Please check the examination details below before entering your candidate information

Candidate surname	Other names

Pearson Edexcel Level 3 GCE

Centre Number | Candidate Number

Tuesday 2 June 2020

Afternoon (Time: 1 hour 45 minutes) | Paper Reference **9CH0/01**

Chemistry

Advanced
Paper 1: Advanced Inorganic and Physical Chemistry

Candidates must have: Scientific calculator
Data Booklet
Ruler

Total Marks

Instructions

- Use **black** ink or **black** ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided – *there may be more space than you need.*

Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets – *use this as a guide as to how much time to spend on each question.*
- For the question marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

Advice

- Read each question carefully before you start to answer it.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.

Turn over ▶

1/1/1/1/1/1

Pearson

Answer ALL questions.

Some questions must be answered with a cross in a box ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 (a) Which equation shows the third ionisation energy of aluminium?

(1)

☐ **A** $Al(g) \rightarrow Al^{3+}(g) + 3e^-$

☐ **B** $Al^{2+}(g) \rightarrow Al^{3+}(g) + e^-$

☐ **C** $Al^{3+}(g) + 3e^- \rightarrow Al(g)$

☐ **D** $Al^{3+}(g) + e^- \rightarrow Al^{2+}(g)$

(b) Which element in this table is in Group 2?

	Ionisation energy / kJ mol^{-1}			
Element	First	Second	Third	Fourth
W	1086	2353	4621	6223
X	653	1592	2987	4740
Y	590	1145	4912	6474
Z	496	4563	6913	9544

(1)

☐ **A** W

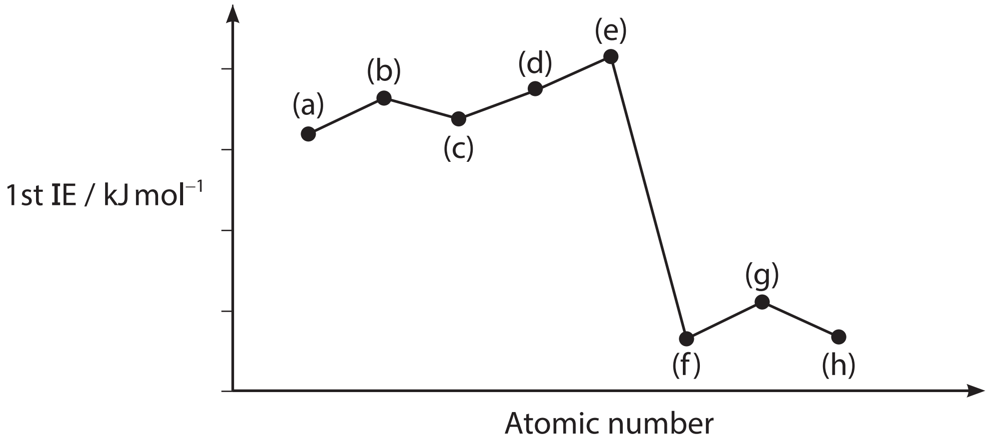
☐ **B** X

☐ **C** Y

☐ **D** Z

(c) The graph shows the first ionisation energies (IE) of eight successive elements from the first 20 elements in the Periodic Table.

Which letter represents the first ionisation energy of oxygen?



(1)

☒ **A** (a)

☒ **B** (b)

☒ **C** (c)

☒ **D** (h)

(d) Give the formula of a stable **ion** that is isoelectronic with the magnesium ion, Mg^{2+}.

(1)

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(e) A student stated that 'the elements scandium and zinc are d-block elements but are not transition metals'.

Discuss this statement, using appropriate electronic configurations to support your answer.

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(Total for Question 1 = 8 marks)

2 This question is about acids and bases.

(a) What is the order of **decreasing** pH for 0.100 mol dm^{-3} solutions of these three acids?

(1)

☒ **A** $CH_3COOH > CH_2ClCOOH > HCl$

☒ **B** $HCl > CH_3COOH > CH_2ClCOOH$

☒ **C** $CH_2ClCOOH > CH_3COOH > HCl$

☒ **D** $HCl > CH_2ClCOOH > CH_3COOH$

(b) A solution of methanoic acid, HCOOH, has a concentration of 0.240 mol dm^{-3} and a pH of 2.20.

Calculate the value of pK_a for methanoic acid.

(3)

(c) Which of these mixtures would form a buffer solution with a pH **below** 7?

(1)

☒ **A** NaOH(aq) and excess HCl(aq)

☒ **B** NaOH(aq) and excess CH_3COOH(aq)

☒ **C** excess NaOH(aq) and HCl(aq)

☒ **D** excess NaOH(aq) and CH_3COOH(aq)

(d) Bromothymol blue, methyl orange and phenolphthalein are indicators used in titrations.

Which, if any, of these indicators could be used for a titration of ammonia, $NH_3(aq)$, with ethanoic acid, $CH_3COOH(aq)$?

(1)

☒ **A** bromothymol blue

☒ **B** methyl orange

☒ **C** phenolphthalein

☒ **D** none of these three indicators

(Total for Question 2 = 6 marks)

3 This question is about transition metals and transition metal complexes.

(a) Describe the bonding in the element chromium and use your answer to justify why it has such a high melting temperature.

You may find it helpful to draw a labelled diagram.

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(b) When chromium(III) sulfate dissolves in water, a green solution containing the $[Cr(H_2O)_6]^{3+}$ ion forms.

(i) Give the shape of this complex ion.

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(ii) Explain why the chromium complex ion is coloured.

(3)

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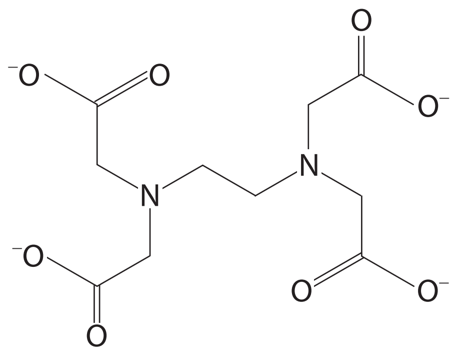
(c) The ligand ethylenediaminetetraacetate, $EDTA^{4-}$, has the structure shown.



When a solution of $EDTA^{4-}$ is added to a solution of $[Cr(H_2O)_6]^{3+}$ ions, a new complex ion is formed.

$$[Cr(H_2O)_6]^{3+} + EDTA^{4-} \rightleftharpoons [Cr(EDTA)]^{-} + 6H_2O$$

The equilibrium constant for this equilibrium is 2.51×10^{23} $dm^3\ mol^{-1}$.

By considering the equilibrium for this reaction and changes in entropy, comment on the value of the equilibrium constant. No calculations are required.

(3)

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(d) Aqueous vanadium(II) chloride, $VCl_2(aq)$, can be oxidised by bubbling gaseous chlorine, $Cl_2(g)$, through the solution in the absence of air.

$40.0\,cm^3$ of $0.100\,mol\,dm^{-3}$ VCl_2 solution was oxidised by $144\,cm^3$ of chlorine gas, at room temperature and pressure (r.t.p.).
The chlorine was reduced to chloride ions, according to the half-equation

$$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$$

[Molar volume of a gas at r.t.p. = $24.0\,dm^3\,mol^{-1}$]

(i) Use these data to calculate the final oxidation state of vanadium.
You **must** show your working.

(5)

(ii) State the initial and final colours you would see as the chlorine bubbles through the aqueous vanadium(II) chloride, $VCl_2(aq)$.

(2)

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(Total for Question 3 = 18 marks)

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4 This question is about dissolving different compounds.

(a) Which of these compounds is the most soluble in water?

(1)

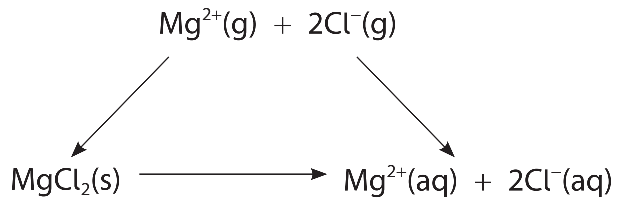
☒ **A** barium sulfate

☒ **B** calcium sulfate

☒ **C** magnesium sulfate

☒ **D** strontium sulfate

(b) What is the value, in kJ mol^{-1}, for the standard enthalpy change of solution of magnesium chloride?



Lattice energy $MgCl_2(s)$ = −2526 kJ mol^{-1}

Hydration enthalpy of $Cl^-(g)$ = − 381 kJ mol^{-1}

Hydration enthalpy of $Mg^{2+}(g)$ = −1921 kJ mol^{-1}

(1)

☒ **A** +157

☒ **B** −157

☒ **C** +224

☒ **D** −224

*(c) The solubility of two compounds in different solvents was investigated.
A summary of the findings is shown.

Compound	Soluble in water	Soluble in hexane
2-methylpentane	X	✓
potassium bromide	✓	X

Explain the findings of the investigation by considering the interactions between the compounds and each of the solvents.

(6)

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(Total for Question 4 = 8 marks)

5 This question is about the chemistry of hydrated magnesium nitrate, $Mg(NO_3)_2.xH_2O$.

(a) Group 2 nitrates decompose when heated.

(i) State **two** observations you would see when hydrated magnesium nitrate is heated.

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(ii) Explain the trend in thermal stability of Group 2 nitrates.

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(b) In an experiment, a sample of hydrated magnesium nitrate, $Mg(NO_3)_2.xH_2O$, with a mass of 0.765 g, was dissolved in water and reacted with an excess of sodium hydroxide solution, NaOH(aq).
The precipitate of magnesium hydroxide, $Mg(OH)_2$, produced was removed and dried. The mass of the dried sample was 0.174 g.

(i) Draw dot-and-cross diagrams for the ions in magnesium hydroxide.
Show the outer electrons only.

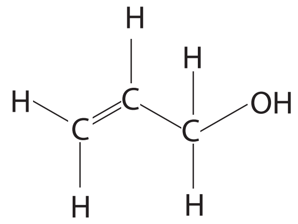
(2)

(ii) Use the experimental data to calculate the value for x in the formula $Mg(NO_3)_2.xH_2O$.
You **must** show all your working.

(5)

(Total for Question 5 = 12 marks)

6 Prop-2-en-1-ol is an unsaturated alcohol with the structure shown.



(a) A student planned to use bond enthalpy data to calculate a value for the enthalpy change of combustion of prop-2-en-1-ol.

(i) When researching the bond enthalpy data, the student claimed that it was not necessary to find the value for the C=C bond as they could use the value for a C–C bond and multiply it by two.
Explain why the student is **incorrect**.

(2)

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(ii) Calculate a value for the enthalpy of combustion of prop-2-en-1-ol using the data shown.

$$C_3H_6O(g) + 4O_2(g) \rightarrow 3CO_2(g) + 3H_2O(g)$$

Bond	C–C	C=C	C–O	C=O	O–H	C–H	O=O
Bond enthalpy / $kJ\ mol^{-1}$	347	612	358	805	464	413	498

(3)

(iii) Explain, in terms of entropy, why the combustion of prop-2-en-1-ol is always feasible in the gaseous state.

(2)

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(b) Chemists are researching a process to make ethanol and ethene directly from carbon dioxide and water.

$$4CO_2(g) + 5H_2O(l) \rightarrow CH_3CH_2OH(l) + C_2H_4(g) + 6O_2(g) \quad \Delta H^\ominus = +2778 \text{ kJ mol}^{-1}$$

	$CO_2(g)$	$H_2O(l)$	$CH_3CH_2OH(l)$	$C_2H_4(g)$	$O_2(g)$
$S^\ominus$ / J K^{-1} mol^{-1}	213.6	69.9	160.7	219.5	205.0

Calculate $\Delta S^\ominus_{total}$ for the reaction and hence determine whether the reaction is feasible under standard conditions.

(5)

(Total for Question 6 = 12 marks)

7 A mixture of ethanoic acid, ethanol and a catalyst was left for several days to reach equilibrium.

$$CH_3COOH(l) + CH_3CH_2OH(l) \rightleftharpoons CH_3COOCH_2CH_3(l) + H_2O(l)$$

The equilibrium constant, K_c, **under these conditions**, was 0.28.

(a) (i) Write the expression for the equilibrium constant, K_c.

(1)

(ii) The initial amounts of ethanol and ethanoic acid used were 1.2 mol of each reactant.

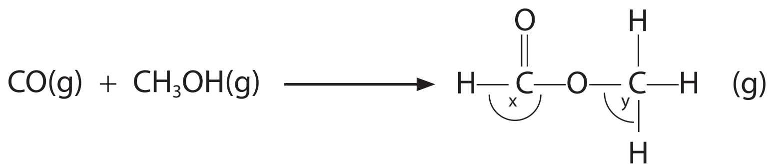
Use this information, your expression for the equilibrium constant, K_c, and the value for K_c, to find the amounts of each product at equilibrium, in moles.

(3)

Amount of $CH_3COOCH_2CH_3$ = ...

Amount of H_2O = ...

(b) Another ester, methyl methanoate, can be formed by the reaction between methanol and carbon monoxide in the gaseous phase.



(i) The two O–C–H bond angles, x and y, in the ester are approximately

(1)

☒ **A** 180° and 90°

☒ **B** 120° and 90°

☒ **C** 120° and 109.5°

☒ **D** 109.5° and 109.5°

(ii) The reaction often forms an equilibrium mixture.

Which could be the units for the equilibrium constant, K_p?

(1)

☒ **A** mol dm^{-3}

☒ **B** dm^{3} mol^{-1}

☒ **C** atm

☒ **D** atm^{-1}

(iii) Describe what effect, if any, increasing the pressure would have on the equilibrium constant, K_p. Justify your answer.

(2)

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(Total for Question 7 = 8 marks)

8 Tablets containing potassium manganate(VII), $KMnO_4$, are dissolved in water forming an antiseptic solution to treat skin conditions. The manufacturers claim that each tablet contains 400 mg of $KMnO_4$.

To check the claim, the titration procedure outlined was carried out.

- Five tablets were dissolved in distilled water to make 100.0 cm^3 of solution.
- Some of the $KMnO_4$ solution was used to fill a burette.
- 25.0 cm^3 of sodium ethanedioate solution, $Na_2C_2O_4(aq)$, of concentration 0.200 mol dm^{-3}, was added to a conical flask and warmed.
- Sulfuric acid, of concentration 2 mol dm^{-3}, was also added to the conical flask.
- The $KMnO_4$ solution was added to the flask from the burette, until the end-point.

The equation for the reaction between MnO_4^- ions from the $KMnO_4$ and $C_2O_4^{2-}$ ions from the sodium ethanedioate solution is shown.

$$16H^+(aq) + 2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

(a) Give the colour **change** at the end-point of the titration.

(1)

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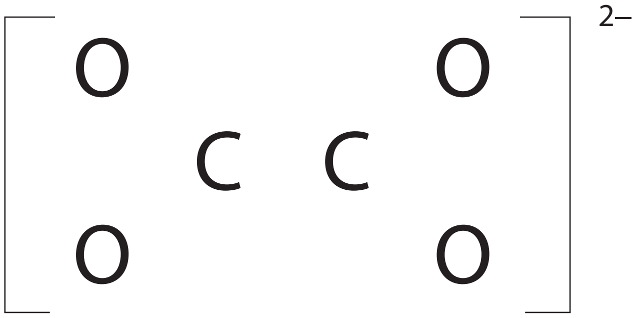
(b) (i) Complete the dot-and-cross diagram for the ethanedioate ion.
Show the outer electrons only.

(2)



(ii) Determine the oxidation number of carbon in the ethanedioate ion, $C_2O_4^{2-}$.

(1)

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(c) Give the reason why sulfuric acid was also added to the conical flask.

(1)

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(d) This redox reaction could be used in an electrochemical cell.

The cell half-equations are

$$2CO_2(g) + 2e^- \rightleftharpoons C_2O_4^{2-}(aq)$$

$$8H^+(aq) + MnO_4^-(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$$

Write a cell diagram for this cell using the conventional representation.

(2)

(e) The results of the titration are shown.

Run	Trial	1	2	3
Final volume / cm^3	17.50	34.10	17.20	34.10
Initial volume / cm^3	0.00	17.30	0.00	17.20
Titre / cm^3	17.50		17.20	
Concordant titres (✓)				
Mean titre / cm^3				

(i) Complete the table.

(2)

(ii) The equation for the reaction between MnO_4^- ions from the $KMnO_4$ and $C_2O_4^{2-}$ ions from the sodium ethanedioate solution is shown.

$$16H^+(aq) + 2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

Use this equation and your mean titre from (e)(i) to calculate the mass, in mg, of $KMnO_4$ in **one** tablet.

Give your answer to an appropriate number of significant figures.

(5)

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(iii) A textbook suggested the conical flask should be heated during the titration, as the reaction between the MnO_4^- ions and the $C_2O_4^{2-}$ ions is slow.

Use these electrode potentials and your knowledge of homogeneous catalysis to deduce why the heating is very important at the start of the titration, but less important as the titration proceeds. Justify your answer.
You may include equations in your justification.

Electrode system	$E^\ominus$ / V
$2CO_2(g) + 2e^- \rightleftharpoons C_2O_4^{2-}(aq)$	+0.64
$Mn^{3+}(aq) + e^- \rightleftharpoons Mn^{2+}(aq)$	+1.49
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51

(4)

(Total for Question 8 = 18 marks)

TOTAL FOR PAPER = 90 MARKS

The Periodic Table of Elements

Key

relative atomic mass
atomic symbol
name
atomic (proton) number

1.0
H
hydrogen
1

1	2											3	4	5	6	7	0 (8)
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*	*(15)*	*(16)*	*(17)*	*(18)*
																	4.0 **He** helium 2
6.9 **Li** lithium 3	9.0 **Be** beryllium 4											10.8 **B** boron 5	12.0 **C** carbon 6	14.0 **N** nitrogen 7	16.0 **O** oxygen 8	19.0 **F** fluorine 9	20.2 **Ne** neon 10
23.0 **Na** sodium 11	24.3 **Mg** magnesium 12											27.0 **Al** aluminium 13	28.1 **Si** silicon 14	31.0 **P** phosphorus 15	32.1 **S** sulfur 16	35.5 **Cl** chlorine 17	39.9 **Ar** argon 18
39.1 **K** potassium 19	40.1 **Ca** calcium 20	45.0 **Sc** scandium 21	47.9 **Ti** titanium 22	50.9 **V** vanadium 23	52.0 **Cr** chromium 24	54.9 **Mn** manganese 25	55.8 **Fe** iron 26	58.9 **Co** cobalt 27	58.7 **Ni** nickel 28	63.5 **Cu** copper 29	65.4 **Zn** zinc 30	69.7 **Ga** gallium 31	72.6 **Ge** germanium 32	74.9 **As** arsenic 33	79.0 **Se** selenium 34	79.9 **Br** bromine 35	83.8 **Kr** krypton 36
85.5 **Rb** rubidium 37	87.6 **Sr** strontium 38	88.9 **Y** yttrium 39	91.2 **Zr** zirconium 40	92.9 **Nb** niobium 41	95.9 **Mo** molybdenum 42	[98] **Tc** technetium 43	101.1 **Ru** ruthenium 44	102.9 **Rh** rhodium 45	106.4 **Pd** palladium 46	107.9 **Ag** silver 47	112.4 **Cd** cadmium 48	114.8 **In** indium 49	118.7 **Sn** tin 50	121.8 **Sb** antimony 51	127.6 **Te** tellurium 52	126.9 **I** iodine 53	131.3 **Xe** xenon 54
132.9 **Cs** caesium 55	137.3 **Ba** barium 56	138.9 **La*** lanthanum 57	178.5 **Hf** hafnium 72	180.9 **Ta** tantalum 73	183.8 **W** tungsten 74	186.2 **Re** rhenium 75	190.2 **Os** osmium 76	192.2 **Ir** iridium 77	195.1 **Pt** platinum 78	197.0 **Au** gold 79	200.6 **Hg** mercury 80	204.4 **Tl** thallium 81	207.2 **Pb** lead 82	209.0 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
[223] **Fr** francium 87	[226] **Ra** radium 88	[227] **Ac*** actinium 89	[261] **Rf** rutherfordium 104	[262] **Db** dubnium 105	[266] **Sg** seaborgium 106	[264] **Bh** bohrium 107	[277] **Hs** hassium 108	[268] **Mt** meitnerium 109	[271] **Ds** darmstadtium 110	[272] **Rg** roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

* Lanthanide series	140 **Ce** cerium 58	141 **Pr** praseodymium 59	144 **Nd** neodymium 60	[147] **Pm** promethium 61	150 **Sm** samarium 62	152 **Eu** europium 63	157 **Gd** gadolinium 64	159 **Tb** terbium 65	163 **Dy** dysprosium 66	165 **Ho** holmium 67	167 **Er** erbium 68	169 **Tm** thulium 69	173 **Yb** ytterbium 70	175 **Lu** lutetium 71
* Actinide series	232 **Th** thorium 90	[231] **Pa** protactinium 91	238 **U** uranium 92	[237] **Np** neptunium 93	[242] **Pu** plutonium 94	[243] **Am** americium 95	[247] **Cm** curium 96	[245] **Bk** berkelium 97	[251] **Cf** californium 98	[254] **Es** einsteinium 99	[253] **Fm** fermium 100	[256] **Md** mendelevium 101	[254] **No** nobelium 102	[257] **Lr** lawrencium 103