Week 16

A-Level Chemistry

Homework bundle for this week

本周作业合集

exercises.lol

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11. Group 17

Starter Quiz · 课前小测

A-Level Chemistry Name: _____ Score: _____

1. At room temperature, the states of chlorine, bromine and iodine are:

   ☐ gas, liquid, solid

   ☐ all gases

   ☐ all solids

   ☐ liquid, solid, gas

2. A halogen acts as an oxidising agent because it:

   ☐ gains an electron to form a 1− ion

   ☐ loses an electron

   ☐ gives away protons

   ☐ gains a proton

3. The reducing power of the halide ions increases down the group because:

   ☐ a larger ion holds its outer electron less tightly, so it is given up more easily

   ☐ a larger ion holds its electron more tightly

   ☐ they gain electrons

   ☐ the nuclear charge falls

4. Chlorine with cold, dilute sodium hydroxide forms:

   ☐ sodium chloride and sodium chlorate(I)

   ☐ sodium chloride only

   ☐ sodium chlorate(V) only

   ☐ sodium oxide

5. Volatility decreases down Group 17 because:

   ☐ larger molecules with more electrons have stronger London forces

   ☐ the molecules get smaller

   ☐ covalent bonds get stronger

   ☐ they become ionic

6. The halogens exist as diatomic molecules.

   ☐ True ☐ False

7. Silver nitrate solution is used to test for _____ ions.

   _____

8. In the reaction of chlorine with sodium hydroxide, chlorine is both oxidised and reduced.

   ☐ True ☐ False

9. The halogens become less reactive down Group 17.

   ☐ True ☐ False

10. A more reactive halogen will _____ a less reactive one from solution.

    _____

11. Group 17

Answers · 答案

A-Level Chemistry

1. **gas, liquid, solid**

   Chlorine is a gas, bromine a liquid and iodine a solid — volatility falls down the group.

2. **gains an electron to form a 1− ion**

   Halogens gain an electron (so they oxidise other species); this power falls down the group.

3. **a larger ion holds its outer electron less tightly, so it is given up more easily**

   Reducing means losing an electron; bigger ions lose theirs more easily, so reducing power rises down the group.

4. **sodium chloride and sodium chlorate(I)**

   $Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$ (chlorate(I)); hot concentrated NaOH gives chlorate(V) instead.

5. **larger molecules with more electrons have stronger London forces**

   More electrons give stronger instantaneous/induced dipole (London) forces, raising the boiling point.

6. **True**

   They form X_2 molecules: Cl_2, Br_2, I_2.

7. **halide**

   Different halides give different coloured precipitates.

8. **True**

   That is what makes it a disproportionation reaction.

9. **True**

   The outer shell is further from the nucleus, so gaining an electron is harder.

10. **displace**

    e.g. chlorine displaces bromine.

A-LEVEL CHEMISTRY • EXERCISE SHEET

11.1 Physical properties of the Group 17 elements

Name: _____ Class: _____ Date: _____ **Total: 10 marks**

KEY WORDS volatility 挥发性 • bond energy 键能 • group 族 • induced dipole 诱导偶极 • instantaneous dipole 瞬时偶极

Objective

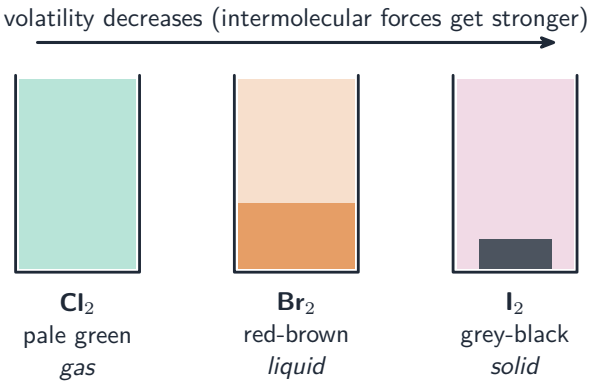
Build the skills to answer exam questions on the **physical properties of the halogens** 卤素 — their colours, the trend in **volatility** 挥发性, and the trend in bond strength.

You must be able to:

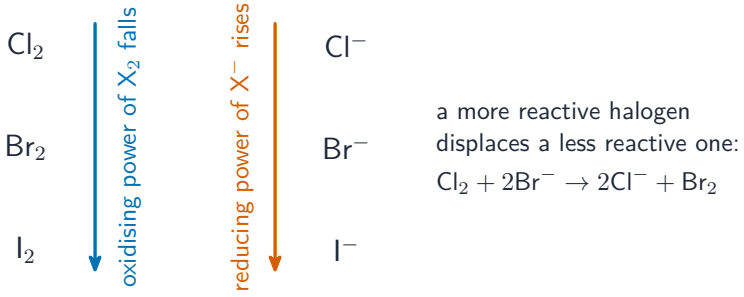
- describe the colours and the trend in volatility of chlorine, bromine and iodine
- explain volatility in terms of instantaneous dipole–induced dipole forces
- describe and explain the trend in halogen bond strength

1 Worked examples

■ Colours and volatility



Down Group 17 volatility falls: chlorine (gas) → bromine (liquid) → iodine (solid)



Trends in oxidising power down Group 17

Volatility **decreases** down the group because the molecules get larger with more electrons, so the **instantaneous dipole–induced dipole** forces between them get stronger — harder to overcome, so boiling point rises.

■ Bond strength

The X–X bond energy generally **falls** from Cl_2 to I_2: the shared electrons are further from the nuclei in larger atoms.

2 Practice

2.1 State the colour and physical state of bromine at room temperature. [2]

2.2 State the trend in volatility down Group 17. [1]

3 Exam-style questions

3.1 Why is iodine a solid while chlorine is a gas at room temperature? [1]

- **A** iodine has stronger covalent bonds
- **B** iodine molecules have more electrons, so stronger id–id forces
- **C** iodine is ionic
- **D** chlorine has more electrons

3.2 The type of force broken when iodine sublimes is: [1]

- **A** the I–I covalent bond
- **B** instantaneous dipole–induced dipole forces
- **C** ionic bonds
- **D** hydrogen bonds

3.3 Explain, in terms of intermolecular forces, why the boiling points of the halogens increase down the group. [3]

3.4 Suggest why the bond energy of I_2 is less than that of Cl_2. [2]

Solutions

2.1 red-brown / orange-brown; liquid.

2.2 volatility decreases down the group.

3.1 B. Iodine has more electrons, so stronger id–id forces between molecules.

3.2 B. Subliming breaks the intermolecular (id–id) forces, not the covalent bond.

3.3 down the group the molecules have more electrons; so the instantaneous dipole–induced dipole forces are stronger; more energy is needed to separate the molecules, so the boiling point rises.

3.4 the I_2 atoms are larger, so the shared bonding electrons are further from the nuclei; the weaker attraction gives a lower bond energy.

1 The Group 17 elements are oxidising agents.

(a) **(i)** Explain how the Group 17 elements act as oxidising agents.

.....

..... [1]

(ii) Write an equation to show the reaction in which Cl_2 oxidises aluminium metal.

..... [1]

(iii) A student heats equal amounts of $I_2(g)$ and $H_2(g)$ in a sealed flask. The student leaves the contents to cool.

State what you would observe during the reaction.

..... [1]

(b) Cl_2 and Br_2 can each react with NH_3 to give N_2 and a hydrogen halide, HX.

$$3X_2 + 2NH_3 \rightarrow N_2 + 6HX \qquad X = Cl \text{ or } Br$$

The relative bond strengths of X–X and H–X determine the difference in enthalpy change of the two reactions.

(i) Describe and explain the difference in the X–X bond strengths of Cl_2 and Br_2.

.....

.....

.....

..... [2]

(ii) Describe the relative thermal stabilities of HCl and HBr.

..... [1]

(iii) Define enthalpy change of formation, ΔH_f.

.....

.....

..... [2]

(iv) Table 1.1 gives data relevant to the reaction of $Cl_2(g)$ with $NH_3(g)$.

Table 1.1

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$NH_3(g)$	–46
$HCl(g)$	–92

Use the data in Table 1.1 to calculate the enthalpy change of the reaction of $Cl_2(g)$ with $NH_3(g)$.

enthalpy change of reaction = ... kJ mol^{-1} [2]

(v) I_2 reacts with NH_3 to form NI_3.

Predict the shape of a molecule of NI_3. Explain your answer.

shape .....

explanation .....

.....

[2]

(c) Table 1.2 shows some information about reactions of NaCl, NaBr and NaI.

Table 1.2

	NaCl	**NaBr**	**NaI**
observation with $Ag^+(aq)$	white precipitate		
type of reaction with concentrated H_2SO_4	acid–base	acid–base, then redox	acid–base, then redox
observations with concentrated H_2SO_4			• black solid • yellow solid • effervescence

(i) Complete Table 1.2. [4]

(ii) Suggest an identity for the species that produces each observation in the reaction of NaI with concentrated H_2SO_4.

black solid .....

yellow solid .....

effervescence .....

[2]

(d) Table 1.3 gives some information about $MgCl_2$ and $SiCl_4$.

Table 1.3

	$MgCl_2$	**$SiCl_4$**
electrical conductivity when liquid	conducts	does **not** conduct
observation when added to water	dissolves	vigorous reaction

(i) Explain the difference between the electrical conductivity of liquid $MgCl_2$ and of liquid $SiCl_4$. Refer to bonding and relevant particles in your answer.

.....

.....

.....

.....

..... [2]

(ii) Suggest the pH of the solutions that form when each chloride is added to water.

$MgCl_2$ ..... $SiCl_4$ .....

[2]

A-LEVEL CHEMISTRY • EXERCISE SHEET

11.2 Chemical properties of the halogens and hydrogen halides

Name: _____ Class: _____ Date: _____ **Total: 11 marks**

KEY WORDS oxidising agent 氧化剂 • hydrogen halide 卤化氢 • thermal stability 热稳定性 • group 族 • halogen 卤素

Objective

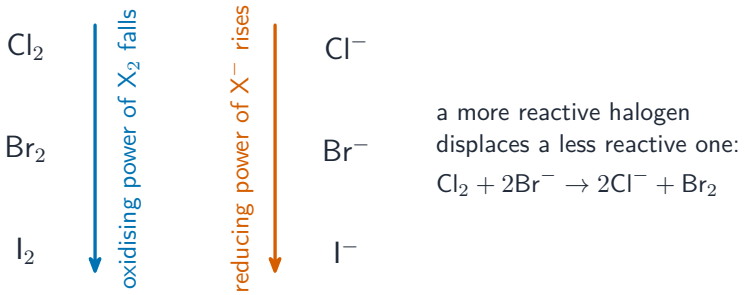
Build the skills to answer exam questions on the **chemical properties of the halogens and hydrogen halides** — the halogens as **oxidising agents** 氧化剂, reactions with hydrogen, and the thermal stability of the **hydrogen halides** 卤化氢.

You must be able to:

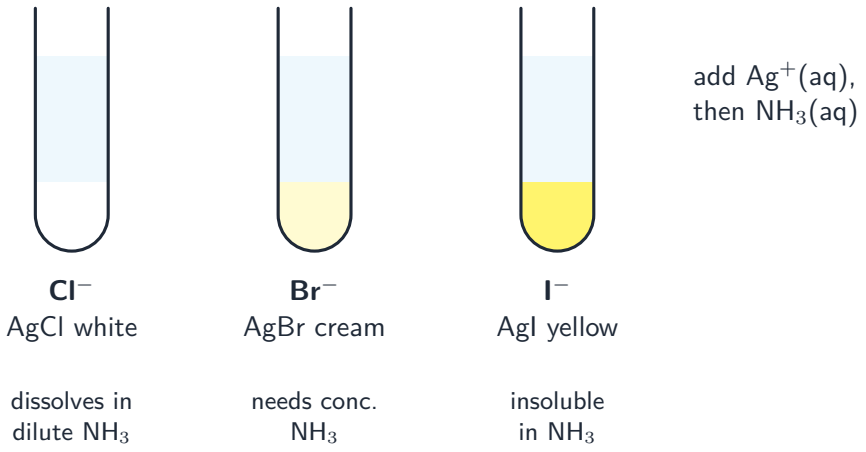
- describe the relative reactivity of the halogens as oxidising agents
- describe the reactions with hydrogen and explain the reactivity trend
- explain the thermal stabilities of the hydrogen halides in terms of bond strength

1 Worked examples

■ Halogens as oxidising agents



Oxidising power of the halogens falls down the group (the larger atom attracts an extra electron less)



Silver halide tests distinguish the halides

Each halogen gains one electron to form X^-, so it is an **oxidising agent**. A more reactive halogen **displaces** a less reactive one: $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$.

■ Reactions with hydrogen and HX stability

$H_2 + Cl_2 \rightarrow 2HCl$ — the reaction gets **less vigorous** down the group (Cl_2 explosive in light; I_2 slow). The thermal stability of HX **decreases** down the group, because the H–X bond weakens as the atom gets larger (HI breaks easily; HCl is stable).

2 Practice

2.1 State the trend in oxidising power down Group 17 and explain it. [2]

2.2 Write the equation for the displacement reaction of chlorine with potassium bromide. [1]

3 Exam-style questions

3.1 Which is the strongest oxidising agent? [1]

- **A** Cl_2
- **B** Br_2
- **C** I_2
- **D** they are equal

3.2 Which hydrogen halide is the **least** thermally stable? [1]

- **A** HCl
- **B** HBr
- **C** HI
- **D** HF

3.3 (a) State and explain whether bromine would displace chlorine from sodium chloride. [2]

(b) Explain why HI is less thermally stable than HCl. [2]

3.4 Explain why the halogens become less reactive as oxidising agents down the group. [2]

Solutions

2.1 oxidising power decreases down the group; the larger atoms attract an extra electron less strongly.

2.2 $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$.

3.1 A. Chlorine is the strongest oxidising agent.

3.2 C. HI is the least thermally stable (weakest H–X bond).

3.3 (a) no; bromine is a weaker oxidising agent than chlorine, so it cannot displace chloride.
(b) the H–I bond is longer and weaker than H–Cl, so HI decomposes more easily on heating.

3.4 down the group the atoms get larger with more shielding, so they attract an extra electron less strongly — weaker oxidising agents.

22 What happens when iodine solution is added to a solution of sodium bromide?

A A reaction occurs without changes in oxidation state.

B Bromide ions are oxidised; iodine atoms are reduced.

C Bromide ions are reduced; iodine atoms are oxidised.

D No reaction occurs.

23 Which statement is correct?

A Nitrogen is unreactive due to the absence of lone pairs in the molecule.

B Aqueous ammonia contains both $NH_3(aq)$ and $NH_4^+(aq)$. The $NH_4^+(aq)$ ion is a Brønsted–Lowry acid.

C High temperatures are needed to supply the energy to break the strong double bonds in nitrogen molecules when they react.

D Atmospheric SO_2 reacts with unburnt hydrocarbons to form a component of photochemical smog.

1 The Group 17 elements are oxidising agents.

(a) **(i)** Explain how the Group 17 elements act as oxidising agents.

.....

..... [1]

(ii) Write an equation to show the reaction in which Cl_2 oxidises aluminium metal.

..... [1]

(iii) A student heats equal amounts of $I_2(g)$ and $H_2(g)$ in a sealed flask. The student leaves the contents to cool.

State what you would observe during the reaction.

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(b) Cl_2 and Br_2 can each react with NH_3 to give N_2 and a hydrogen halide, HX.

$$3X_2 + 2NH_3 \rightarrow N_2 + 6HX \qquad X = Cl \text{ or } Br$$

The relative bond strengths of X–X and H–X determine the difference in enthalpy change of the two reactions.

(i) Describe and explain the difference in the X–X bond strengths of Cl_2 and Br_2.

.....

.....

.....

..... [2]

(ii) Describe the relative thermal stabilities of HCl and HBr.

..... [1]

(iii) Define enthalpy change of formation, ΔH_f.

.....

.....

..... [2]

(iv) Table 1.1 gives data relevant to the reaction of $Cl_2(g)$ with $NH_3(g)$.

Table 1.1

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Use the data in Table 1.1 to calculate the enthalpy change of the reaction of $Cl_2(g)$ with $NH_3(g)$.

enthalpy change of reaction = ... kJ mol^{-1} [2]

(v) I_2 reacts with NH_3 to form NI_3.

Predict the shape of a molecule of NI_3. Explain your answer.

shape .....

explanation .....

.....

[2]

(c) Table 1.2 shows some information about reactions of NaCl, NaBr and NaI.

Table 1.2

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type of reaction with concentrated H_2SO_4	acid–base	acid–base, then redox	acid–base, then redox
observations with concentrated H_2SO_4			• black solid • yellow solid • effervescence

(i) Complete Table 1.2. [4]

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black solid .....

yellow solid .....

effervescence .....

[2]

(d) Table 1.3 gives some information about $MgCl_2$ and $SiCl_4$.

Table 1.3

	$MgCl_2$	**$SiCl_4$**
electrical conductivity when liquid	conducts	does **not** conduct
observation when added to water	dissolves	vigorous reaction

(i) Explain the difference between the electrical conductivity of liquid $MgCl_2$ and of liquid $SiCl_4$. Refer to bonding and relevant particles in your answer.

.....

.....

.....

.....

..... [2]

(ii) Suggest the pH of the solutions that form when each chloride is added to water.

$MgCl_2$ ..... $SiCl_4$ .....

[2]

A-LEVEL CHEMISTRY • EXERCISE SHEET

11.3 Some reactions of the halide ions

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS reducing agent 还原剂 • precipitate 沉淀 • ammonia 氨 • halide ion 卤离子 • silver halide 卤化银

Objective

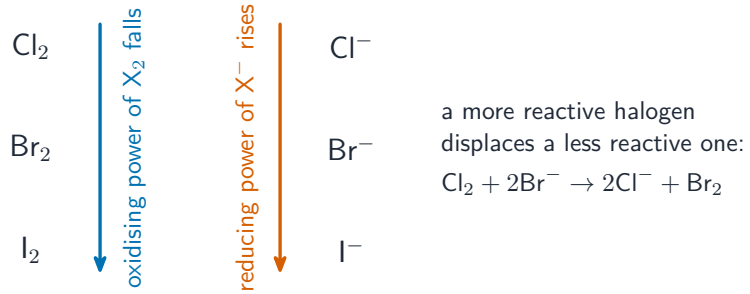
Build the skills to answer exam questions on **reactions of the halide ions** 卤离子 — halides as **reducing agents** 还原剂, the **silver halide** 卤化银 test, and the reaction with concentrated sulfuric acid.

You must be able to:

- describe the relative reactivity of the halide ions as reducing agents
- describe the test with aqueous silver ions followed by ammonia
- describe and write equations for the reactions with concentrated sulfuric acid

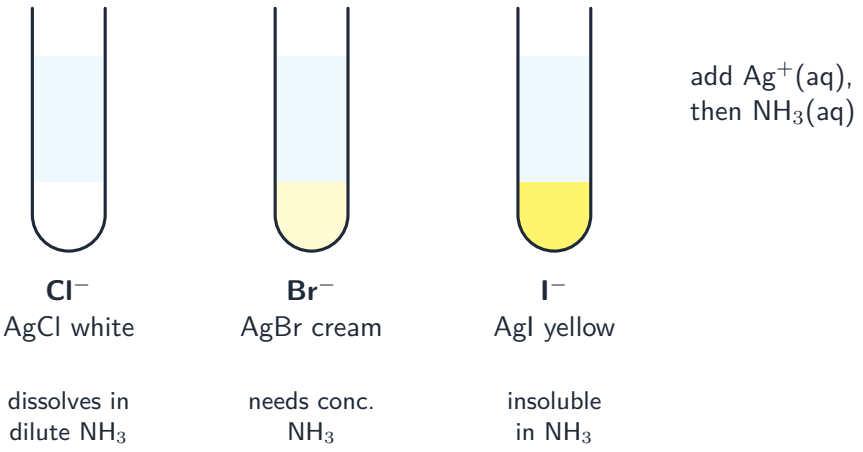
1 Worked examples

■ Halides as reducing agents



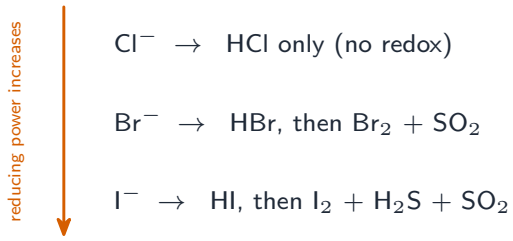
Reducing power of the halide ions increases down the group (a larger ion loses its electron more easily)

■ The silver halide test



Add $AgNO_3$ then ammonia: AgCl white (dissolves in dilute NH_3), AgBr cream (dissolves in conc. NH_3), AgI yellow (insoluble)

■ With concentrated sulfuric acid



The stronger reducing agents (Br^-, I^-) are oxidised to the halogen, reducing the sulfur

- Cl^-: only HCl (no redox): $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$.
- Br^-: HBr + brown Br_2 + SO_2. I^-: HI + I_2 + H_2S + SO_2 (I^- is the strongest reducing agent).

2 Practice

2.1 State the colour of the precipitate formed when silver nitrate is added to (a) chloride and (b) iodide ions. [2]

2.2 State the trend in reducing power of the halide ions down the group. [1]

3 Exam-style questions

3.1 A halide gives a cream precipitate with silver nitrate that dissolves only in concentrated ammonia. The halide is: [1]

- **A** chloride
- **B** bromide
- **C** iodide
- **D** fluoride

3.2 Which halide is oxidised to a coloured element by concentrated sulfuric acid, also producing H_2S? [1]

- **A** chloride
- **B** bromide
- **C** iodide
- **D** none of them

3.3 (a) Describe how you would use silver nitrate and ammonia to distinguish between solutions of sodium chloride and sodium iodide. [3]

(b) Explain why iodide ions are oxidised by concentrated sulfuric acid but chloride ions are not. [2]

3.4 Write the equation for the reaction of solid sodium chloride with concentrated sulfuric acid. [1]

3.5 Separate samples of solid NaCl, NaBr and NaI are each warmed with concentrated sulfuric acid.

(a) State what is observed with each solid, naming the sulfur-containing product where one is formed. [5]

(b) Explain the pattern in (a) in terms of the reducing power of the halide ions. [3]

(c) Describe the test that distinguishes chloride, bromide and iodide ions **in solution**, giving the result in each case and the effect of adding aqueous ammonia. [4]

(d) State why dilute nitric acid is added before the silver nitrate. [1]

Solutions

2.1 (a) white; (b) yellow.

2.2 reducing power increases down the group.

3.1 B. A cream precipitate dissolving only in concentrated ammonia is bromide.

3.2 C. Iodide is the strongest reducing agent, reducing the acid to H_2S.

3.3 (a) add silver nitrate to each — both give a precipitate; chloride gives white, iodide gives yellow; add ammonia — the chloride (white) dissolves in dilute ammonia, the iodide (yellow) is insoluble.
(b) iodide ions are stronger reducing agents (lose their electron more easily), so they reduce the sulfuric acid; chloride ions are too weak a reducing agent.

3.4 $NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$.

3.5 (a) NaCl: steamy white fumes of HCl only — no redox occurs. NaBr: steamy fumes of HBr, plus orange-brown bromine vapour and a colourless choking gas, **sulfur dioxide**. NaI: purple-black iodine, a yellow solid (sulfur) and the smell of bad eggs — **hydrogen sulfide**.
(b) Reducing power increases down the group; the ion gets larger, so its outermost electron is further from the nucleus and better shielded and is lost more easily; iodide can therefore reduce sulfur from +6 all the way to −2, whereas chloride cannot reduce it at all.
(c) Acidify with dilute nitric acid, then add aqueous silver nitrate. White precipitate = chloride, cream = bromide, yellow = iodide. The white dissolves in **dilute** ammonia; the cream dissolves only in **concentrated** ammonia, and the yellow dissolves in neither.
(d) To remove carbonate and other ions that would themselves precipitate with silver nitrate and give a false positive.

21 Equation 1 and equation 2 show two different reactions of halide ion Q^- with concentrated sulfuric acid.

equation 1 $H_2SO_4 + Q^- \rightarrow HSO_4^- + HQ$

equation 2 $H_2SO_4 + 2Q^- + 2H^+ \rightarrow SO_2 + Q_2 + 2H_2O$

What is Q?

A Cl^- or Br^- **B** Br^- or I^- **C** Cl^- only **D** I^- only

22 X and Y are sodium salts of Group 17 elements.

When X reacts with concentrated sulfuric acid, hydrogen sulfide, H_2S, is produced.

When Y reacts with concentrated sulfuric acid, there is no change in the oxidation number of the sulfur.

Which statement is correct?

A Aqueous X reduces aqueous bromine.

B Aqueous Y reacts with aqueous silver nitrate to give a precipitate which is insoluble in concentrated aqueous ammonia.

C X and Y react separately with concentrated sulfuric acid to produce halogens.

D When X reacts with concentrated sulfuric acid, six halide ions are needed to reduce one sulfur atom to H_2S.

21 X, Y and Z are three aqueous solutions. Equal volumes of pairs of the solutions are mixed and observations noted.

X mixed with Y shows no reaction.

X mixed with Z shows an immediate reaction.

Z mixed with Y shows no reaction.

What are X, Y and Z?

	X	Y	Z
A	Br_2(aq)	I_2(aq)	HBr(aq)
B	Cl_2(aq)	I_2(aq)	HBr(aq)
C	HCl(aq)	HI(aq)	Br_2(aq)
D	HCl(aq)	Br_2(aq)	HBr(aq)

3 **(a)** A bottle labelled **FA 5** is thought to contain hydrated zinc sulfate. It would therefore contain zinc ions and sulfate ions as well as water of crystallisation.

(i) Devise and carry out tests to investigate whether zinc ions, sulfate ions and water of crystallisation are present.

Record the tests you carry out and the observations you see in the space provided.

[5]

(ii) Use your observations in **(a)(i)** to complete Table 3.1 to show whether each species is present in **FA 5**.

Use a tick (✓) if the species is present.

Use a cross (✗) if the species is **not** present.

Table 3.1

Zn^{2+}	
SO_4^{2-}	
H_2O	

[1]

(b) You are provided with solid **FA 6**.

(i) Heat a few crystals of **FA 6** in a hard-glass test-tube until no further gas is evolved. Record all your observations.

Leave the test-tube until it is cool.

Keep the cooled residue for use in (b)(ii).

.....

.....

..... [2]

(ii) To the cooled residue from **(b)(i)**, add approximately 3 cm depth of distilled water and stir. Filter the solution formed into a test-tube.

The colour of the solution is ..... . [1]

(c) You are provided with aqueous solutions **FA 7** and **FA 8** and with solid **FA 9**.

FA 7 is an aqueous solution of **FA 6**.
FA 7, **FA 8** and **FA 9** contain compounds which all have one metal that is the same but which may be in different oxidation states.

(i) Carry out the following tests on **FA 7**, **FA 8** and **FA 9** and record your observations in Table 3.2. For each test use a 1 cm depth of a solution or a spatula measure of solid.

Table 3.2

test	*observations*		
	FA 7	**FA 8**	**FA 9**
Test 1 Add hydrogen peroxide.			
Test 2 Add aqueous sodium hydroxide, then			
leave to stand.			
Test 3 Add aqueous iron(II) sulfate.			

[4]

(ii) Suggest the identity of the metal in **FA 6**/**FA 7**, **FA 8** and **FA 9**.

The metal is ..... . [1]

(iii) Complete Table 3.3 to suggest the oxidation state of the metal in **FA 6**/**FA 7** and **FA 8**.

Table 3.3

	FA 6/**FA 7**	**FA 8**
oxidation state		

[1]

[Total: 15]

Qualitative analysis notes

1 Reactions of cations

cation	reaction with	
	NaOH(aq)	**NH_3(aq)**
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	no ppt. ammonia produced on warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless [Ba^{2+}(aq)] is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless [Ca^{2+}(aq)] is very low	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	pale blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high [Ca^{2+}(aq)]
sulfite, SO_3^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (soluble in excess dilute strong acids); decolourises acidified ous $KMnO_4$
thiosulfate, $S_2O_3^{2-}$(aq)	gives off-white / pale yellow ppt. slowly with H^+

3 Tests for gases

gas	test and test result
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
hydrogen, H_2	'pops' with a lighted splint
oxygen, O_2	relights a glowing splint

3 (a) (i) To a 1 cm depth of **FB 4** in a boiling tube, slowly add a 1 cm depth of dilute nitric acid. Stir gently until the reaction is complete. Use this solution for your tests.
Select reagents to identify which sodium halide is present.
Record details of the reagents used and your observations.
Identify the sodium halide that is present as an impurity in **FB 4**.

The formula of the impurity is .....

[2]

(ii) Suggest why it is necessary to add the nitric acid to **FB 4** before carrying out your tests in **(a)(i)**.

.....

..... [1]

(b) **FB 7** contains a metal cation which is listed in the Qualitative analysis notes.

(i) Place half the sample of **FB 7** in a hard-glass test-tube. Heat gently at first and then more strongly.
Record your observations.

.....

.....

..... [2]

(ii) Use the 25 cm^3 measuring cylinder to measure 20 cm^3 of **FB 1**.
Place the remaining sample of **FB 7** in a boiling tube and add portions of **FB 1** from the measuring cylinder until all the **FB 7** has reacted. Stir until the reaction is complete.
Record your observations.

Keep this solution for use in (b)(iii).

.....

.....

.....

..... [2]

(iii) Carry out the following tests. For each test use a 1 cm depth of the solution from **(b)(ii)** in a test-tube.
Record your observations in Table 3.1.
Identify the metal ion present in **FB 7**.

Table 3.1

test	*observations*
Test 1 Add aqueous sodium hydroxide.	
Test 2 Add aqueous ammonia.	
Test 3 Add a piece of aluminium foil.	

The formula of the metal ion in **FB 7** is .....

[4]

(c) **FB 8** is an acidified aqueous solution containing a metal cation which is listed in the Qualitative analysis notes.

(i) Carry out the following tests. For each test use a 1 cm depth of **FB 8** in a test-tube.
Record your observations in Table 3.2.
Identify the metal ion present in **FB 8**.

Table 3.2

test	*observations*
Test 1 Add aqueous sodium hydroxide.	
Test 2 Add a 1 cm depth of acidified aqueous potassium manganate(VII).	

The formula of the metal ion in **FB 8** is .....

[3]

(ii) State the type of reaction between the metal ion in **FB 8** and acidified aqueous potassium manganate(VII).
Explain how your observations support your answer.

.....

.....

..... [1]

[Total: 15]

Qualitative analysis notes

1 Reactions of cations

cation	reaction with	
	NaOH(aq)	**NH_3(aq)**
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	no ppt. ammonia produced on warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless [Ba^{2+}(aq)] is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless [Ca^{2+}(aq)] is very low	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	pale blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high [Ca^{2+}(aq)]
sulfite, SO_3^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (soluble in excess dilute strong acids); decolourises acidified aqueous $KMnO_4$
thiosulfate, $S_2O_3^{2-}$(aq)	gives off-white / pale yellow ppt. slowly with H^+

3 Tests for gases

gas	test and test result
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
hydrogen, H_2	'pops' with a lighted splint
oxygen, O_2	relights a glowing splint

3 (a) (i) **FB 6**, **FB 7** and **FB 8** are aqueous solutions of different compounds that each contain at least one oxygen atom.

Carry out the following tests and record your observations in Table 3.1. Three of the tests have been done for you. Use a 1 cm depth of solution in a test-tube for each test.

Table 3.1

test	*observations*		
	FB 6	**FB 7**	**FB 8**
Test 1 Add a small spatula measure of manganese(IV) oxide.	No change.	No change.	
Test 2 Add a 1 cm length of magnesium.			No change.
Test 3 Add a few drops of aqueous iron(II) sulfate.			

[4]

(ii) Use your observations in Table 3.1 to suggest a possible formula for each of **FB 6**, **FB 7** and **FB 8**.

FB 6 .....

FB 7 .....

FB 8 .....

[2]

(b) **FB 9** contains two anions and two cations, three of which are listed in the Qualitative analysis notes.

(i) To a small spatula measure of **FB 9** in a test-tube, add a 2 cm depth of dilute nitric acid. Record your observations.

Keep the resulting solution for the test in (b)(ii).

.....

.....

..... [2]

(ii) To the solution from **(b)(i)**, add a few drops of aqueous silver nitrate. Then add excess aqueous ammonia. Record your observations.

.....

.....

..... [1]

(iii) Make an aqueous solution of **FB 9** by adding a 5 cm depth of distilled water to a spatula measure of **FB 9** in a test-tube. Carry out the following tests on the aqueous solution of **FB 9** and record your observations in Table 3.2.

Table 3.2

test	*observations*
Test 1 To a 1 cm depth in a boiling tube, add aqueous sodium hydroxide, then	
warm.	
Test 2 To a 1 cm depth in a test-tube, add a few drops of dilute hydrochloric acid, then add a few drops of aqueous chlorine. **Empty and rinse the test-tube with water immediately after use.**	

[2]

(iv) Use your observations in **(b)(i)**, **(b)(ii)** and Table 3.2 to deduce the formulae of the cations and anions in **FB 9**. If you are unable to identify an ion, write 'unknown'.

cations ..... and .....

anions ..... and .....

[2]

(v) Write an ionic equation for the reaction in **(b)(ii)**. Include state symbols.

..... [1]

[Total:14]

Qualitative analysis notes

1 Reactions of cations

cation	reaction with	
	NaOH(aq)	**NH_3(aq)**
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	no ppt. ammonia produced on warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless [Ba^{2+}(aq)] is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless [Ca^{2+}(aq)] is very low	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	pale blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high [Ca^{2+}(aq)]
sulfite, SO_3^{2-}(aq)	gives white ppt. with B[illegible]q) (soluble in excess dilute strong acids); decolourises acidified aqueous $KMnO_4$
thiosulfate, $S_2O_3^{2-}$(aq)	gives off-white / pale yellow ppt. slowly with H^+

3 Tests for gases

gas	test and test result
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
hydrogen, H_2	‘pops’ with a lighted splint
oxygen, O_2	relights a glowing splint

11.4 The reactions of chlorine

Name: _____ Class: _____ Date: _____ **Total: 11 marks**

KEY WORDS disproportionation 歧化 • water purification 水净化 • bacteria 细菌 • oxidation number 氧化数

Objective

Build the skills to answer exam questions on the **reactions of chlorine** — its **disproportionation** 歧化 with sodium hydroxide, and its use in **water purification** 水净化.

You must be able to:

- interpret chlorine's reactions with cold and hot NaOH as disproportionation
- use oxidation numbers to show the disproportionation
- explain the use of chlorine in water purification

1 Worked examples

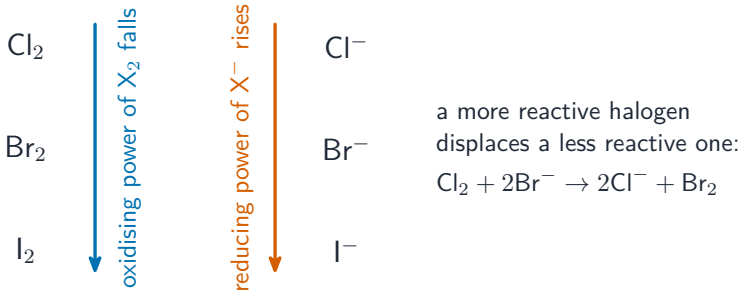
■ Chlorine with sodium hydroxide

- **cold, dilute** NaOH: $Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$.
- **hot, concentrated** NaOH: $3Cl_2 + 6NaOH \rightarrow 5NaCl + NaClO_3 + 3H_2O$.

Both are **disproportionation**: chlorine (0) is both oxidised (to +1 in ClO^-, or +5 in $ClO_3{}^-$) and reduced (to −1 in Cl^-).

■ Water purification

A little chlorine kills bacteria, making water safe to drink



Chlorine is a strong oxidiser in its reactions

$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$. The active species **HOCl** and **ClO^-** kill **bacteria** 细菌.

2 Practice

2.1 Write the equation for chlorine reacting with cold, dilute sodium hydroxide. [1]

2.2 Name the active species, formed when chlorine reacts with water, that kills bacteria. [1]

3 Exam-style questions

3.1 Chlorine reacting with cold dilute NaOH is a disproportionation reaction because: [1]

- **A** chlorine is only oxidised
- **B** chlorine is only reduced
- **C** chlorine is both oxidised and reduced
- **D** no redox occurs

3.2 What is the oxidation number of chlorine in the chlorate(I) ion, ClO^-? [1]

- **A** -1
- **B** 0
- **C** $+1$
- **D** $+5$

3.3 When chlorine reacts with hot concentrated sodium hydroxide:

(a) Write the equation. [2]

(b) Give the oxidation number of chlorine in each chlorine-containing product, and explain why this is disproportionation. [3]

3.4 Explain, with an equation, how chlorine makes drinking water safe. [2]

Solutions

2.1 $Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$.

2.2 HOCl (chloric(I) acid) / ClO^-.

3.1 C. Chlorine is both oxidised and reduced — disproportionation.

3.2 C. Chlorine in ClO^- is +1.

3.3 (a) $3Cl_2 + 6NaOH \rightarrow 5NaCl + NaClO_3 + 3H_2O$.
(b) Cl in NaCl = −1; Cl in $NaClO_3$ = +5; chlorine starts at 0 and is both reduced (to −1) and oxidised (to +5).

3.4 chlorine reacts with water: $Cl_2 + H_2O \rightleftharpoons HOCl + HCl$; the $HOCl/ClO^-$ kills bacteria, making the water safe.

21 In an experiment, 0.600 mol of chlorine gas, Cl_2, is reacted with an excess of hot aqueous sodium hydroxide. One of the products is $NaClO_3$.

Which mass of $NaClO_3$ is formed?

A 21.3 g **B** 44.7 g **C** 63.9 g **D** 128 g

22 An excess of chlorine gas is bubbled into hot potassium hydroxide solution.

Which chlorine-containing species are present in the final solution?

A Cl^- and ClO^-

B Cl^- and ClO_3^-

C ClO^- and ClO_3^-

D ClO_3^- only

1 The Group 17 elements are oxidising agents.

(a) **(i)** Explain how the Group 17 elements act as oxidising agents.

.....

..... [1]

(ii) Write an equation to show the reaction in which Cl_2 oxidises aluminium metal.

..... [1]

(iii) A student heats equal amounts of $I_2(g)$ and $H_2(g)$ in a sealed flask. The student leaves the contents to cool.

State what you would observe during the reaction.

..... [1]

(b) Cl_2 and Br_2 can each react with NH_3 to give N_2 and a hydrogen halide, HX.

$$3X_2 + 2NH_3 \rightarrow N_2 + 6HX \qquad X = Cl \text{ or } Br$$

The relative bond strengths of X–X and H–X determine the difference in enthalpy change of the two reactions.

(i) Describe and explain the difference in the X–X bond strengths of Cl_2 and Br_2.

.....

.....

.....

..... [2]

(ii) Describe the relative thermal stabilities of HCl and HBr.

..... [1]

(iii) Define enthalpy change of formation, ΔH_f.

.....

.....

..... [2]

(iv) Table 1.1 gives data relevant to the reaction of $Cl_2(g)$ with $NH_3(g)$.

Table 1.1

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$NH_3(g)$	–46
$HCl(g)$	–92

Use the data in Table 1.1 to calculate the enthalpy change of the reaction of $Cl_2(g)$ with $NH_3(g)$.

enthalpy change of reaction = ... kJ mol^{-1} [2]

(v) I_2 reacts with NH_3 to form NI_3.

Predict the shape of a molecule of NI_3. Explain your answer.

shape .....

explanation .....

.....

[2]

(c) Table 1.2 shows some information about reactions of NaCl, NaBr and NaI.

Table 1.2

	NaCl	**NaBr**	**NaI**
observation with $Ag^+(aq)$	white precipitate		
type of reaction with concentrated H_2SO_4	acid–base	acid–base, then redox	acid–base, then redox
observations with concentrated H_2SO_4			• black solid • yellow solid • effervescence

(i) Complete Table 1.2. [4]

(ii) Suggest an identity for the species that produces each observation in the reaction of NaI with concentrated H_2SO_4.

black solid .....

yellow solid .....

effervescence .....

[2]

(d) Table 1.3 gives some information about $MgCl_2$ and $SiCl_4$.

Table 1.3

	$MgCl_2$	**$SiCl_4$**
electrical conductivity when liquid	conducts	does **not** conduct
observation when added to water	dissolves	vigorous reaction

(i) Explain the difference between the electrical conductivity of liquid $MgCl_2$ and of liquid $SiCl_4$. Refer to bonding and relevant particles in your answer.

.....

.....

.....

.....

..... [2]

(ii) Suggest the pH of the solutions that form when each chloride is added to water.

$MgCl_2$ ..... $SiCl_4$ .....

[2]