

QCE Chemistry Units 3&4

Paper 1

Student's Name: _____

Teacher's Name: _____

Time allowed

- Perusal time – 10 minutes
- Working time – 90 minutes

General instructions

- Answer all questions in this question and response booklet.
- QCAA-approved calculator permitted.
- Formula and data booklet provided.
- Planning paper will not be marked.

Section 1 (25 marks)

- 25 multiple choice questions

Section 2 (35 marks)

- 8 short response questions

Students are advised that this is a trial examination only and cannot in any way guarantee the content or the format of the 2021 QCE Chemistry Units 3&4 Written Examination.

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SECTION 1**Instructions**

- Choose the best answer for Questions 1–25.
- This section has 25 questions and is worth 25 marks.
- Use a 2B pencil to fill in the A, B, C or D answer bubble completely.
- If you change your mind or make a mistake, use an eraser to remove your response and fill in the new answer bubble completely.

	A	B	C	D
Example:	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

	A	B	C	D
1.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
13.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
14.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
15.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
16.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
17.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
18.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
19.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
20.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
21.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
22.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
23.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
24.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
25.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

SECTION 2**Instructions**

- Write using black or blue pen.
 - If you need more space for a response, use the additional pages at the back of this booklet.
 - On the additional pages, write the question number you are responding to.
 - Cancel any incorrect response by ruling a single diagonal line through your work.
 - Write the page number of your alternative/additional response, i.e. See page ...
 - If you do not do this, your original response will be marked.
 - This section has eight questions and is worth 35 marks.
-

QUESTION 26 (4 marks)

An aqueous solution containing 1.0 M copper(II) nitrate and 1.0 M magnesium nitrate was electrolysed using inert electrodes. It was found that pure copper metal was deposited on one electrode.

- a) At the other electrode, the pH of the electrolyte near the electrode decreased as the electrolysis proceeded.

Using a balanced half-equation, explain why this happened.

[2 marks]

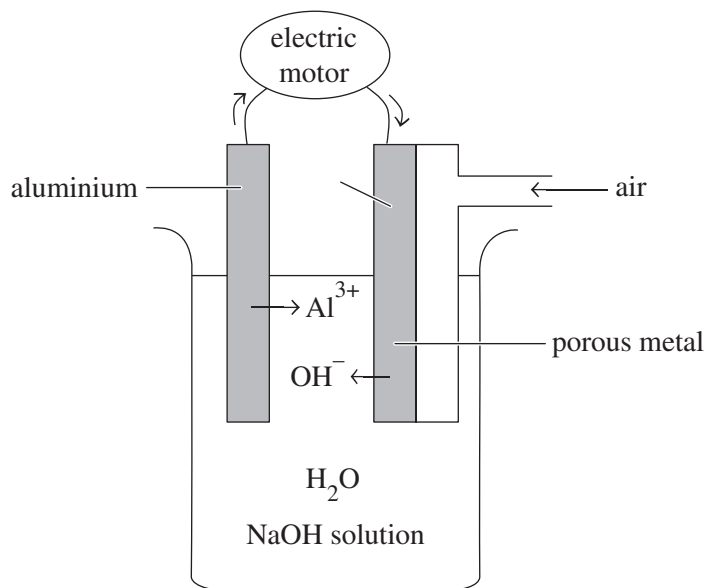
- b) No magnesium metal was deposited during the electrolysis.

Apply your understanding of the standard reduction potentials table to explain why magnesium metal could **not** be deposited in this type of electrolysis experiment.

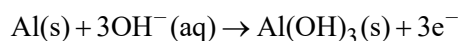
[2 marks]

QUESTION 27 (4 marks)

The aluminum–air battery is a promising power source for electric motor cars. The main features of the battery are shown below.



When the cell operates, the aluminum loses electrons and dissolves, forming aluminum hydroxide. The aluminum plate must be periodically replaced. One reaction in this cell is represented by the following half-equation.



- a) Identify the polarity (positive or negative) of the aluminium electrode. [1 mark]

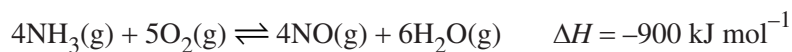
- b) Write a balanced half-equation for the reaction occurring at the surface of the porous metal where oxygen is reduced. [1 mark]

- c) i) Identify one way in which the aluminum–air battery resembles a fuel cell. [1 mark]

- ii) Identify one way in which the aluminum–air battery differs from a fuel cell. [1 mark]

QUESTION 28 (6 marks)

Ammonia gas reacts with oxygen gas according to the following chemical equation.



- a) In one experiment at a particular temperature, 0.300 mol of ammonia gas was mixed with 0.400 mol of oxygen gas in a sealed 2.00 L container and was allowed to reach equilibrium. 0.200 mol of nitrogen oxide gas was present in the equilibrium mixture. Calculate the amount (in mol) of NH_3 , O_2 and H_2O in the equilibrium mixture. Show your working. [3 marks]

Amount of NH_3 at equilibrium = _____ mol (to three significant figures)

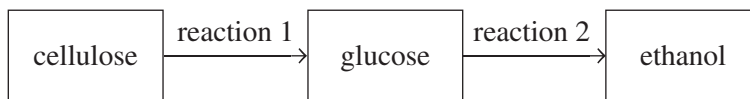
Amount of O_2 at equilibrium = _____ mol (to three significant figures)

Amount of H_2O at equilibrium = _____ mol (to three significant figures)

- b) Apply your understanding of Le Châtelier's principle to predict the effect that an increase in pressure would have on the position of equilibrium for this reaction. Explain your reasoning. [3 marks]

QUESTION 29 (4 marks)

The flow chart below shows a pathway for the production of ethanol.



- a) i) Identify a likely source of cellulose. *[1 mark]*

- ii) Identify the type of chemical reaction labelled as reaction 1 in the flow chart above. *[1 mark]*

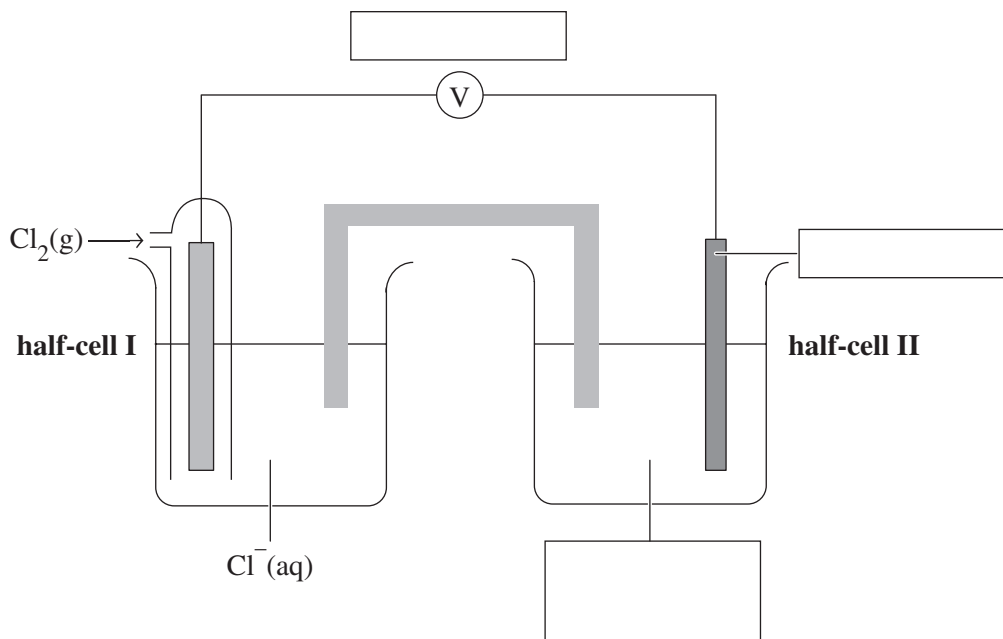
- b) Reaction 2 is known as fermentation and occurs in the presence of a yeast enzyme. Describe two characteristics of enzymes. *[2 marks]*

QUESTION 30 (4 marks)

Using equations, describe a reaction pathway for the two-step conversion of 1-bromopropane ($\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$) to 1-butanamine. Use semi-structural formulas for organic compounds and include inorganic reagents in your response.

QUESTION 31 (5 marks)

A student wanted to construct a galvanic cell under standard conditions with cell voltage of exactly 0.84 V, using the Cl_2/Cl^- half-cell. A partly labelled diagram of the planned cell is shown below.



- a) Calculate the standard reduction potential (E°) for half-cell II. [1 mark]

Standard reduction potential = _____ V (to two significant figures)

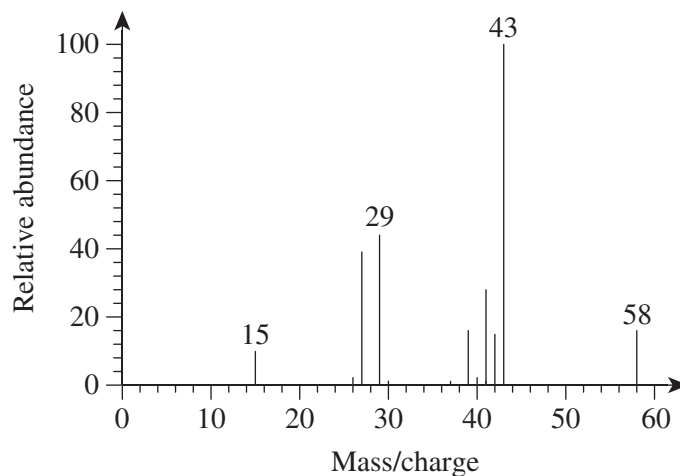
- b) Complete the diagram above by adding the following features. [3 marks]

- an arrow in the box directly above the voltmeter to indicate the direction of movement of electrons
- the composition of the electrolyte in half-cell II
- the composition of the electrode in half-cell II

- c) A salt bridge can be made using a piece of filter paper soaked in a particular liquid. Identify **one** property of the liquid that is required for its use in making a salt bridge. [1 mark]

QUESTION 32 (4 marks)

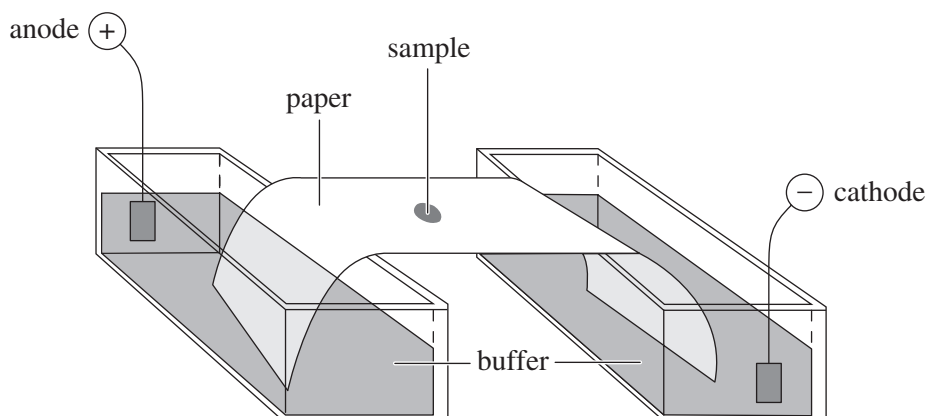
The simplified mass spectrum of a compound with empirical formula C_2H_5 is shown below.



Analyse the spectrum to deduce the semi-structural formula for the molecule. Explain your reasoning.

QUESTION 33 (4 marks)

Electrophoresis can be used to separate a mixture of amino acids containing valine. A sample of the mixture for separation is placed on a paper and an electric field is applied. This set-up is shown in the diagram below.



Valine migrates towards the anode (+) if the buffer solution has a high pH, and towards the cathode (-) if the buffer solution has a low pH.

Explain why this occurs.

END OF PAPER



Trial Examination 2021

Formula and data booklet

QCE Chemistry Units 3&4

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FORMULAS**Processing of data**

$$\text{Absolute uncertainty of the mean } \Delta\bar{x} = \pm \frac{(x_{\max} - x_{\min})}{2}$$

$$\text{Percentage uncertainty (\%)} = \frac{\text{absolute uncertainty}}{\text{measurement}} \times \frac{100}{1}$$

$$\text{Percentage error (\%)} = \left| \frac{\text{measured value} - \text{true value}}{\text{true value}} \right| \times 100$$

Chemical reactions – reactants, products and energy change

$$\Delta H = H_{(\text{products})} - H_{(\text{reactants})}$$

$$\Delta H = \Sigma(\text{bonds broken}) - \Sigma(\text{bonds formed})$$

$$Q = mc\Delta T$$

$$\text{Percentage yield (\%)} = \frac{\text{experimental yield}}{\text{theoretical yield}} \times \frac{100}{1}$$

Aqueous solutions and acidity

$$\text{Molarity} = \frac{\text{moles of solute (n)}}{\text{volume of solution (V)}}$$

Chemical equilibrium systems

$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b} \text{ for the reaction: } aA + bB \rightleftharpoons cC + dD$$

$$K_w = [H^+][OH^-]$$

$$\text{pH} = -\log_{10} [H^+]$$

$$\text{pOH} = -\log_{10} [OH^-]$$

$$K_w = K_a \times K_b$$

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

$$K_b = \frac{[BH^+][OH^-]}{[B]}$$

PHYSICAL CONSTANTS AND UNIT CONVERSIONS

Physical constants and unit conversions	
Absolute zero	$0 \text{ K} = -273^\circ\text{C}$
Atomic mass unit	$1 \text{ amu} = 1.66 \times 10^{-27} \text{ kg}$
Avogadro's constant	$N_{\text{A}} = 6.02 \times 10^{23} \text{ mol}^{-1}$
Ideal gas constant	$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
Ionic product constant for water (at 298 K)	$K_{\text{w}} = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$
Molar volume of an ideal gas (at STP)	$2.27 \times 10^{-2} \text{ m}^3 \text{ mol}^{-1} = 22.7 \text{ dm}^3 \text{ mol}^{-1}$
Specific heat capacity of water (at 298 K)	$c_{\text{w}} = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$
Standard temperature and pressure (STP)	273 K and 100 kPa
Volume and capacity conversions	$1 \text{ dm}^3 = 1 \times 10^{-3} \text{ m}^3 = 1 \times 10^3 \text{ cm}^3 = 1 \text{ L}$

LIST OF ELEMENTS

Name	Atomic no.	Symbol
Hydrogen	1	H
Helium	2	He
Lithium	3	Li
Beryllium	4	Be
Boron	5	B
Carbon	6	C
Nitrogen	7	N
Oxygen	8	O
Fluorine	9	F
Neon	10	Ne
Sodium	11	Na
Magnesium	12	Mg
Aluminium	13	Al
Silicon	14	Si
Phosphorus	15	P
Sulfur	16	S
Chlorine	17	Cl
Argon	18	Ar
Potassium	19	K
Calcium	20	Ca
Scandium	21	Sc
Titanium	22	Ti
Vanadium	23	V
Chromium	24	Cr
Manganese	25	Mn
Iron	26	Fe
Cobalt	27	Co
Nickel	28	Ni
Copper	29	Cu
Zinc	30	Zn
Gallium	31	Ga
Germanium	32	Ge
Arsenic	33	As
Selenium	34	Se
Bromine	35	Br

Name	Atomic no.	Symbol
Krypton	36	Kr
Rubidium	37	Rb
Strontium	38	Sr
Yttrium	39	Y
Zirconium	40	Zr
Niobium	41	Nb
Molybdenum	42	Mo
Technetium	43	Tc
Ruthenium	44	Ru
Rhodium	45	Rh
Palladium	46	Pd
Silver	47	Ag
Cadmium	48	Cd
Indium	49	In
Tin	50	Sn
Antimony	51	Sb
Tellurium	52	Te
Iodine	53	I
Xenon	54	Xe
Cesium	55	Cs
Barium	56	Ba
Lanthanum	57	La
Cerium	58	Ce
Praseodymium	59	Pr
Neodymium	60	Nd
Promethium	61	Pm
Samarium	62	Sm
Europium	63	Eu
Gadolinium	64	Gd
Terbium	65	Tb
Dysprosium	66	Dy
Holmium	67	Ho
Erbium	68	Er
Thulium	69	Tm
Ytterbium	70	Yb

LIST OF ELEMENTS (CONTINUED)

Name	Atomic no.	Symbol
Lutetium	71	Lu
Hafnium	72	Hf
Tantalum	73	Ta
Tungsten	74	W
Rhenium	75	Re
Osmium	76	Os
Iridium	77	Ir
Platinum	78	Pt
Gold	79	Au
Mercury	80	Hg
Thallium	81	Tl
Lead	82	Pb
Bismuth	83	Bi
Polonium	84	Po
Astatine	85	At
Radon	86	Rn
Francium	87	Fr
Radium	88	Ra
Actinium	89	Ac
Thorium	90	Th
Protactinium	91	Pa
Uranium	92	U
Neptunium	93	Np
Plutonium	94	Pu

Name	Atomic no.	Symbol
Americium	95	Am
Curium	96	Cm
Berkelium	97	Bk
Californium	98	Cf
Einsteinium	99	Es
Fermium	100	Fm
Mendelevium	101	Md
Nobelium	102	No
Lawrencium	103	Lr
Rutherfordium	104	Rf
Dubnium	105	Db
Seaborgium	106	Sg
Bohrium	107	Bh
Hassium	108	Hs
Meitnerium	109	Mt
Darmstadtium	110	Ds
Roentgenium	111	Rg
Copernicium	112	Cn
Nihonium	113	Nh
Flerovium	114	Fl
Moscovium	115	Mc
Livermorium	116	Lv
Tennessine	117	Ts
Oganesson	118	Og

PERIODIC TABLE OF THE ELEMENTS

		KEY																
		1 atomic number																
		H symbol																
		1.01 relative atomic mass*																
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
H 1.01	He 4.00	Li 6.94	Be 9.01	B 10.81	C 12.01	N 14.01	O 16.00	F 19.00	Ne 20.18	Na 22.99	Mg 24.31	Al 26.98	Si 28.09	P 30.97	S 32.06	Cl 35.45	Ar 39.95	
K 39.10	Ca 40.08	Sc 44.96	Ti 47.87	V 50.94	Cr 52.00	Mn 54.94	Fe 55.85	Co 58.93	Ni 58.69	Cu 63.55	Zn 65.38	Ga 69.72	Ge 72.63	As 74.92	Se 78.97	Br 79.90	Kr 83.80	
Rb 85.47	Sr 87.62	Y 88.91	Zr 91.22	Nb 92.91	Mo 95.95	Tc (98.91)	Ru 101.07	Rh 102.91	Pd 106.42	Ag 107.87	Cd 112.41	In 114.82	Sn 118.71	Sb 121.76	Te 127.60	I 126.90	Xe 131.29	
Cs 132.91	Ba 137.33	Lanthanoids 57-71	Hf 178.49	Ta 180.95	W 183.84	Re 186.21	Os 190.23	Ir 192.22	Pt 195.08	Au 196.97	Hg 200.59	Tl 204.38	Pb 207.2	Bi 208.98	Po (210.0)	At (210.0)	Rn (222.0)	
Fr (223.0)	Ra (226.1)	Actinoids 89-103	Rf (261.1)	Db (262.1)	Sg (263.1)	Bh (264.1)	Hs (265.1)	Mt (268)	Ds (281)	Rg (272)	Cn (285)	Nh (284)	Fl (289)	Mc (288)	Lv (293)	Ts (294)	Og (294)	
			Lanthanoids															
			57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	
			La 138.91	Ce 140.12	Pr 140.91	Nd 144.24	Pm (146.9)	Sm 150.36	Eu 151.96	Gd 157.25	Tb 158.93	Dy 162.50	Ho 164.93	Er 167.26	Tm 168.93	Yb 173.05	Lu 174.97	
			Actinoids															
			89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	
			Ac (227.0)	Th 232.0	Pa 231.0	U 238.0	Np (237.0)	Pu (239.1)	Am (241.1)	Cm (244.1)	Bk (249.1)	Cf (252.1)	Es (252.1)	Fm (252.1)	Md (258.1)	No (259.1)	Lr (262.1)	

Groups are numbered according to IUPAC convention 1-18.
*Values in brackets are for the isotope with the longest half-life.

ATOMIC AND IONIC RADII OF SELECTED ELEMENTS

		KEY																																																																																	
		atomic number																																																																																	
		symbol																																																																																	
		atomic radius (10^{-12} m)																																																																																	
		charge of ion																																																																																	
		ionic radius (10^{-12} m)																																																																																	
		atomic number																																																																																	
		symbol																																																																																	
		atomic radius (10^{-12} m)																																																																																	
		charge of ion																																																																																	
1	H 1 32 208 (1-)	2	Be 4 99 45 (2+)	3	Li 3 130 76 (1+)	4	Na 11 160 102 (1+)	5	Mg 12 140 72 (2+)	6	K 19 200 138 (1+)	7	Ca 20 174 100 (2+)	8	Rb 37 215 152 (1+)	9	Sr 38 190 118 (2+)	10	Ba 56 206 135 (2+)	11	Sc 21 159 75 (3+)	12	Ti 22 148 86 (2+)	13	V 23 144 79 (2+)	14	Cr 24 130 62 (3+)	15	Mn 25 129 83 (2+)	16	Fe 26 124 78 (2+)	17	Co 27 118 74 (2+)	18	Ni 28 117 69 (2+)	19	Cu 29 122 77 (1+)	20	Zn 30 120 74 (2+)	21	Ga 31 123 62 (3+)	22	Ge 32 120 53 (4+)	23	As 33 120 58 (3+)	24	Se 34 118 188 (2-)	25	Br 35 117 196 (1-)	26	Kr 36 116	27	Y 39 176 90 (3+)	28	Zr 40 164 72 (4+)	29	Nb 41 156 64 (5+)	30	Mo 42 148 65 (4+)	31	Tc 43 138 65 (4+)	32	Ru 44 136 62 (4+)	33	Rh 45 134 67 (3+)	34	Pd 46 130 86 (2+)	35	Ag 47 136 115 (1+)	36	Cd 48 140 95 (2+)	37	In 49 142 80 (3+)	38	Sn 50 140 69 (4+)	39	Sb 51 140 76 (3+)	40	Te 52 137 221 (2-)	41	I 53 136 220 (1-)	42	Xe 54 136

Groups are numbered according to IUPAC convention 1–18.

ELECTRONEGATIVITIES AND FIRST IONISATION ENERGIES OF SELECTED ELEMENTS

1											13	14	15	16	17	18	
1 H 2.2 1318											5 B 2.0 807	6 C 2.6 1093	7 N 3.0 1407	8 O 3.4 1320	9 F 4.0 1687	2 He 2379	
3 Li 1.0 526	4 Be 1.6 906											13 Al 1.6 584	14 Si 1.9 793	15 P 2.2 1018	16 S 2.6 1006	17 Cl 3.2 1257	10 Ne 2087
11 Na 0.9 502	12 Mg 1.3 744											31 Ga 1.8 585	32 Ge 2.0 768	33 As 2.2 953	34 Se 2.6 947	18 Ar 1527	
19 K 0.8 425	20 Ca 1.0 596	3	4	5	6	7	8	9	10	11	12	30 Zn 1.7 913	35 Br 3.0 1146	36 Kr 2.9 1357			
37 Rb 0.8 409	38 Sr 1.0 556	21 Sc 1.4 637	22 Ti 1.5 664	23 V 1.6 656	24 Cr 1.7 659	25 Mn 1.6 724	26 Fe 1.8 766	27 Co 1.9 765	28 Ni 1.9 743	29 Cu 1.9 752	30 Zn 1.7 913	47 Ag 1.9 737	51 Sb 2.1 840	52 Te 2.1 876	53 I 2.7 1015		
55 Cs 0.8 382	56 Ba 0.9 509	39 Y 1.2 606	40 Zr 1.3 666	41 Nb 1.6 670	42 Mo 2.2 691	43 Tc 1.9 708	44 Ru 2.2 717	45 Rh 2.3 726	46 Pd 2.2 811	47 Ag 1.9 737	48 Cd 1.7 874	50 Sn 2.0 715	54 Xe 2.6 1177				

KEY

1	atomic number
H	symbol
2.2	electronegativity
1318	first ionisation enthalpies (kJ mol ⁻¹)

Groups are numbered according to IUPAC convention 1–18.

SOLUBILITY OF SELECTED COMPOUNDS AT 298 K

	bromide	carbonate	chloride	hydroxide	iodide	nitrate	oxide	phosphate	sulfate
aluminium	s	–	s	i	s	s	i	i	s
ammonium	s	s	s	s	s	s	–	s	s
barium	s	i	s	s	s	s	s	i	i
calcium	s	i	s	p	s	s	p	i	p
cobalt(II)	s	i	s	i	s	s	i	i	s
copper(II)	s	–	s	i	i	s	i	i	s
iron(II)	s	i	s	i	s	s	i	i	s
iron(III)	s	–	s	i	s	s	i	i	s
lead(II)	p	i	s	i	i	s	i	i	i
lithium	s	s	s	s	s	s	s	–	s
magnesium	s	i	s	i	s	s	i	p	s
manganese(II)	s	i	s	i	s	s	i	p	s
potassium	s	s	s	s	s	s	s	s	s
silver	i	i	i	i	i	s	i	i	p
sodium	s	s	s	s	s	s	s	s	s
zinc	s	i	s	i	s	s	i	i	s

Key

Abbreviation	Explanation
s	soluble in water (solubility greater than 10 g L ⁻¹)
p	partially soluble in water (solubility between 1 and 10 g L ⁻¹)
i	insoluble in water (solubility less than 1 g L ⁻¹)
–	no data


AVERAGE BOND ENTHALPIES AT 298 K**Single bonds**

	ΔH (kJ mol ⁻¹)								
	H	C	N	O	F	S	Cl	Br	I
H	436								
C	414	346							
N	391	286	158						
O	463	358	214	144					
F	567	492	278	191	159				
S	364	289			327	266			
Cl	431	324	192	206	255	271	242		
Br	366	285		201	249	218	219	193	
I	298	228		201	280		211	178	151

Multiple bonds

Bond	ΔH (kJ mol ⁻¹)
C=C	614
C≡C	839
C=N	615
C≡N	890
C=O	804
N=N	470
N≡N	945
O=O	498

REACTIVITY SERIES OF METALS

Element	Reactivity
K	<p>most reactive</p>  <p>least reactive</p>
Na	
Li	
Ba	
Sr	
Ca	
Mg	
Al	
C*	
Mn	
Zn	
Cr	
Fe	
Cd	
Co	
Ni	
Sn	
Pb	
H ₂ *	
Sb	
Bi	
Cu	
Hg	
Ag	
Au	
Pt	

* Carbon (C) and hydrogen gas (H₂) added for comparison

STANDARD ELECTRODE POTENTIALS AT 298 K

Oxidised species \rightleftharpoons Reduced species	E° (V)
$\text{Li}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Li}(\text{s})$	-3.04
$\text{K}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{K}(\text{s})$	-2.94
$\text{Ba}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ba}(\text{s})$	-2.91
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ca}(\text{s})$	-2.87
$\text{Na}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Na}(\text{s})$	-2.71
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg}(\text{s})$	-2.36
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Al}(\text{s})$	-1.68
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mn}(\text{s})$	-1.18
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$	-0.83
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni}(\text{s})$	-0.24
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}(\text{s})$	-0.14
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}(\text{s})$	-0.13
$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g})$	0.00
$\text{Cu}^{2+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Cu}^+(\text{aq})$	+0.16
$\text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{SO}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$	+0.16
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightleftharpoons 4\text{OH}^-(\text{aq})$	+0.40
$\text{Cu}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.52
$\text{I}_2(\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{I}^-(\text{aq})$	+0.54
$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-(\text{aq})$	+1.08
$\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Cl}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-(\text{aq})$	+1.36
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	+1.36
$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51
$\text{F}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{F}^-(\text{aq})$	+2.89

COMMON AMINO ACIDS

Common name (symbol)	Structural formula	pH of isoelectric point	Common name (symbol)	Structural formula	pH of isoelectric point
Alanine (Ala)	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_3 \end{array}$	6.1	Arginine (Arg)	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{NH} \\ \\ \text{C}=\text{NH} \\ \\ \text{NH}_2 \end{array}$	10.7
Asparagine (Asn)	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{C}=\text{O} \\ \\ \text{NH}_2 \end{array}$	5.4	Aspartic acid (Asp)	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{C}=\text{O} \\ \\ \text{OH} \end{array}$	3.0
Cysteine (Cys)	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{SH} \end{array}$	5.1	Glutamic acid (Glu)	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{C}=\text{O} \\ \\ \text{OH} \end{array}$	3.2
Glutamine (Gln)	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{C}=\text{O} \\ \\ \text{NH}_2 \end{array}$	5.7	Glycine (Gly)	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$	6.1

COMMON AMINO ACIDS (continued)

Common name (symbol)	Structural formula	pH of isoelectric point	Common name (symbol)	Structural formula	pH of isoelectric point
Histidine (His)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{N} \quad \text{NH} \\ \diagup \quad \diagdown \\ \text{C} \\ \diagdown \quad \diagup \\ \text{N} \end{array} $	7.6	Isoleucine (Ile)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CHCH}_3 \\ \\ \text{CH}_2 \\ \\ \text{CH}_3 \end{array} $	6.0
Leucine (Leu)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{CHCH}_3 \\ \\ \text{CH}_3 \end{array} $	6.0	Lysine (Lys)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{NH}_2 \end{array} $	9.7
Methionine (Met)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{S} \\ \\ \text{CH}_3 \end{array} $	5.7	Phenylalanine (Phe)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{C}_6\text{H}_5 \end{array} $	5.7
Proline (Pro)	$ \begin{array}{c} \text{O} \\ \\ \text{C}-\text{OH} \\ \\ \text{HN} \\ \diagup \quad \diagdown \\ \text{C} \\ \diagdown \quad \diagup \\ \text{C} \\ \diagup \quad \diagdown \\ \text{C} \\ \diagdown \quad \diagup \\ \text{C} \end{array} $	6.3	Serine (Ser)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{OH} \end{array} $	5.7

COMMON AMINO ACIDS (continued)

Common name (symbol)	Structural formula	pH of isoelectric point	Common name (symbol)	Structural formula	pH of isoelectric point
Threonine (Thr)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CHOH} \\ \\ \text{CH}_3 \end{array} $	5.6	Tryptophan (Trp)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{HN} \text{---} \text{Indole ring} \end{array} $	5.9
Tyrosine (Tyr)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CH}_2 \\ \\ \text{C}_6\text{H}_4 \\ \\ \text{OH} \end{array} $	5.7	Valine (Val)	$ \begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}_2\text{N}-\text{C}-\text{C}-\text{OH} \\ \\ \text{CHCH}_3 \\ \\ \text{CH}_3 \end{array} $	6.0

ACID-BASE INDICATORS

Name	pKa	pH range of colour change	Colour change (acidic to basic)
Methyl orange	3.7	3.1–4.4	red to yellow
Bromophenol blue	4.2	3.0–4.6	yellow to blue
Bromocresol green	4.7	3.8–5.4	yellow to blue
Methyl red	5.1	4.4–6.2	pink to yellow
Bromothymol blue	7.0	6.0–7.6	yellow to blue
Phenol red	7.9	6.8–8.4	yellow to red
Phenolphthalein	9.6	8.3–10.0	colourless to pink

INFRARED DATA

The table below shows the characteristic range of infrared absorption due to stretching in organic molecules.

Bond	Organic molecules	Wavelength (cm^{-1})
C–I	iodoalkanes	490–620
C–Br	bromoalkanes	500–600
C–Cl	chloroalkanes	600–800
C–F	fluoroalkanes	1000–1400
C–O	alcohol, ester	1050–1410
C=C	alkenes	1620–1680
C=O	aldehydes, carboxylic acid, ester, ketones	1700–1750
C≡C	alkynes	2100–2260
O–H	carboxylic acids (hydrogen-bonded)	2500–3000
C–H	alkanes, alkenes, alkynes, aldehydes, amides	2720–3100
O–H	alcohol (hydrogen-bonded)	3200–3600
N–H	amines	3300–3500

FORMULAS AND CHARGES FOR COMMON POLYATOMIC IONS

Anions		Cations	
acetate (ethanoate)	CH_3COO^- or $\text{C}_2\text{H}_3\text{O}_2^-$	ammonium	NH_4^+
carbonate	CO_3^{2-}	hydronium	H_3O^+
chlorate	ClO_3^-		
chlorite	ClO_2^-		
chromate	CrO_4^{2-}		
citrate	$\text{C}_6\text{H}_5\text{O}_7^{3-}$		
cyanide	CN^-		
dichromate	$\text{Cr}_2\text{O}_7^{2-}$		
dihydrogen phosphate	H_2PO_4^-		
hypochlorite	ClO^-		
hydrogen carbonate	HCO_3^-		
hydrogen sulfate	HSO_4^-		
hydrogen phosphate	HPO_4^{2-}		
hydroxide	OH^-		
nitrate	NO_3^-		
nitrite	NO_2^-		
perchlorate	ClO_4^-		
permanganate	MnO_4^-		
peroxide	O_2^{2-}		
phosphate	PO_4^{3-}		
sulfate	SO_4^{2-}		
sulfite	SO_3^{2-}		
thiosulfate	$\text{S}_2\text{O}_3^{2-}$		

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