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CHEMISTRY

0620/41

Paper 4 Theory (Extended)

May/June 2022

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION

- The total mark for this paper is 80.
- The number of marks for each question or part question is shown in brackets [].
- The Periodic Table is printed in the question paper.

This document has **16** pages. Any blank pages are indicated.

1 A list of substances is shown.

aluminium oxide	carbon dioxide	chlorine	diamond	ethanol
glucose	iron(III) oxide	limestone	nitrogen	oxygen

Answer the questions using the list of substances.

Each substance may be used once, more than once or not at all.

State which of the substances:

(a) is a reactant in photosynthesis

..... [1]

(b) is the main constituent of bauxite

..... [1]

(c) are **two** products of fermentation

..... and [2]

(d) is used as a fuel

..... [1]

(e) is a gas used to convert iron into steel

..... [1]

(f) is a greenhouse gas

..... [1]

(g) is a gas that is approximately 78% of clean, dry air

..... [1]

(h) is a form of carbon.

..... [1]

[Total: 9]

- 2 (a) Atoms are made of protons, neutrons and electrons. Atoms of the same element are known as isotopes.

(i) Complete the table.

particle	relative charge	relative mass
electron		$\frac{1}{1840}$
neutron		
proton	+1	

[2]

- (ii) ${}^{24}_{12}\text{Mg}$ and ${}^{25}_{12}\text{Mg}$ are isotopes of magnesium.

Complete the table to show the numbers of electrons, neutrons and protons in these isotopes of magnesium.

isotope	number of electrons	number of neutrons	number of protons
${}^{24}_{12}\text{Mg}$			
${}^{25}_{12}\text{Mg}$			

[2]

- (iii) Explain why magnesium ions have a charge of 2+.

.....
 [1]

- (b) Mg^{2+} ions have the electronic structure 2,8.

Give the formula of the following particles which have the same electronic structure as Mg^{2+} ions.

- a cation (positive ion)

.....

- an anion (negative ion)

.....

- an atom

.....

[3]

[Total: 8]

3 This question is about sodium and compounds of sodium.

(a) (i) Describe the bonding in a metallic element such as sodium.

You may include a diagram as part of your answer.

.....
.....
..... [3]

(ii) Describe how solid sodium conducts electricity.

..... [1]

(b) Some properties of sodium chloride are shown:

- melting point of 801 °C
- non-conductor of electricity when solid
- conductor of electricity when molten
- soluble in water.

(i) Name the type of bonding in sodium chloride.

..... [1]

(ii) Explain why sodium chloride conducts electricity when molten.

.....
..... [1]

(c) A student determines the concentration of a solution of dilute sulfuric acid, H_2SO_4 , by titration with aqueous sodium hydroxide, NaOH.

step 1 25.0 cm³ of 0.200 mol/dm³ NaOH is transferred into a conical flask.

step 2 Three drops of methyl orange indicator are added to the conical flask.

step 3 A burette is filled with H_2SO_4 .

step 4 The acid in the burette is added to the conical flask until the indicator changes colour. The volume of acid is recorded. This process is known as titration.

step 5 The titration is repeated several times until a suitable number of results is obtained.

(i) Name the piece of apparatus used to measure exactly 25.0 cm³ of 0.200 mol/dm³ NaOH in **step 1**.

..... [1]

(ii) State the colour change of the methyl orange indicator in **step 4**.

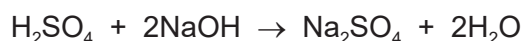
from to [1]

(iii) State how the student decides that a suitable number of results have been obtained.

.....
 [1]

(iv) 20.0 cm³ of H_2SO_4 reacts with 25.0 cm³ of 0.200 mol/dm³ NaOH.

The equation for the reaction is shown.



Calculate the concentration of H_2SO_4 using the following steps.

- Calculate the number of moles in 25.0 cm³ of 0.200 mol/dm³ NaOH.

..... mol

- Determine the number of moles of H_2SO_4 that react with the NaOH.

..... mol

- Calculate the concentration of H_2SO_4 .

..... mol/dm³
 [3]

[Total: 12]

4 This question is about compounds of sulfur.

(a) Sulfuric acid, H_2SO_4 , is manufactured using the Contact process. This manufacture involves four stages.

stage 1 Molten sulfur burns in air to produce sulfur dioxide.

stage 2 Sulfur dioxide reacts with oxygen to form sulfur trioxide.

stage 3 Sulfur trioxide combines with concentrated sulfuric acid to form oleum, $\text{H}_2\text{S}_2\text{O}_7$.

stage 4 Oleum reacts to form concentrated sulfuric acid.

(i) Write a chemical equation for the reaction occurring in **stage 1**.

..... [1]

(ii) State the essential conditions that are necessary for **stage 2**. Write an equation for the chemical reaction that occurs.

.....

 [4]

(iii) Write a chemical equation for the reaction occurring in **stage 3**.

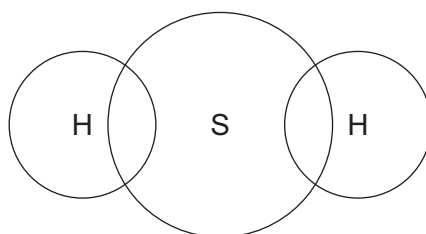
..... [1]

(iv) Name the substance that reacts with oleum in **stage 4**.

..... [1]

(b) Hydrogen sulfide has the formula H_2S .

(i) Complete the dot-and-cross diagram to show the electron arrangement in a molecule of hydrogen sulfide. Show outer shell electrons only.



[2]

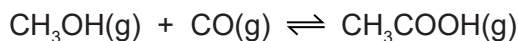
(ii) Balance the chemical equation for the reaction of hydrogen sulfide with sulfur dioxide shown.



[Total: 10]

- 5 Ethanoic acid is manufactured by the reaction of methanol with carbon monoxide.

An equilibrium mixture is produced.



- (a) State **two** characteristics of an equilibrium.

1

2 [2]

- (b) The purpose of the industrial process is to produce a high yield of ethanoic acid at a high rate of reaction.

The manufacture is carried out at a temperature of 300 °C.

The forward reaction is exothermic.

Use this information to state why the manufacture is **not** carried out at temperatures:

- **below** 300 °C

.....

- **above** 300 °C.

..... [2]

- (c) Complete the table using only the words *increases*, *decreases* or *no change*.

	effect on the rate of the forward reaction	effect on the equilibrium yield of CH ₃ COOH(g)
adding a catalyst		no change
decreasing the pressure		

[3]

- (d) Suggest which of the following metals is a suitable catalyst for the reaction. Give a reason for your answer.

aluminium calcium cobalt magnesium potassium

suitable catalyst

reason

[2]

- (e) Ethanoic acid is a member of the homologous series of carboxylic acids.

State the general formula of this homologous series.

..... [1]

- (f) Draw the structure of the carboxylic acid containing three carbon atoms. Show all of the atoms and all of the bonds.

[2]

- (g) When carboxylic acids react with alcohols, esters are produced.

The formula of ester **X** is $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOCH}_3$.

- (i) Name ester **X**.

..... [1]

- (ii) Give the name of the carboxylic acid and the alcohol that react together to produce ester **X**.

carboxylic acid

alcohol

[2]

- (h) Ester **Y** has the following composition by mass:

C, 48.65%; H, 8.11%; O, 43.24%.

Calculate the empirical formula of ester **Y**.

empirical formula = [3]

(i) Ester **Z** has the empirical formula C_2H_4O and a relative molecular mass of 88.

Determine the molecular formula of ester **Z**.

molecular formula = [1]

[Total: 19]

6 This question is about zinc and its compounds.

(a) Zinc is extracted from its ore which is mainly zinc sulfide, ZnS.

The steps for this extraction are shown.

step 1 Zinc sulfide is converted into zinc oxide.

step 2 The zinc oxide is then reduced to zinc in a furnace. The zinc formed becomes a gas.

step 3 The zinc gas is cooled to form molten zinc.

(i) Name the ore of zinc, which is mainly zinc sulfide.

..... [1]

(ii) Describe how zinc sulfide is converted into zinc oxide in **step 1**.

.....
 [1]

(iii) Name the reducing agent used in **step 2**.

..... [1]

(iv) Explain why the zinc forms a gas in **step 2** inside the furnace.

..... [1]

(v) State the name of the physical change occurring when zinc gas is converted into molten zinc.

..... [1]

(b) Zinc sulfate crystals, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, are hydrated.

Zinc sulfate crystals are made by reacting zinc carbonate with dilute sulfuric acid.

The equation for the overall process is shown.



step 1 Large pieces of solid zinc carbonate are added to dilute sulfuric acid until the zinc carbonate is in excess. This forms aqueous zinc sulfate.

step 2 The excess zinc carbonate is separated from the aqueous zinc sulfate.

step 3 The aqueous zinc sulfate is heated until a saturated solution is formed.

step 4 The saturated solution is allowed to cool and crystallise.

step 5 The crystals are removed and dried.

(i) In **step 1**, zinc carbonate is in excess when no more zinc carbonate dissolves.

State one **other** observation that indicates the zinc carbonate is in excess in **step 1**.

..... [1]

(ii) Name a different substance, other than zinc carbonate, that can be added to dilute sulfuric acid to produce aqueous zinc sulfate in **step 1**.

..... [1]

(iii) **Step 1** is repeated using powdered zinc carbonate instead of large pieces.

All other conditions are kept the same.

The rate of reaction increases.

Give a reason why the rate of reaction increases. Explain your answer in terms of particles.

.....
.....
..... [2]

(iv) Suggest what is observed when the solution is saturated in **step 3**.

.....
.....
..... [1]

(v) The formula of zinc sulfate crystals is $ZnSO_4 \cdot 7H_2O$.

Give the formula of the solid formed if the crystals are heated to dryness in **step 3**.

..... [1]

[Total: 11]

7 The Periodic Table can be used to classify elements.

(a) Group I elements react with cold water to form alkaline solutions.

(i) Place the Group I elements caesium, lithium, potassium, rubidium and sodium in their order of reactivity with water.

Put the most reactive element first.

most reactive $\xrightarrow{\hspace{15em}}$ least reactive

--	--	--	--	--

[1]

(ii) Name the alkaline solution formed when caesium reacts with cold water.

..... [1]

(b) Group I elements have lower melting points than transition elements.

Describe one **other** difference in the **physical** properties of Group I elements and transition elements.

..... [1]

(c) Group VII elements are known as the halogens.

Astatine is below iodine in Group VII.

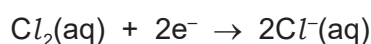
Predict the physical state of astatine at room temperature and pressure.

..... [1]

(d) Some Group VII elements react with aqueous solutions containing halide ions.

When aqueous chlorine is added to aqueous potassium bromide a reaction occurs.

The ionic half-equations for the reaction are shown.



(i) Describe the colour change of the solution.

original colour of potassium bromide solution

final colour of reaction mixture

[2]

(ii) Identify the species that is oxidised.

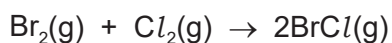
Explain your decision.

species oxidised

explanation

[2]

(e) Bromine monochloride, BrCl , is made by the reaction between bromine and chlorine. The chemical equation is shown.



bond	bond energy in kJ/mol
Br–Br	190
Cl–Cl	242
Br–Cl	218

Calculate the overall energy change for the reaction using bond energies.

Use the following steps.

- Calculate the total amount of energy required to break the bonds in 1 mole of $\text{Br}_2(\text{g})$ and 1 mole of $\text{Cl}_2(\text{g})$.

..... kJ

- Calculate the total amount of energy released when the bonds in 2 moles of $\text{BrCl}(\text{g})$ are formed.

..... kJ

- Calculate the overall energy change for the reaction.

..... kJ/mol
[3]

[Total: 11]

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The Periodic Table of Elements

		Group							
I	II	III	IV	V	VI	VII	VIII		
1	2	3	4	5	6	7	8	9	10
H hydrogen 1	He helium 4	B boron 11	C carbon 12	N nitrogen 14	O oxygen 16	F fluorine 19	Ne neon 20		
11	12	13	14	15	16	17	18		
Na sodium 23	Mg magnesium 24	Al aluminium 27	Si silicon 28	P phosphorus 31	S sulfur 32	Cl chlorine 35.5	Ar argon 40		
19	20	21	22	23	24	25	26	27	28
K potassium 39	Ca calcium 40	Sc scandium 45	Ti titanium 48	V vanadium 51	Cr chromium 52	Mn manganese 55	Fe iron 56	Co cobalt 59	Ni nickel 59
37	38	39	40	41	42	43	44	45	46
Rb rubidium 85	Sr strontium 88	Y yttrium 89	Zr zirconium 91	Nb niobium 93	Mo molybdenum 96	Tc technetium —	Ru ruthenium 101	Rh rhodium 103	Pd palladium 106
55	56	57–71	72	73	74	75	76	77	78
Cs caesium 133	Ba barium 137	lanthanoids	Hf hafnium 178	Ta tantalum 181	W tungsten 184	Re rhenium 186	Os osmium 190	Ir iridium 192	Pt platinum 195
87	88	89–103	104	105	106	107	108	109	110
Fr francium —	Ra radium —	actinoids	Rf rutherfordium —	Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —
81	82	83	84	85	86	87	88	89	90
Tl thallium 204	Pb lead 207	Bi bismuth 209	Po polonium —	At astatine —	Rn radon —	Cn copernicium —	Hg mercury 201	Au gold 197	Pt platinum 195
113	114	115	116	117	118	119	120	121	122
In indium 115	Sn tin 119	Sb antimony 122	Te tellurium 128	I iodine 127	Xe xenon 131	Pb lead 207	Hg mercury 201	Au gold 197	Pt platinum 195
151	152	153	154	155	156	157	158	159	160
Fl flerovium —	Lv livermorium —	Cn copernicium —	Rg roentgenium —	Ds darmstadtium —	Hs hassium —	Mt meitnerium —	Hg mercury 201	Au gold 197	Pt platinum 195
167	168	169	170	171	172	173	174	175	176
Er erbium 167	Tm thulium 169	Yb ytterbium 173	Lu lutetium 175	Ho holmium 165	Er erbium 167	Dy dysprosium 163	Cf californium —	Bk berkelium —	Cm curium —
101	102	103	104	105	106	107	108	109	110
Md mendelevium —	No nobelium —	Lr lawrencium —	Es einsteinium —	Fm fermium —	Mn manganese —	Cf californium —	Bk berkelium —	Cm curium —	Am americium —
99	100	101	102	103	104	105	106	107	108
Es einsteinium —	Fm fermium —	Md mendelevium —	No nobelium —	Lr lawrencium —	Lu lutetium 175	Dy dysprosium 163	Cf californium —	Bk berkelium —	Cm curium —
67	68	69	70	71	72	73	74	75	76
Ho holmium 165	Er erbium 167	Tm thulium 169	Yb ytterbium 173	Lu lutetium 175	Ho holmium 165	Dy dysprosium 163	Cf californium —	Bk berkelium —	Cm curium —
65	66	67	68	69	70	71	72	73	74
Tb terbium 159	Dy dysprosium 163	Ho holmium 165	Er erbium 167	Tm thulium 169	Yb ytterbium 173	Lu lutetium 175	Cf californium —	Bk berkelium —	Cm curium —
63	64	65	66	67	68	69	70	71	72
Eu europium 152	Gd gadolinium 157	Tb terbium 159	Dy dysprosium 163	Ho holmium 165	Er erbium 167	Tm thulium 169	Cf californium —	Bk berkelium —	Cm curium —
61	62	63	64	65	66	67	68	69	70
Pm promethium —	Sm samarium 150	Eu europium 152	Gd gadolinium 157	Tb terbium 159	Dy dysprosium 163	Ho holmium 165	Er erbium 167	Tm thulium 169	Lu lutetium 175
59	60	61	62	63	64	65	66	67	68
Pr praseodymium 141	Nd neodymium 144	Pm promethium —	Sm samarium 150	Eu europium 152	Gd gadolinium 157	Tb terbium 159	Dy dysprosium 163	Ho holmium 165	Er erbium 167
89	90	91	92	93	94	95	96	97	98
Ac actinium —	Th thorium 232	Pa protactinium 231	U uranium 238	Np neptunium —	Pu plutonium —	Am americium —	Cm curium —	Bk berkelium —	Cf californium —

Key

atomic number
atomic symbol
name
relative atomic mass

lanthanoids

actinoids

The volume of one mole of any gas is 24 dm³ at room temperature and pressure (r.t.p.).