Answer **all** the questions in the spaces provided.

1 **Determination of the concentration of a solution of hydrogen peroxide**

Hydrogen peroxide, H_2O_2, can be oxidised to give oxygen, O_2. This reaction happens rapidly in the presence of acidified potassium manganate(VII), $KMnO_4$.

$$2MnO_4^-(aq) + 5H_2O_2(aq) + 6H^+(aq) \longrightarrow 2Mn^{2+}(aq) + 5O_2(g) + 8H_2O(l)$$

To determine the concentration of a solution of hydrogen peroxide, you will first dilute the solution and then carry out a titration using acidified potassium manganate(VII), $KMnO_4$.

FA 1 is aqueous hydrogen peroxide.
FA 2 is 0.0200 mol dm^{-3} potassium manganate(VII), $KMnO_4$.
FA 3 is 1.0 mol dm^{-3} sulfuric acid, H_2SO_4.

Keep **FA 1** for use in **Question 3**

(a) Method

Dilution

- Pipette 25.0 cm^3 of **FA 1** into the 250 cm^3 volumetric flask.
- Add distilled water to make 250 cm^3 of solution and shake the flask thoroughly.
- Label this diluted solution of hydrogen peroxide as **FA 4**.

Titration

- Fill the burette with **FA 2**.
- Pipette 25.0 cm^3 of **FA 4** into a conical flask.
- Use the measuring cylinder to add 25 cm^3 of **FA 3** to the conical flask.
- Titrate **FA 4** against **FA 2** and record your readings in the space below.
- Carry out as many accurate titrations as you think necessary.

<u>Results</u>

[5]

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(b) From your titrations, obtain a suitable volume of **FA 2** to be used in your calculations.

Show clearly how you obtained this volume.

25.0 cm^3 of **FA 4** required ______________ cm^3 of **FA 2** for titration [1]

(c) **Calculations**

Show your working and give appropriate significant figures in the final answer for **each** step of your calculations.

(i) Calculate the amount of potassium manganate(VII) present in the volume of **FA 2** calculated in **(b).**

amount of $KMnO_4$ = ____________________ [1]

(ii) Calculate the amount of hydrogen peroxide present in 25.0 cm^3 of **FA 4**.

amount of H_2O_2 in 25.0 cm^3 of **FA4** = ____________________ [1]

(iii) Calculate the concentration, in mol dm^{-3}, of H_2O_2 in **FA 4.**

concentration of H_2O_2 in **FA 4** = ____________________ [1]

(iv) Calculate the concentration, in mol dm^{-3}, of H_2O_2 in **FA 1.**

concentration of H_2O_2 in **FA 1** = ______________ [1]

(d) Another experiment was conducted to determine the concentration of hydrogen peroxide. Different volumes of hydrogen peroxide were added to identical 25.0 cm^3 samples of 0.0400 mol dm^{-3} aqueous iron(II) solution. Iron(II) is oxidised by hydrogen peroxide as shown by the following equation.

$$2Fe^{2+} + H_2O_2 + 2H^+ \rightarrow 2Fe^{3+} + 2H_2O$$

The remaining iron(II) ions in each of the resulting mixtures were then titrated against potassium manganate(VII) and the results were shown in the table below:

Volume of H_2O_2 added / cm^3	**Volume of $KMnO_4$ / cm^3**
2.00	11.60
12.00	5.20
16.00	2.60
25.00	3.40
30.00	6.70
35.00	10.00

(i) Plot, on the grid on page 5, the values for the volume of potassium manganate(VII) (*y-axis*) against the volume of hydrogen peroxide added (*x-axis*).

Draw two straight lines of best fit, taking into account all of your plotted points.

Your graph should enable you to determine the values for **(d)(ii)**.

[3]

(ii) Hence obtain values for

- the volume of potassium manganate(VII) required, $V_{max}(KMnO_4)$, to react completely with 25.0 cm^3 of iron(II) solution if no hydrogen peroxide is added.
- the volume of hydrogen peroxide required, $V_{max}(H_2O_2)$, to react completely with 25.0 cm^3 of iron(II) solution if no potassium manganate(VII) is added.

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$V_{max}(KMnO_4)$ = ____________________

$V_{max}(H_2O_2)$ = ____________________

[1]

(iii) Determine the concentration of hydrogen peroxide, in mol dm^{-3}, in this experiment.

Concentration of hydrogen peroxide = ________________

[4]
[Total: 18]

2 Determination of the enthalpy change of reaction, ΔH_r

You are to determine the enthalpy change of reaction, ΔH_r, for the following reactions:

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + CO_2(g) + H_2O(l) \qquad \Delta H_1$$

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + CO_2(g) + H_2O(l) \qquad \Delta H_2$$

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FA 5 is anhydrous sodium carbonate, Na_2CO_3

FA 6 is solid sodium hydrogen carbonate, $NaHCO_3$

You are also provided with 2.0 mol dm^{-3} HC*l*

(a) Reaction of FA 5, Na_2CO_3, with an excess of 2.0 mol dm^{-3} hydrochloric acid

Method

Read through the instructions carefully before starting any practical work.

1. Support the styrofoam cup in the 250 cm^3 beaker.
2. Use the measuring cylinder to transfer 50 cm^3 of 2.0 mol dm^{-3} hydrochloric acid into the styrofoam cup.
3. Place the thermometer in the styrofoam cup and record the temperature of the solution.
4. Weigh the weighing bottle containing **FA 5**, anhydrous sodium carbonate.
5. With the aid of a dry spatula, add the contents of the weighing bottle to the styrofoam cup in **three separate portions**, taking care that the mixture does not overflow.

[Safety precaution: DO NOT add FA 5 all at once. The reaction is very vigourous.]

6. Stir and record the highest temperature obtained.
7. Reweigh the weighing bottle containing residual **FA 5**.

Record in an appropriate form below, all of your weighings and temperature measurements together with the mass, $\mathbf{m_1}$, of **FA 5** added and the maximum temperature rise, $\mathbf{\Delta T_1}$.

Results

[2]

(b) **(i)** Calculate the temperature rise per gram of **FA 5**, Na_2CO_3, used in the experiment.

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$\frac{\Delta T_1}{m_1}$ = ______________________

[2]

(ii) Calculate the enthalpy change, ΔH_1, for the reaction

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl\ (aq) + CO_2\ (g) + H_2O(l)$$

$$\Delta H_1 = -\ (22.79 \times \frac{\Delta T_1}{m_1})\ \text{kJ mol}^{-1}$$

ΔH_1 = ______________________

[1]

(c) Reaction of FA 6, $NaHCO_3$, with an excess of 2.0 mol dm^{-3} hydrochloric acid

Method

Read through the instructions carefully before starting any practical work.

1. Support another styrofoam cup in the 250 cm^3 beaker provided.
2. Use the measuring cylinder to transfer 50 cm^3 of 2.0 mol dm^{-3} hydrochloric acid into the styrofoam cup.
3. Place the thermometer in the styrofoam cup and record the temperature of the solution.
4. Weigh the empty weighing bottle labelled **"FA 6"**.
5. Weigh approximately 7.0 – 8.0 g of **FA 6**, anhydrous sodium hydrogen carbonate into the empty weighing bottle labelled **"FA 6"**.
6. With the aid of a dry spatula, add the contents of the weighing bottle to the styrofoam cup in **three separate portions**, taking care that the mixture does not overflow.

[Safety precaution: DO NOT add FA6 all at once. The reaction is very vigourous.]

7. Stir and record the lowest temperature obtained.
8. Reweigh the weighing bottle containing residual **FA 6**.

Record in an appropriate form below, all of your weighings and temperature measurements together with the mass, $\mathbf{m_2}$, of **FA 6** added and the maximum temperature fall, $\mathbf{\Delta T_2}$.

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<u>Results</u>

(d) **(i)** Calculate the temperature fall per gram of **FA 6**, $NaHCO_3$, used in the experiment.

$\frac{\Delta T_2}{m_2}$ = ______________________ [2]

(ii) Calculate the enthalpy change, ΔH_2, for the reaction

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + CO_2(g) + H_2O(l)$$

$$\Delta H_2 = +\left(18.06 \times \frac{\Delta T_2}{m_2}\right) \text{ kJ mol}^{-1}$$

ΔH_2 = ______________________ [1]

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(e) **(i)** The smallest graduation in reading a –10 °C to +110 °C thermometer is 1.0 °C

Suggest the maximum error of a temperature change calculated with two temperature readings.

Maximum error = ______________________ [1]

(ii)

The expected fall in temperature when 1.0 g of $NaHCO_3(s)$ is added to 50 cm^3 of 2.0 mol dm^{-3} hydrochloric acid is approximately 1.5°C

Determine the maximum percentage error in the calculated temperature change when 1.0 g of $NaHCO_3$ is added to 50 cm^3 of 2.0 mol dm^{-3} hydrochloric acid.

Maximum percentage error = ______________________ [1]

(f) It is not possible to measure experimentally the enthalpy change, ΔH_3, for the following reaction as it does not take place in the laboratory.

$$Na_2CO_3(s) + CO_2(g) + H_2O(l) \rightarrow 2NaHCO_3(s)$$

It is possible, however, to calculate a “theoretical” value of ΔH_3 for this reaction from the results of the experiments you have carried out.

Using an energy cycle and your results from **(b)(ii)** and **(d)(ii),** calculate a value for ΔH_3.

ΔH_3 = ______________________

[2]

[Total: 12]

3 Qualitative Analysis

At each stage of any test you are to record details of the following:

- colour changes seen;
- the formation of any precipitate;
- the solubility of such precipitates in an excess of the reagent added.

Where reagents are selected for use in a test, the **name or correct formula** of the element or compound must be given.

Where gases are released they should be identified by a test**, described in the appropriate place in your observations.**

You should indicate clearly at what stage in a test a change occurs.

No additional tests for ions present should be attempted.

Rinse and reuse test-tubes where possible.

[Turn over

(a) **FA 7, FA 8** and **FA 9** are aqueous solutions that each have an ion containing one of the metals from those listed in the Qualitative Analysis Notes.

FA 1 from Question 1 is to be used in some of these tests.

Carry out the following tests and record your observations.

	Test	*Observation*
(i)	To a 1 cm depth of **FA 7** in a test-tube, add a 1 cm depth aqueous sodium hydroxide.	
	Then, add several drops of **FA 1**.	
(ii)	To a 1 cm depth of **FA 8** in a test-tube, add a few drops of aqueous sodium hydroxide.	
	Then, add excess aqueous sodium hydroxide.	
(iii)	To a 1 cm depth of **FA 8** in a test-tube, add several drops of **FA 1.**	
	Then, add aqueous sodium hydroxide until in excess.	
(iv)	To a 1 cm depth of **FA 8** in a test-tube, add a 1 cm depth of dilute sulfuric acid, and then a few drops of **FA 9**.	

(v)	To a 1 cm depth of aqueous potassium iodide in a test-tube, add a few drops of **FA 9**.	
	Then, add a few drops of starch solution	

[5]

(b) Identify the cation present in **FA 7** and **FA 8**.

The cation present in **FA 7** is ______________________

The cation present in **FA 8** is ______________________

[2]

(c) Explain the chemistry involved in the effervescence observed in both **(a)(i)** and **(a)(iii).**

[1]

(d) A student added 1 cm^3 of **FA 9** to a test-tube containing **FA 8**. A strip of magnesium ribbon was then added to the mixture. Effervescence was observed.

Deduce the identity of the gas evolved and explain the chemistry involved in this reaction.

[3]

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[Turn over

(e) **Figure 1** below shows the thermal decomposition of **FA 10**, which is a solid sample of the compound present in the aqueous solution of **FA 9**.

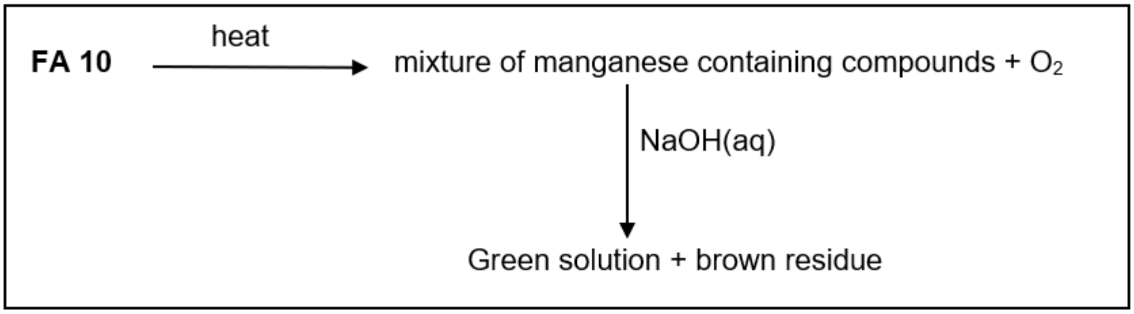


Figure 1

Consider the observations in **Figure 1**, suggest the identity of the manganese-containing species in the green solution and the residue.

____

[1]

(f) **FA 8** contains one of the anions Cl^-, Br^-, I^-, SO_4^{2-} or SO_3^{2-}.

Plan an experiment to determine the reagents you would use to identify which anion is present in **FA 8**.

Carry out your tests on **FA 8** to identify the anion present. Record your observations in the table below.

Test	**Observation**

Suggest the identity of the anion present in **FA 8**.

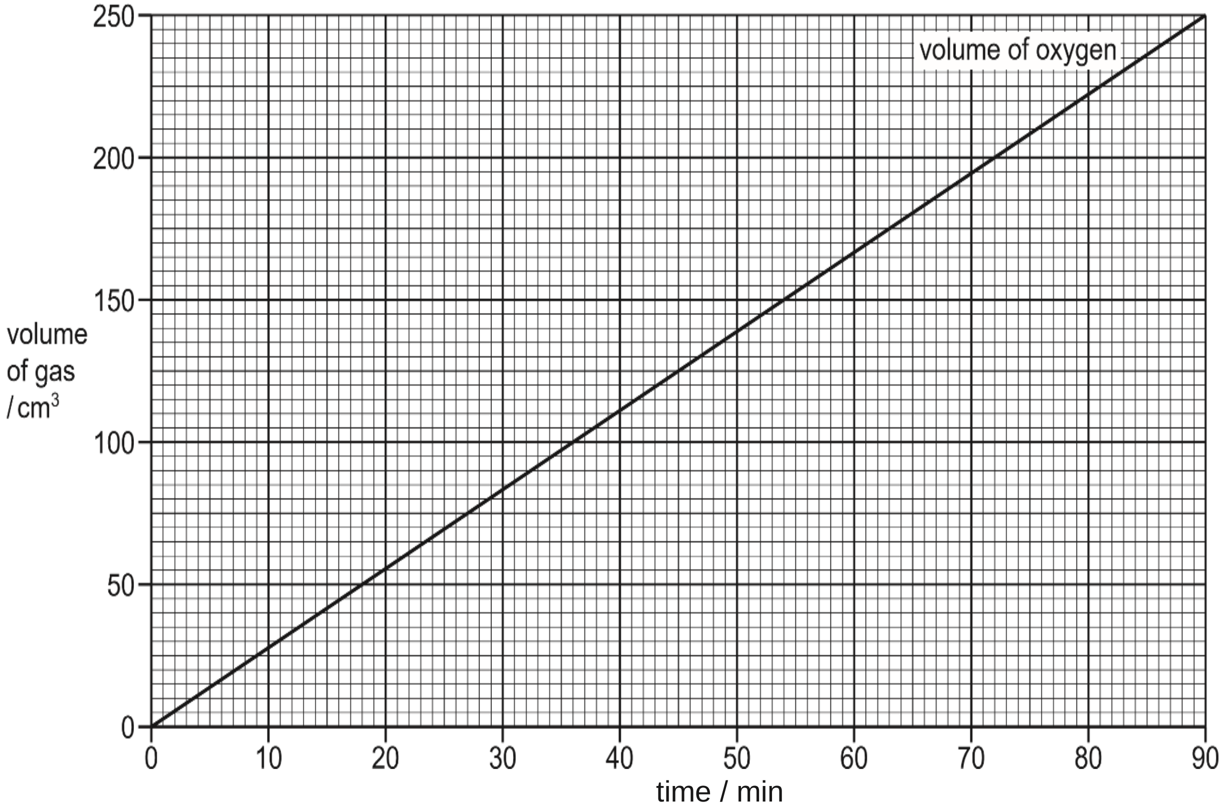
____

[3]
[Total:15]

[Turn over

4 **(a)** This question is about the electrolysis of different compounds.

During the electrolysis of dilute sulfuric acid using a current of 0.75 A for 90 minutes, the volume of oxygen gas collected was recorded and is shown in the graph below.



(i) **Table 1** below gives some standard electrode potential values

Electrode reaction	**E$^\ominus$ / V**
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+1.23
$O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$	+0.40
$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$	–0.83
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2 + 2H_2O$	+0.17
$S_2O_8^{2-} + 2e^- \rightleftharpoons 2SO_4^{2-}$	+2.01

Table 1

With reference to the values in the **Table 1**, write equations for the reactions that occur at each electrode in the electrolysis of sulfuric acid.

Cathode: ______________________________

Anode: ______________________________

[2]

[Turn over

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On the graph on page 14,

(ii) Draw a straight line to show the volume of hydrogen evolved in the same experiment. Label the line as “hydrogen”.

[1]

(iii) Draw a straight line to show the volume of oxygen evolved if a current of 0.45 A was used instead of the 0.75 A used in the original experiment. Label the line as “oxygen”.

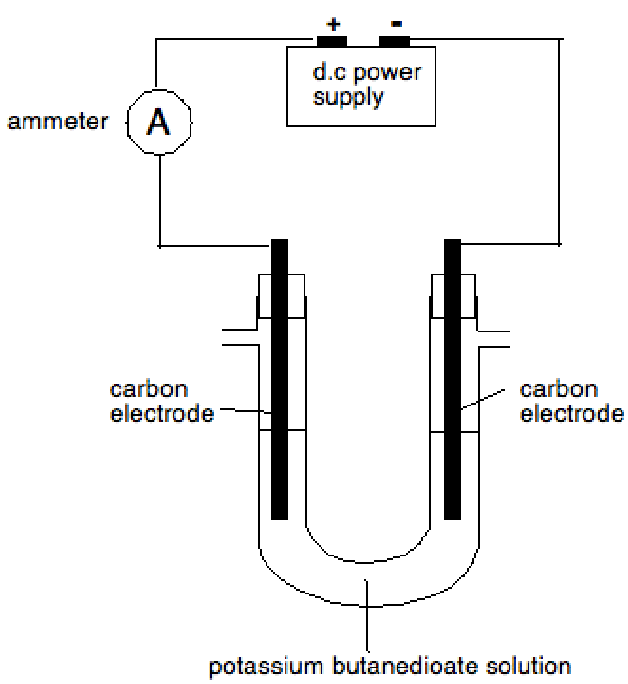
[1]

(b) During the electrolysis of potassium butanedioate, the following reaction occurs.

$$2H_2O + \begin{array}{l} CH_2COO^-\ K^+ \\ | \\ CH_2COO^-\ K^+ \end{array} \rightarrow C_2H_4 + 2CO_2 + H_2 + 2KOH$$

potassium butanedioate

An experiment can be conducted to verify the stoichiometric ratio between hydrogen gas and ethene gas collected using the following set-up.



Hydrogen is produced at one electrode, ethene and carbon dioxide are produced at the other. The carbon dioxide can be separated from the ethene by absorbing it using a suitable reagent before the volume of ethene is measured.

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(i) Complete the diagram on page 15 to show how:

- the hydrogen could be collected and its volume measured,
- the carbon dioxide could be removed,
- the volume of ethene could be measured.

Your diagram should include appropriate apparatus and the identity of the suitable reagent used to remove carbon dioxide.

[3]

(ii) Calculate the number of coulombs, **N**, that would be required to produce **V** cm^3 of hydrogen at room temperature and pressure.

[Faraday constant, F = 9.65×10^4 C mol^{-1}] [1]

(iii) Write an equation for the reaction that takes place for the removal of carbon dioxide.

[1]

(iv) Predict the organic product that would be obtained at the electrode when a solution of potassium *hexanedioate* is electrolysed.

[1]
[Total: 10]

Qualitative Analysis Notes

[ppt. = precipitate]

(a) Reactions of aqueous 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)	ammonia produced on heating	–
barium, Ba^{2+}(aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca^{2+}(aq)	white ppt. with high [Ca^{2+}(aq)]	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	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

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(b) 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 pale cream ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives 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; NO liberated by dilute acids (colourless NO $\rightarrow$ (pale) brown NO_2 in air)
sulfate, SO_4^{2-} (aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids)
sulfite, SO_3^{2-} (aq)	SO_2 liberated with dilute acids; gives white ppt. with Ba^{2+}(aq) (soluble in dilute strong acids)

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(c) Test for gases

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gas	*test and test result*
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	"pops" with a lighted splint
oxygen, O_2	relights a glowing splint
sulfur dioxide, SO_2	turns aqueous acidified potassium manganate(VII) from purple to colourless

(d) Colour of halogens

halogen	*colour of element*	*colour in aqueous solution*	*colour in hexane*
chlorine, Cl_2	greenish yellow gas	pale yellow	pale yellow
bromine, Br_2	reddish brown gas / liquid	orange	orange-red
iodine, I_2	black solid / purple gas	brown	purple

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