MEGA LECTURE

IB DP CHEMISTRY

Reactivity 3 · What Are the Mechanisms of Change?

TOPICAL WORKSHEET

R3.1 Proton Transfer · R3.2 Electron Transfer
R3.3 Radical Substitution · R3.4 Electron Pair Sharing

Standard and Higher Level · Syllabus 2025

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Original exam-style questions written for the IB Diploma Programme Chemistry course (first assessment 2025)

Section A — Multiple Choice (15 marks)

Circle the letter of the best answer to each question. Each question is worth 1 mark.

1. For the reaction $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$, which species acts as the Bronsted-Lowry base? **[1]**

A H_2O, because it donates a proton

B NH_3, because it accepts a proton to form NH_4^+

C OH^-, because it is formed in the reaction

D NH_4^+, because it contains four hydrogen atoms

2. A 0.010 mol dm^{-3} solution of HCl(aq) has a pH closest to **[1]**

A 1

B 2

C 10

D 12

3. Which statement best describes a weak acid? **[1]**

A It has a low pH in all concentrations

B It is fully ionized (dissociated) in aqueous solution

C It is only partially ionized (dissociated) in aqueous solution

D It contains fewer hydrogen atoms than a strong acid

4. In a titration of a strong monoprotic acid with a strong monobasic alkali, the pH at the equivalence point is closest to **[1]**

A 3

B 5

C 7

D 10

5. In the reaction $2Fe^{3+} + Sn^{2+} \rightarrow 2Fe^{2+} + Sn^{4+}$, the species that is oxidized is **[1]**

A Fe^{3+}

B Sn^{2+}

C Fe^{2+}

D Sn^{4+}

6. The oxidation state of sulfur in the sulfate ion, SO_4^{2-}, is **[1]**

A +2

B +4

C +6

D -2

7. Given the standard electrode potentials $Mg^{2+}/Mg = -2.37$ V, $Zn^{2+}/Zn = -0.76$ V, $Cu^{2+}/Cu = +0.34$ V, and $Ag^{+}/Ag = +0.80$ V, the strongest oxidizing agent is **[1]**

A Mg^{2+}

B Zn^{2+}

C Cu^{2+}

D Ag^{+}

8. A voltaic (galvanic) cell operates by converting **[1]**

A electrical energy into chemical energy

B chemical energy into electrical energy

C thermal energy into chemical energy

D electrical energy into thermal energy only

9. The initiation step of the free-radical substitution of methane by chlorine requires **[1]**

A heat energy only, to break a C-H bond

B UV (or visible) light, to homolytically break the Cl-Cl bond

C a strong acid catalyst

D the presence of excess methane

10. Homolytic fission of a covalent bond produces **[1]**

A two oppositely charged ions

B two neutral free radicals, each with one unpaired electron

C one cation and one free radical

D no change in the number of unpaired electrons

11. The propagation steps of a free-radical substitution reaction are characterized by **[1]**

A two radicals combining to form a stable molecule

B a radical reacting with a stable molecule to generate a new radical and a product, sustaining the chain

C the complete consumption of all radicals present

D a decrease in the total number of radicals at each step

12. The reaction of a primary halogenoalkane with aqueous OH^{-} typically proceeds by which mechanism? **[1]**

A S_N1 (unimolecular nucleophilic substitution)

B S_N2 (bimolecular nucleophilic substitution)

C electrophilic addition

D free-radical substitution

13. In the electrophilic addition of Br_2 to ethene, the Br_2 molecule acts as **[1]**

A a nucleophile

B an electrophile, due to an induced dipole as it approaches the π bond

C a Bronsted-Lowry acid

D a free radical

14. In the electrophilic addition of HBr to an alkene, the reaction proceeds via an intermediate that is a **[1]**

A free radical

B carbocation

C carbanion

D cyclic ether

15. A nucleophile is best described as a species that **[1]**

A accepts a pair of electrons to form a new covalent bond

B donates a pair of electrons to form a new covalent bond, and is attracted to electron-deficient centres

C always carries a full negative charge

D has an unpaired electron

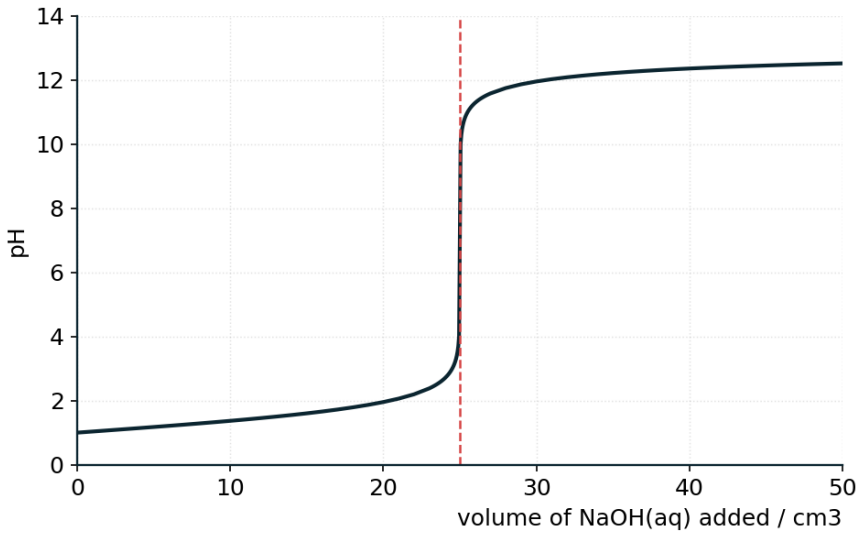
Section B — Structured Questions (65 marks)

Answer all questions in the space provided. Working must be shown for full marks.

R3.1 Proton Transfer

Question 1 [7 marks]

25.0 cm^3 of hydrochloric acid, HCl(aq), of unknown concentration was titrated with 0.100 mol dm^{-3} sodium hydroxide, NaOH(aq). The graph shows how the pH of the mixture changed as NaOH(aq) was added.



Titration curve: HCl(aq) titrated with 0.100 mol dm^{-3} NaOH(aq) (computed from the reacting quantities).

(a) Using the graph, state the volume of NaOH(aq) added at the equivalence point, and explain how you identified it. **[2]**

(b) State the pH at the equivalence point for this titration, and explain why it has this value. **[2]**

(c) Given that the NaOH(aq) has a concentration of 0.100 mol dm^{-3}, calculate the original concentration of the HCl(aq), which had an initial volume of 25.0 cm^3. **[3]**

Question 2 [6 marks]

Bronsted-Lowry theory describes acids and bases in terms of proton transfer.

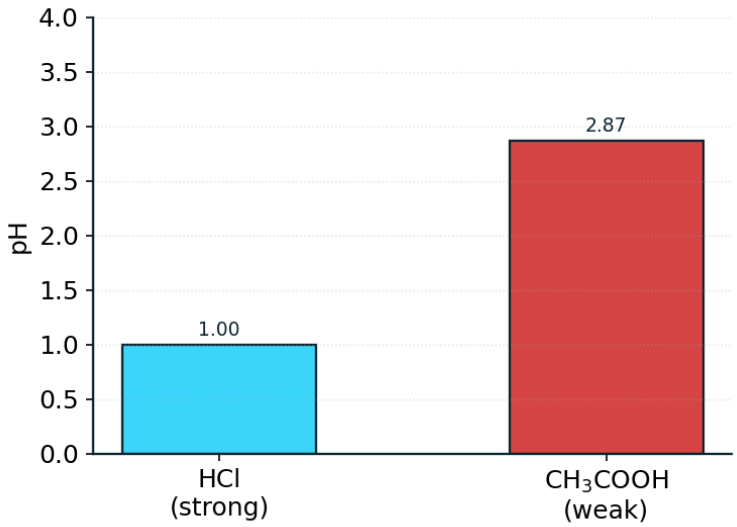
(a) Define a Bronsted-Lowry acid and a Bronsted-Lowry base. **[2]**

(b) For the reaction $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$, identify the two conjugate acid-base pairs. **[2]**

(c) Explain why water can act as either an acid or a base, giving a suitable equation for each role. **[2]**

Question 3 [7 marks]

The bar chart compares the pH of two 0.100 mol dm^{-3} acid solutions at 25°C.



pH of two 0.100 mol dm^{-3} acids (computed from the given K_a of ethanoic acid).

(a) Using the graph, identify which acid is the strong acid, and explain your reasoning. **[2]**

(b) Explain, in terms of the degree of dissociation, why the weak acid has a higher pH than the strong acid at the same concentration. **[2]**

(c) Calculate the $[H^+]$ corresponding to the pH of the weak acid, and hence show that only a small percentage of the acid molecules have dissociated. **[3]**

R3.2 Electron Transfer

Question 4 [6 marks]

Oxidation and reduction can be defined and tracked using oxidation states.

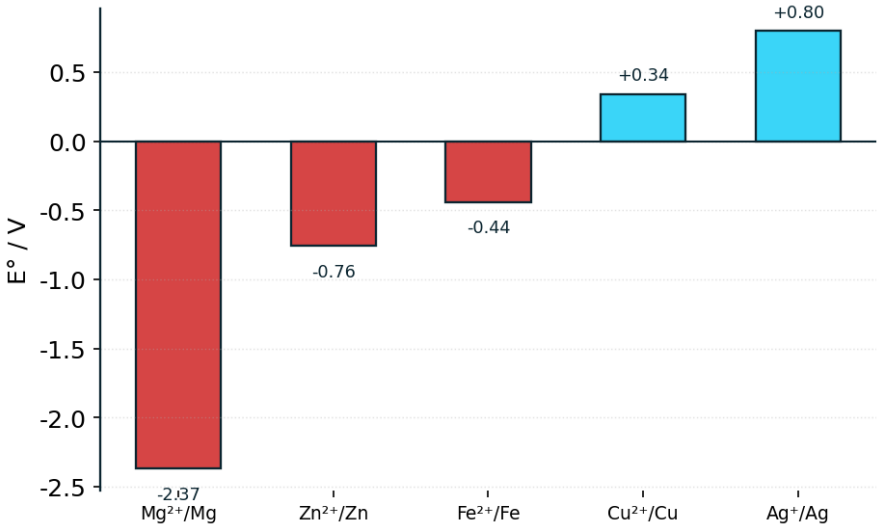
(a) Define oxidation and reduction in terms of electron transfer. **[2]**

(b) Deduce the oxidation state of chromium in the dichromate ion, $Cr_2O_7^{2-}$. Show your working. **[2]**

(c) For the reaction $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$, identify the species oxidized and the species reduced, and state the oxidation state change for each. **[2]**

Question 5 [7 marks]

The graph shows standard electrode potentials, E°, for a series of half-reactions (data booklet values).



Standard electrode potentials, E° (data booklet values).

(a) Using the graph, identify the strongest reducing agent among the metals shown, and explain your reasoning. **[2]**

(b) Predict, with a reason, whether a reaction would occur if solid zinc were added to aqueous copper(II) sulfate. **[2]**

(c) Calculate the standard cell potential, E°_{cell}, for a voltaic cell constructed from the Zn^{2+}/Zn and Cu^{2+}/Cu half-cells, and give the half-equation for the spontaneous cell reaction. **[3]**

Question 6 [6 marks]

Redox reactions can be balanced by combining half-equations.

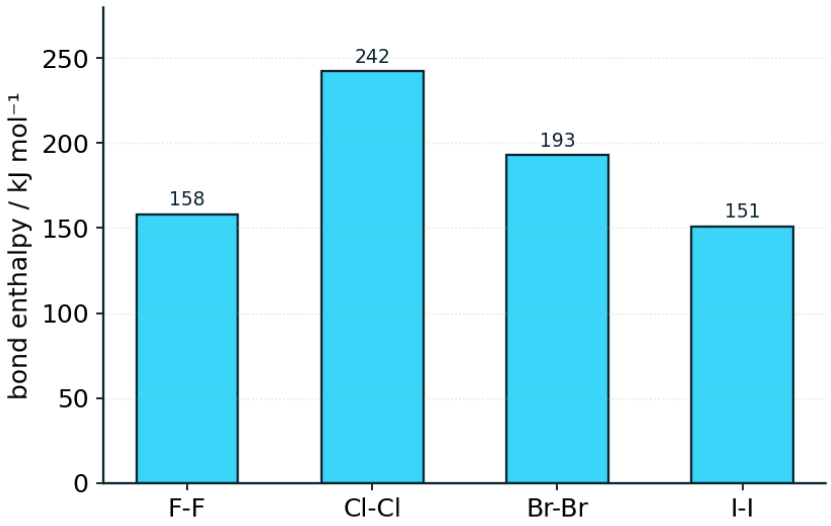
(a) Construct the balanced half-equation for the reduction of MnO_4^- to Mn^{2+} in acidic solution. **[3]**

(b) Combine this with the half-equation $Fe^{2+} \rightarrow Fe^{3+} + e^-$ to construct the overall balanced ionic equation for the reaction between acidified MnO_4^- and Fe^{2+}. **[3]**

R3.3 Radical Substitution

Question 7 [7 marks]

The graph shows the bond enthalpy of the X-X bond for four halogens (data booklet values).



X-X bond enthalpies for the halogens (data booklet values).

(a) Using the graph, identify which halogen molecule requires the least energy to undergo homolytic fission (bond breaking). **[2]**

(b) Write an equation for the initiation step of the reaction between methane and chlorine, and state the type of bond fission involved. **[2]**

(c) Outline, with equations, the propagation steps that occur after initiation, and explain why this is described as a chain reaction. **[3]**

Question 8 [6 marks]

Free-radical substitution reactions eventually stop when radicals are removed from the system.

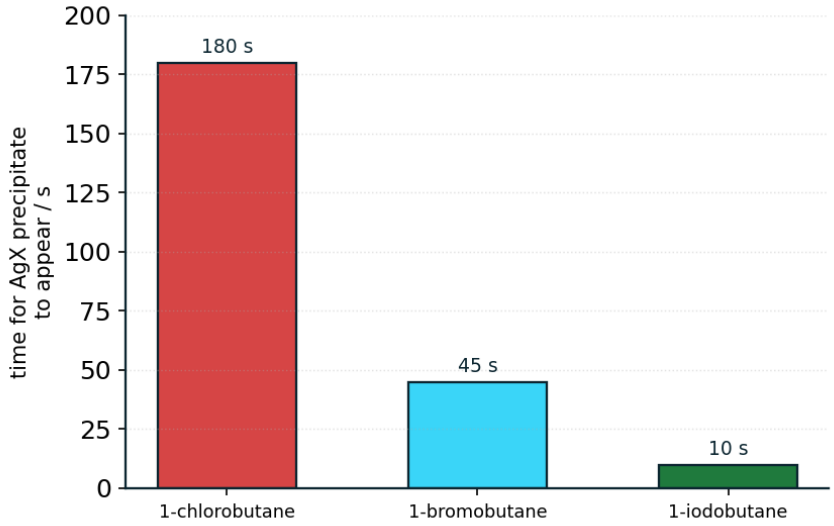
(a) Write equations for the three possible termination steps in the free-radical substitution of methane with chlorine. **[3]**

(b) Explain why the free-radical substitution of methane commonly produces a mixture of products, including CH_2Cl_2, $CHCl_3$ and CCl_4, even when methane is in excess. **[3]**

R3.4 Electron Pair Sharing

Question 9 [7 marks]

The bar chart shows the time taken for a precipitate to form when equal volumes of three halogenoalkanes are each treated with excess ethanolic silver nitrate solution (given data).



Time for AgX precipitate to appear with ethanolic $AgNO_3$ (given data).

(a) Using the graph, identify which halogenoalkane reacts fastest, and state the trend in reactivity shown going down group 17. **[2]**

(b) Explain, in terms of bond enthalpy, why this trend in reactivity is observed. **[3]**

(c) State the type of mechanism occurring in this reaction, and identify the nucleophile involved. **[2]**

Question 10 [6 marks]

Halogenoalkanes and alkenes undergo characteristic addition and substitution reactions.

(a) For the reaction between bromoethane and aqueous NaOH, write the overall equation, name the mechanism, and briefly describe it. **[3]**

(b) For the reaction between ethene and HBr, write the equation, and state the type of intermediate formed. **[3]**