be collected. The solutions are colourless, so a colorimeter cannot be used.

11. C. Gradient = 60/20 = 3.0 cm^3 s^{-1}. B is inverted; A multiplies.

12. B. A small temperature rise greatly increases the fraction of particles with $E \geq E_a$ (the area beyond E_a); the increase in collision frequency is small. E_a does not change.

13. D. The curve flattens and the peak moves to higher energy. The area represents the total number of particles, which does not change.

14. A. A catalyst lowers E_a by providing a different pathway and is regenerated; ΔH depends only on the reactants and products.

15. C. Powder (larger surface area) and more concentrated acid both increase the frequency of collisions; zinc is the limiting reactant, so the volume of H_2 is unchanged. A larger mass of zinc produces more hydrogen.

16. B. Concentrations are constant but rarely equal; both reactions continue; a closed system is needed.

17. D. Products over reactants, each raised to the power of its coefficient. Water is a gas here, so it is included (C omits it).

18. B. Reversing gives 1/400; halving the coefficients takes the square root: $(1/400)^{½} = 0.050$. A only reverses; C only takes the square root.

19. A. A very small K means the equilibrium lies far to the left. K gives no information about rate.

20. C. 3 mol of gas → 2 mol of gas: higher pressure favours fewer gas molecules. A shifts left; B has equal numbers of gas molecules; D shifts left.

21. D. A temperature rise favours the endothermic (backward) reaction, so the position shifts left and K decreases.

22. A. A catalyst speeds up the forward and backward reactions equally, so equilibrium is reached sooner but its position and K are unchanged.

23. B. Experiments 1 → 2: [P] doubles, rate × 4, so second order in P. Experiments 2 → 3: [Q] doubles, rate unchanged, so zero order in Q.

24. C. k = rate/[A]^2[B] = mol dm^{-3} s^{-1}/(mol dm^{-3})^3 = mol^{-2} dm^6 s^{-1}.

25. A. The rate equation contains the species in the slow step: two NO_2. CO enters after the rate-determining step, so it does not appear.

26. D. Y is the minimum between the two peaks (an intermediate); X and Z are transition states. Z is the higher peak, so step 2 has the higher barrier from the intermediate and is rate-determining. The products are lower than the reactants, so the reaction is exothermic.

27. B. 60 s is three half-lives: ½ × ½ × ½ = 1/8.

28. C. Gradient = $-E_a/R$, so $E_a = 6.00 \times 10^3 \times 8.31 = 4.99 \times 10^4$ J mol^{-1} = 49.9 kJ mol^{-1}. D forgets to convert J to kJ.

29. D. $Q = [NO_2]^2/[N_2O_4] = 0.40^2/0.20 = 0.80 > K$, so net reaction to the left.

30. A. $\Delta G^{\ominus} = -8.31 \times 298 \times \ln(1.0 \times 10^{-3}) = +1.71 \times 10^4$ J mol^{-1}. C uses $\log_{10}$; D converts J to kJ twice.

31. C. 0.80 mol each of H_2 and I_2 reacted, so 0.20 mol of each remains: $K = 1.60^2/(0.20 \times 0.20) = 64$. B leaves out the square.

32. B. Raising T increases k (Arrhenius); a catalyst lowers E_a and so increases k. Concentration changes the rate but not k.

Markscheme — Section B

Bold **[1]** shows where each mark is awarded. Accept equivalent wording that conveys the same chemistry. Allow follow-through (ECF) from an earlier error unless stated.

Question 1 (8 marks)

(a) Eggshell is insoluble and reacts slowly, so the end point of a direct titration would be unclear (the reaction is incomplete when the indicator changes); an excess of acid makes sure all the carbonate reacts, and the leftover acid is easy to titrate **[1]**.

(b) Mean of the concordant titres 1, 2 and 3 (within 0.10 cm^3; the rough titre is excluded) = (20.30 + 20.20 + 20.25)/3 = 20.25 cm^3 **[1]**.

(c) n(NaOH) = 0.0100 × 0.02025 = 2.025×10^{-4} mol = n(HCl) in 25.0 cm^3 **[1]**; in 250.0 cm^3: $10 \times 2.025 \times 10^{-4} = 2.03 \times 10^{-3}$ mol **[1]**.

(d) n(HCl) at start = 0.200 × 0.0500 = 0.0100 mol; reacted = 0.0100 − 0.00203 = 7.98×10^{-3} mol; $n(CaCO_3)$ = ½ × 7.98×10^{-3} = 3.99×10^{-3} mol **[1]**; mass = $3.99 \times 10^{-3} \times 100.09$ = 0.399 g, so 0.399/0.500 × 100 = 79.8 % **[1]**.

(e) $MgCO_3$ also reacts with the acid (and has a smaller M, so more acid per gram), so the acid used is all counted as $CaCO_3$ and the percentage is too high **[1]**. Any one other error **[1]**: CO_2 dissolved in the solution reacts with NaOH and increases the titre; some acid lost as spray during fizzing; the eggshell membrane (protein) not removed, or the shell not completely dried before weighing; not all of the mixture transferred to the volumetric flask.

Question 2 (8 marks)

(a) n(Mg) = 0.0480/24.31 = 1.97×10^{-3} mol, which needs 3.95×10^{-3} mol HCl; n(HCl) = 1.00 × 0.0500 = 0.0500 mol, so HCl is in excess and Mg is limiting **[1]**; $V(H_2) = 1.97 \times 10^{-3} \times 24.8 = 0.0490$ dm^3 = 49.0 cm^3 **[1]**.

(b) Tangent drawn touching the curve at the origin **[1]**; initial rate = gradient = 2.0 $cm^3\ s^{-1}$ (accept 1.7–2.3 $cm^3\ s^{-1}$) **[1]**.

(c) As the reaction proceeds, the concentration of HCl and the surface area of magnesium decrease **[1]**, so there are fewer collisions per unit time (lower collision frequency) and fewer successful collisions per second **[1]**.

(d) Curve with a less steep initial gradient, reaching the plateau later **[1]**; the same final volume, 49.0 cm^3, because 0.0250 mol HCl is still in excess, so the amount of Mg (the limiting reactant) is unchanged **[1]**.

Question 3 (6 marks)

(a) Stoppering prevents the volatile liquids from evaporating (a closed system is needed for equilibrium); the reaction is slow, so a week allows equilibrium to be reached **[1]**.

(b) n(NaOH) for ethanoic acid = 1.00 × (38.50 − 4.50)/1000 = 0.0340 mol, so $n(CH_3COOH)$ = 0.0340 mol **[1]**.

(c) Reacted: 0.100 − 0.0340 = 0.0660 mol, so ethanol = 0.0340 mol; ethyl ethanoate = water = 0.0660 mol **[1]**.

(d) $K = (0.0660 \times 0.0660)/(0.0340 \times 0.0340) = 3.8$ **[1]**; there are equal numbers of moles on each side, so the volume terms cancel in the expression **[1]**.

(e) The water present at equilibrium is greater than 0.0660 mol, so the calculated K is too low (an underestimate) **[1]**.

HL Question 4 (8 marks)

(a) Experiments 1 → 2: $[H_2]$ doubles and the rate doubles, so first order in H_2 **[1]**; experiments 1 → 3: [NO] doubles and the rate quadruples, so second order in NO **[1]**.

(b) rate = $k[H_2][NO]^2$ **[1]**; $k = 2.0 \times 10^{-5}/(0.010 \times 0.010^2) = 20\ mol^{-2}\ dm^6\ s^{-1}$ **[1]**.

(c) rate = $20 \times 0.030 \times 0.030^2 = 5.4 \times 10^{-4}\ mol\ dm^{-3}\ s^{-1}$ **[1]**.

(d) The equation needs four molecules to collide at the same time with the correct orientation, which is extremely unlikely (molecularity of an elementary step is usually 1 or 2) **[1]**.

(e) $\ln(k_2/k_1) = (E_a/R)(1/T_1 - 1/T_2)$: $\ln 2 = (E_a/8.31)(1/298 - 1/308)$ **[1]**; $E_a = 5.29 \times 10^4\ J\ mol^{-1} = 52.9\ kJ\ mol^{-1}$ **[1]**.

These practice papers are a free resource, shared for any IB student who finds them useful.

If a particular idea here still isn't clicking, specialist one-to-one support in Physics, Chemistry and Maths from a past A Level examiner is available at iBLaurel — call or message **+44 7404 710097**, or use the contact form at **www.iBLaurel.com**.

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