Neap

Trial Examination 2021

Question and response booklet

QCE Chemistry Units 3&4

Paper 2

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.
- Write using black or blue pen.
- QCAA-approved calculator permitted.
- Formula and data booklet provided.
- Planning paper will not be marked.

Section 1 (65 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

- 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.

DO NOT WRITE ON THIS PAGE

THIS PAGE WILL NOT BE MARKED

QUESTION 1 (7 marks)

A synthesis experiment was conducted in which 4.50 g of $CH_3CH_2CH_2COOH$ (M = 88.0 g mol^{-1}) was heated with an excess of $CH_3CH_2CH_2OH$ (M = 60.0 g mol^{-1}) in the presence of a sulfuric acid catalyst. The mass of the ester (M = 130 g mol^{-1}) produced was 5.32 g.

a) Apply IUPAC rules to name the ester produced in this reaction. *[1 mark]*

____

b) Calculate the atom economy for this reaction. Show your working. *[2 marks]*

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____

Atom economy = ____________________ % (to three significant figures)

c) Calculate the percentage yield for the ester synthesis. Show your working. *[4 marks]*

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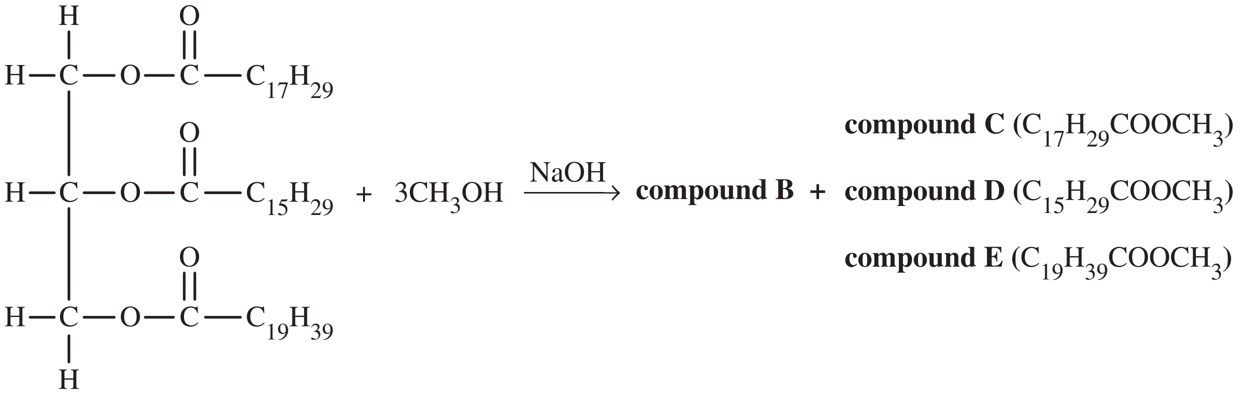
Percentage yield = ____________________ % (to three significant figures)

QUESTION 2 (7 marks)

In the presence of a sodium hydroxide (NaOH) catalyst, a transesterification reaction will occur between methanol and compound A to produce compound B and a mixture of methyl esters (C, D and E).
The mixture of methyl esters is known as biodiesel.



$+ \ 3CH_3OH \xrightarrow{NaOH}$ **compound B** + **compound C** ($C_{17}H_{29}COOCH_3$) **compound D** ($C_{15}H_{29}COOCH_3$) **compound E** ($C_{19}H_{39}COOCH_3$)

compound A

a) i) Identify the type of compound shown as compound A. *[1 mark]*

ii) Deduce the molecular formula of compound B. *[1 mark]*

iii) State which of the methyl esters (compund C, D or E) is derived from a polyunsaturated fatty acid. *[1 mark]*

b) When the transesterification process is conducted, the biodiesel must be extracted from the reaction mixture. To extract the biodiesel, a series of washing steps are used. The biodiesel remains in the upper organic layer, while the NaOH and unreacted methanol move into the lower aqueous layer.

i) In terms of the structure and bonding, explain why the biodiesel is **not** soluble in the aqueous layer of the washing process. *[2 marks]*

ii) In terms of the structure and bonding, explain why methanol is soluble in the aqueous layer of the washing process. *[2 marks]*

QUESTION 3 (8 marks)

Acrylic acid (CH_2CHCO_2H) is a precursor for many important plastics. The value of K_a for acrylic acid is 5.6×10^{-5}.

a) Draw the structural formula for a molecule of acrylic acid. *[1 mark]*

b) Calculate the pH of a 0.10 M solution of acrylic acid. Include the equation for the ionisation of acrylic acid, and state any assumptions made during your calculation. *[5 marks]*

pH = ____________________ % (to two significant figures)

c) 20.0 mL of a 0.10 M solution of acrylic acid was diluted by the addition of 5.0 mL of water.

Will the pH of the solution increase or decrease following the dilution? Explain your reasoning, including reference to any shift in the position of the ionisation equilibrium reaction. *[2 marks]*

QUESTION 4 (10 marks)

Molecular components of food may occur in various structural forms that differ in their properties.

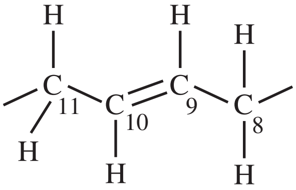
a) i) Monosaccharides may be classified as aldoses or ketoses.

Which of these classifications applies to glucose? *[1 mark]*

ii) Polymerisation of glucose molecules produces two forms of starch – amylose and amylopectin.

Compare amylose and amylopectin in terms of their structure and bonding. *[4 marks]*

b) Fatty acids with the molecular formula $C_{17}H_{33}COOH$ occur as two geometric isomers. Each of these compounds has one double bond at the ninth carbon in the chain. A section of a fatty acid chain with the double bond on the ninth carbon is shown below.



i) Is this section the *cis* or *trans* isomer? *[1 mark]*

ii) Draw the arrangement of the same atoms and bonds in the other fatty acid isomer. *[1 mark]*

c) Another fatty acid containing 18 carbon atoms has the formula $C_{17}H_{35}COOH$.

Describe a chemical test that could be used to distinguish between the two fatty acids $C_{17}H_{33}COOH$ and $C_{17}H_{35}COOH$, and outline the expected results of the test. *[3 marks]*

QUESTION 5 (8 marks)

The boiling points of three compounds are shown in the table below. The three compounds are all colourless liquids at room temperature.

Compound	ethanoic acid	butan-1-ol	butyl ethanoate
Boiling point (°C)	118	118	127

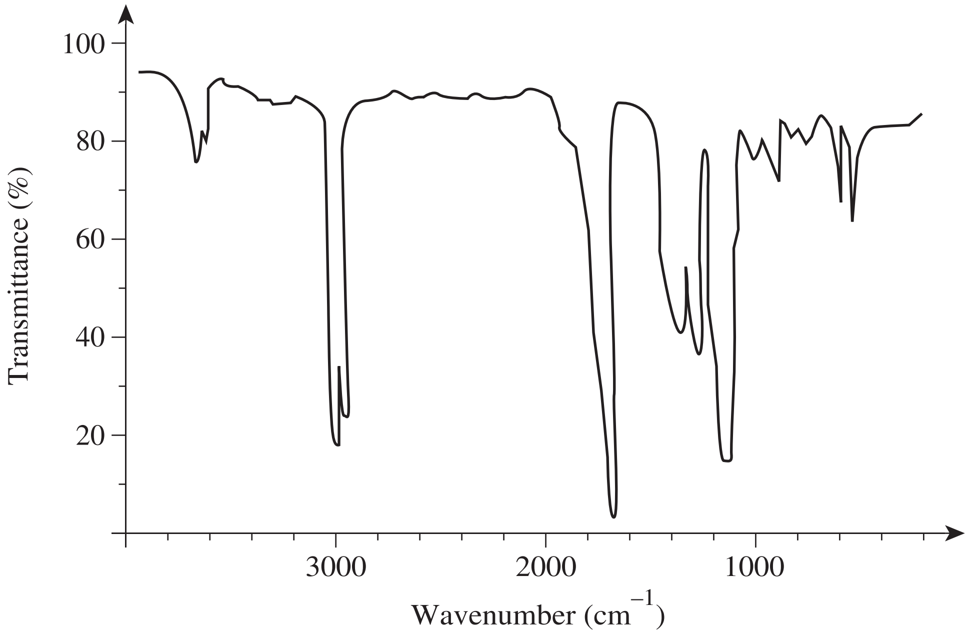
a) Outline how a simple chemical test could be used in a school laboratory to distinguish between ethanoic acid and butan-1-ol. *[2 marks]*

b) Draw the structure of the ester, showing all bonds. *[1 mark]*

c) Even though butan-1-ol is a smaller molecular compound than butyl ethanoate, their boiling points differ by only a small amount.

Explain this observation in terms of the structure and bonding of the compounds. *[3 marks]*

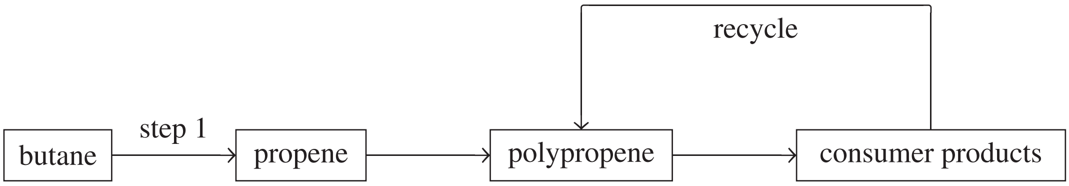
d) Butyl ethanoate is produced by reacting butan-1-ol and ethanoic acid. The reactants are heated under reflux with concentrated sulfuric acid as the catalyst. Following this reaction, a sample was isolated from the reaction mixture and produced the infrared spectrum shown below.



Analyse the data provided to show that the sample is **not** contaminated by either of the reactants. *[2 marks]*

QUESTION 6 (8 marks)

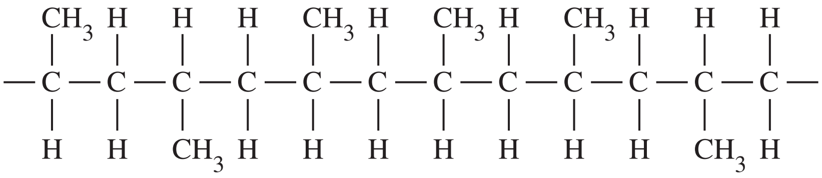
The main steps in the production of polymer products are shown in the flow chart below.



a) Give the formula of a compound from the same homologous series as butane that contains seven carbon atoms per molecule. *[1 mark]*

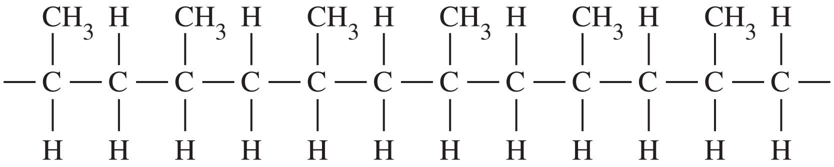
b) Polypropene is a linear polymer. Two forms of the polymer (type I and type II) are shown below.

Type I



$$\begin{array}{ccccccccccccccccccccccccc}
 & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & \\
 & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & \\
— & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — \\
 & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & \\
 & \mathrm{H} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} &
\end{array}$$

Type II



$$\begin{array}{ccccccccccccccccccccccccc}
 & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & \\
 & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & \\
— & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — & \mathrm{C} & — \\
 & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & & | & \\
 & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} &
\end{array}$$

Consider the polymer structures and their intermolecular bonding to deduce which type (I or II) is likely to melt at a higher temperature. Explain your reasoning. *[3 marks]*

c) i) Discuss one advantage of the use of polymer materials such as polypropene. *[2 marks]*

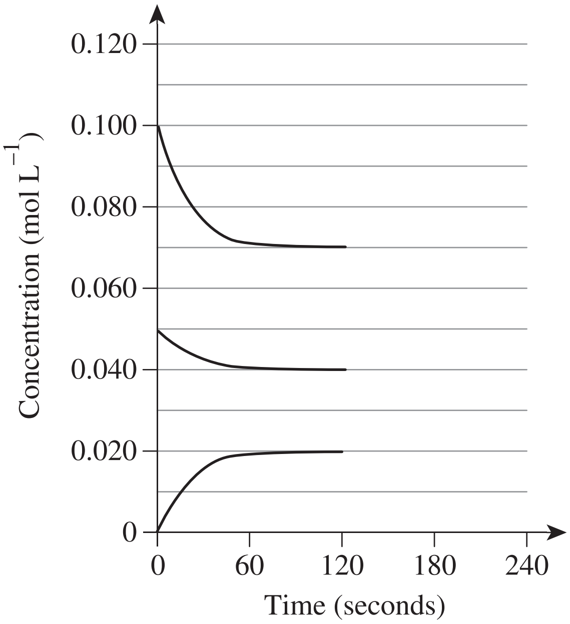
ii) Discuss one disadvantage of the use of polymer materials such as polypropene. *[2 marks]*

QUESTION 7 (9 marks)

0.100 mol of H_2(g) and 0.050 mol of N_2(g) were placed in a sealed 1.0 L container and allowed to come to equilibrium according to the following equation.

$$N_2(g) + 3H_2(g) \rightleftarrows 2NH_3(g)$$

The results from the experiment are shown in the graph below.



a) i) Write the equilibrium expression, K_c, for the reaction. *[1 mark]*

____

____

ii) Using the data from the graph, calculate the value of the equilibrium constant for the reaction. *[2 marks]*

____

____

____

Equilibrium constant = ______________________________ M^{-1} (to two significant figures)

b) i) At 120 seconds, the volume of the container was changed to 2.0 L, while maintaining a constant temperature.

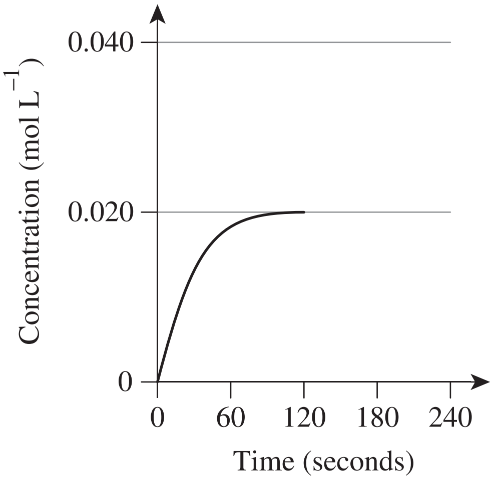
On the axes above, show the change to the concentration of ammonia at 120 seconds. *[2 marks]*

ii) Complete the table below to show the expected changes as the system returns to equilibrium between 120 and 180 seconds. Indicate your choices by placing a tick in one box in each column. *[2 marks]*

Shift in equilibrium position		**Effect on the value of K_c**	
to the product side	☐	increases	☐
to the reactant side	☐	decreases	☐
no change	☐	no change	☐

c) The original experiment was repeated under identical conditions except that a catalyst was present in the container.

On the enlarged graph below, sketch the effect of the catalyst on the concentration of NH_3 between 0 and 120 seconds. *[2 marks]*



QUESTION 8 (8 marks)

Lemon juice contains several acidic chemicals, including citric acid and vitamin C (ascorbic acid).

a) A student determined the citric acid content of a lemon juice sample using an acid–base titration. Citric acid is a weak, triprotic acid and reacts with sodium hydroxide according to the following equation.

$$C_6H_8O_7(aq) + 3NaOH(aq) \rightarrow Na_3C_6H_5O_7(aq) + 3H_2O(l)$$

2.00 mL of lemon juice was diluted to a total volume of 20.0 mL with distilled water. This 20.0 mL solution was titrated against a standardised 0.102 M sodium hydroxide solution. The average titre required was 14.6 mL. Note that $M(C_6H_8O_7) = 192 \text{ g mol}^{-1}$.

i) Calculate the concentration of citric acid in the undiluted lemon juice. *[5 marks]*

Concentration = ____________________ % m/v (to three significant figures)

ii) During the titration, the student incorrectly rinsed their burette with deionised water.

Deduce which of the following would occur as a result of the student's error. Indicate your response by placing a tick in one of the boxes. *[1 mark]*

The calculated level of citric acid would be higher than the true value.	☐
The calculated level of citric acid would be lower than the true value.	☐
There would be no effect on the calculated level of citric acid.	☐

b) The level of vitamin C in lemon juice can be determined using a redox titration with iodine. The reaction produces dehydroascorbic acid and iodide ions as its products, and starch is used as an indicator. The equation for the reaction is as follows.

$$C_6H_8O_6(aq) + I_2(aq) \rightarrow C_6H_6O_6(aq) + 2I^- + 2H^+(aq)$$

Deduce the oxidation half-equation for the reaction. *[1 mark]*

c) Assuming the titration is performed correctly, suggest why the result for citric acid concentration obtained by the acid–base titration described in a) will be an overestimate of the actual level of citric acid in the lemon juice. *[1 mark]*

END OF PAPER

ADDITIONAL PAGE FOR STUDENT RESPONSES

Write the question number you are responding to.

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Neap

Trial Examination 2021

Formula and data booklet

QCE Chemistry Units 3&4

ABN 43 634 499 791 91a Orrong Cres Caulfield North VIC 3161 Tel: (03) 9639 4318

FORMULAS

Processing of data

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

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

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

Chemical reactions – reactants, products and energy change

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

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

$Q = mc\Delta T$

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

Aqueous solutions and acidity

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

Chemical equilibrium systems

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

$K_\text{w} = [\text{H}^+][\text{OH}^-]$

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

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

$K_\text{w} = K_\text{a} \times K_\text{b}$

$K_\text{a} = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$

$K_\text{b} = \frac{[\text{BH}^+][\text{OH}^-]}{[\text{B}]}$

PHYSICAL CONSTANTS AND UNIT CONVERSIONS

Physical constants and unit conversions	
Absolute zero	$0\text{ K} = -273°\text{C}$
Atomic mass unit	$1\text{ amu} = 1.66 \times 10^{-27}\text{ kg}$
Avogadro's constant	$N_A = 6.02 \times 10^{23}\text{ mol}^{-1}$
Ideal gas constant	$R = 8.31\text{ J mol}^{-1}\text{ K}^{-1}$
Ionic product constant for water (at 298 K)	$K_w = 1.00 \times 10^{-14}\text{ mol}^2\text{ dm}^{-6}$
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)	$c_w = 4.18\text{ J g}^{-1}\text{ K}^{-1}$
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
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
Tellerium	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 **H** 1.01																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** (98.91)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57–71 Lanthanoids	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (210.0)	85 **At** (210.0)	86 **Rn** (222.0)
87 **Fr** (223.0)	88 **Ra** (226.1)	89–103 Actinoids	104 **Rf** (261.1)	105 **Db** (262.1)	106 **Sg** (263.1)	107 **Bh** (264.1)	108 **Hs** (265.1)	109 **Mt** (268)	110 **Ds** (281)	111 **Rg** (272)	112 **Cn** (285)	113 **Nh** (284)	114 **Fl** (289)	115 **Mc** (288)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

Lanthanoids

57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (146.9)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97

Actinoids

89 **Ac** (227.0)	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** (237.0)	94 **Pu** (239.1)	95 **Am** (241.1)	96 **Cm** (244.1)	97 **Bk** (249.1)	98 **Cf** (252.1)	99 **Es** (252.1)	100 **Fm** (252.1)	101 **Md** (258.1)	102 **No** (259.1)	103 **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

ionic radius (10^{-12} m)	Li 3 130 76 (1+)	atomic number symbol atomic radius (10^{-12} m) charge of ion

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H 1 32 208 (1–)																	**He** 2 37
Li 3 130 76 (1+)	**Be** 4 99 45 (2+)											**B** 5 84 27 (3+)	**C** 6 75 16 (4+)	**N** 7 71 146 (3–)	**O** 8 64 140 (2–)	**F** 9 60 133 (1–)	**Ne** 10 62
Na 11 160 102 (1+)	**Mg** 12 140 72 (2+)											**Al** 13 124 53 (3+)	**Si** 14 114 40 (4+)	**P** 15 109 38 (5+)	**S** 16 104 184 (2–)	**Cl** 17 100 181 (1–)	**Ar** 18 101
K 19 200 138 (1+)	**Ca** 20 174 100 (2+)	**Sc** 21 159 75 (3+)	**Ti** 22 148 86 (2+) 61 (4+)	**V** 23 144 79 (2+) 54 (5+)	**Cr** 24 130 62 (3+) 44 (6+)	**Mn** 25 129 83 (2+) 64 (3+)	**Fe** 26 124 78 (2+) 64 (3+)	**Co** 27 118 74 (2+) 61 (3+)	**Ni** 28 117 69 (2+) 60 (3+)	**Cu** 29 122 77 (1+) 73 (2+)	**Zn** 30 120 74 (2+)	**Ga** 31 123 62 (3+)	**Ge** 32 120 53 (4+) 272 (4–)	**As** 33 120 58 (3+) 46 (5+)	**Se** 34 118 198 (2–)	**Br** 35 117 196 (1–)	**Kr** 36 116
Rb 37 215 152 (1+)	**Sr** 38 190 118 (2+)	**Y** 39 176 90 (3+)	**Zr** 40 164 72 (4+)	**Nb** 41 156 64 (5+)	**Mo** 42 148 65 (4+)	**Tc** 43 138 65 (4+)	**Ru** 44 136 62 (4+)	**Rh** 45 134 67 (3+)	**Pd** 46 130 86 (2+)	**Ag** 47 136 115 (1+)	**Cd** 48 140 95 (2+)	**In** 49 142 80 (3+)	**Sn** 50 140 69 (4+)	**Sb** 51 140 76 (3+)	**Te** 52 137 221 (2–)	**I** 53 136 220 (1–)	**Xe** 54 136
Cs 55 238 167 (1+)	**Ba** 56 206 135 (2+)																

Groups are numbered according to IUPAC convention 1–18.

ELECTRONEGATIVITIES AND FIRST IONISATION ENERGIES OF SELECTED ELEMENTS

KEY

1	atomic number
H	symbol
2.2	electronegativity
1318	first ionisation enthalpies (kJ mol^{-1})

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 2.2 1318																	2 **He** 2379
3 **Li** 1.0 526	4 **Be** 1.6 906											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	10 **Ne** 2087
11 **Na** 0.9 502	12 **Mg** 1.3 744											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	18 **Ar** 1527
19 **K** 0.8 425	20 **Ca** 1.0 596	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	31 **Ga** 1.8 585	32 **Ge** 2.0 768	33 **As** 2.2 953	34 **Se** 2.6 947	35 **Br** 3.0 1146	36 **Kr** 2.9 1357
37 **Rb** 0.8 409	38 **Sr** 1.0 556	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	49 **In** 1.8 565	50 **Sn** 2.0 715	51 **Sb** 2.1 840	52 **Te** 2.1 876	53 **I** 2.7 1015	54 **Xe** 2.6 1177
55 **Cs** 0.8 382	56 **Ba** 0.9 509																

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

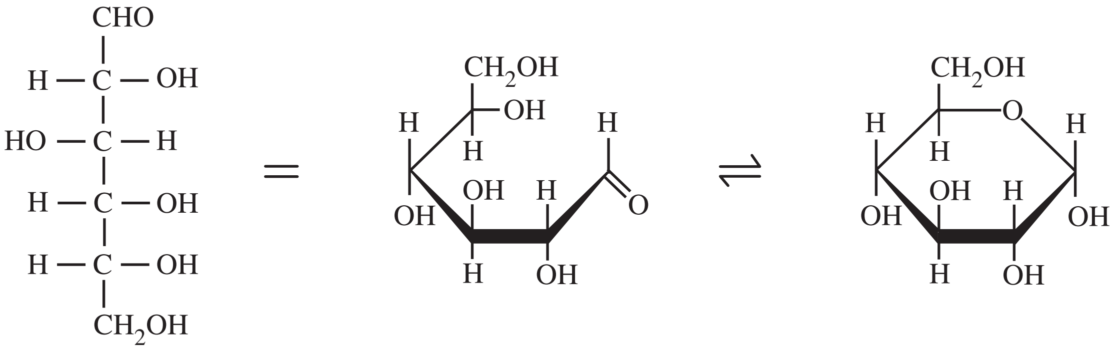
Element	Reactivity
K	most reactive
Na	
Li	
Ba	
Sr	
Ca	
Mg	
Al	
C*	
Mn	
Zn	
Cr	
Fe	
Cd	
Co	
Ni	
Sn	
Pb	
H_2*	
Sb	
Bi	
Cu	
Hg	
Ag	
Au	
Pt	least reactive

* Carbon (C) and hydrogen gas (H_2) added for comparison

STANDARD ELECTRODE POTENTIALS AT 298 K

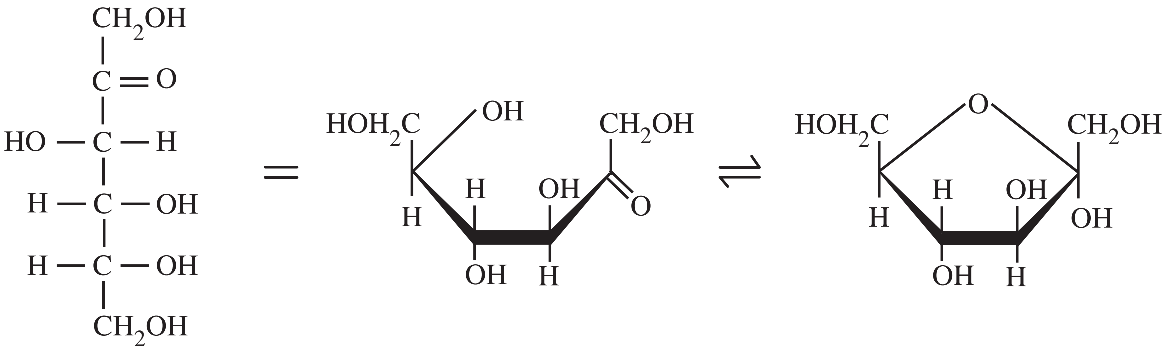
Oxidised species $\rightleftharpoons$ Reduced species	**E° (V)**
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	–3.04
$K^+(aq) + e^- \rightleftharpoons K(s)$	–2.94
$Ba^{2+}(aq) + 2e^- \rightleftharpoons Ba(s)$	–2.91
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	–2.87
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	–2.71
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	–2.36
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	–1.68
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	–1.18
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–0.44
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	–0.24
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	–0.14
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	–0.13
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Cu^{2+}(aq) + e^- \rightleftharpoons Cu^+(aq)$	+0.16
$SO_4{}^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons SO_2(aq) + 2H_2O(l)$	+0.16
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^+(aq) + e^- \rightleftharpoons Cu(s)$	+0.52
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.08
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$Cr_2O_7{}^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.36
$MnO_4{}^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.89

GLUCOSE AND FRUCTOSE: STRAIGHT CHAIN AND α-RING FORMS



straight chain D-glucose

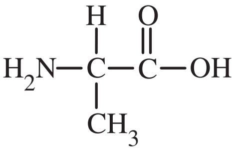
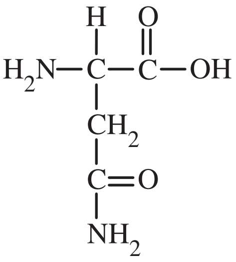
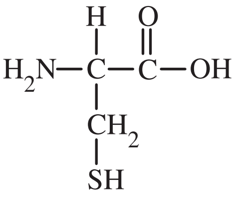
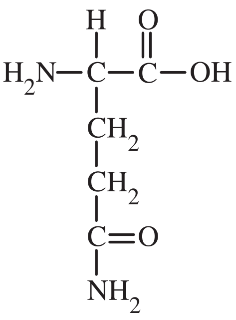
α-D-glucose

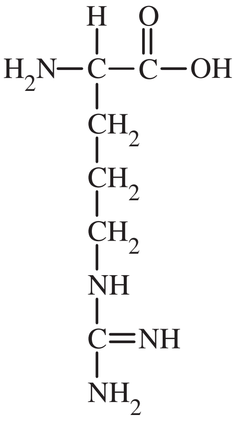
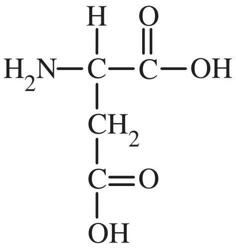
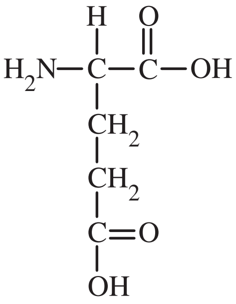
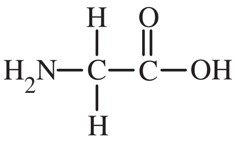


straight chain D-fructose

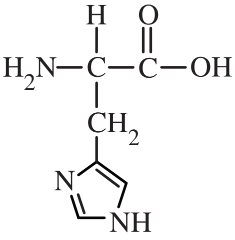
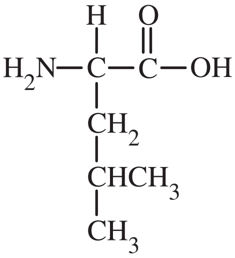
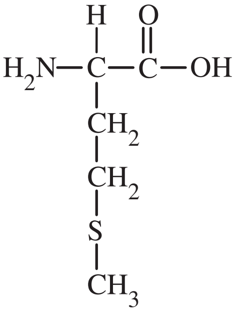
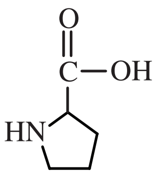
α-D-fructose

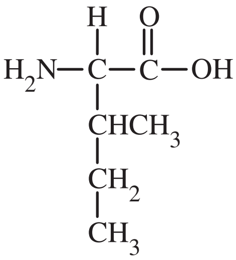
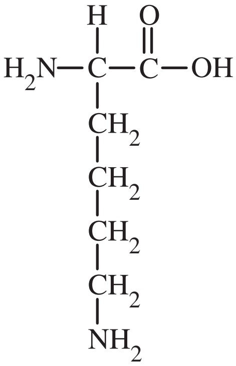
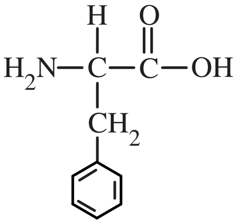
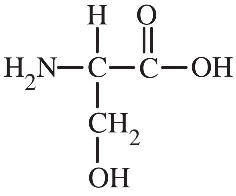
COMMON AMINO ACIDS

Common name (symbol)	Structural formula	pH of isoelectric point
Alanine (Ala)	 $H_2N-CH(CH_3)-COOH$	6.1
Asparagine (Asn)	 $H_2N-CH(CH_2CONH_2)-COOH$	5.4
Cysteine (Cys)	 $H_2N-CH(CH_2SH)-COOH$	5.1
Glutamine (Gln)	 $H_2N-CH(CH_2CH_2CONH_2)-COOH$	5.7

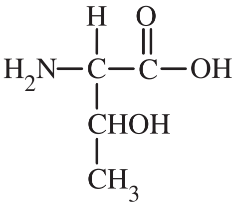
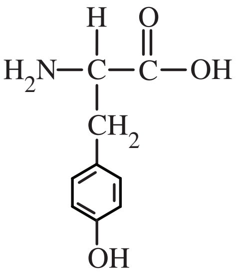
Common name (symbol)	Structural formula	pH of isoelectric point
Arginine (Arg)	 $H_2N-CH(CH_2CH_2CH_2NHC(=NH)NH_2)-COOH$	10.7
Aspartic acid (Asp)	 $H_2N-CH(CH_2COOH)-COOH$	3.0
Glutamic acid (Glu)	 $H_2N-CH(CH_2CH_2COOH)-COOH$	3.2
Glycine (Gly)	 H_2N-CH_2-COOH	6.1

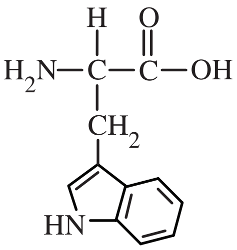
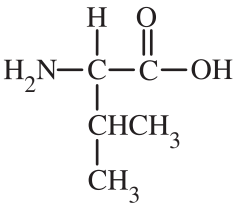
COMMON AMINO ACIDS (continued)

Common name (symbol)	Structural formula	pH of isoelectric point
Histidine (His)		7.6
Leucine (Leu)	 $H_2N-C(H)(CH_2-CHCH_3-CH_3)-C(=O)-OH$	6.0
Methionine (Met)	 $H_2N-C(H)(CH_2-CH_2-S-CH_3)-C(=O)-OH$	5.7
Proline (Pro)		6.3

Common name (symbol)	Structural formula	pH of isoelectric point
Isoleucine (Ile)	 $H_2N-C(H)(CHCH_3-CH_2-CH_3)-C(=O)-OH$	6.0
Lysine (Lys)	 $H_2N-C(H)(CH_2-CH_2-CH_2-CH_2-NH_2)-C(=O)-OH$	9.7
Phenylalanine (Phe)		5.7
Serine (Ser)	 $H_2N-C(H)(CH_2-OH)-C(=O)-OH$	5.7

COMMON AMINO ACIDS (continued)

Common name (symbol)	Structural formula	pH of isoelectric point
Threonine (Thr)	 $H_2N-\overset{H}{\underset{CHOH-CH_3}{C}}-\overset{O}{\overset{\|}{C}}-OH$	5.6
Tyrosine (Tyr)		5.7

Common name (symbol)	Structural formula	pH of isoelectric point
Tryptophan (Trp)		5.9
Valine (Val)	 $H_2N-\overset{H}{\underset{CHCH_3-CH_3}{C}}-\overset{O}{\overset{\|}{C}}-OH$	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	
acetate (ethanoate)	CH_3COO^- or $C_2H_3O_2^-$
carbonate	CO_3^{2-}
chlorate	ClO_3^-
chlorite	ClO_2^-
chromate	CrO_4^{2-}
citrate	$C_6H_5O_7^{3-}$
cyanide	CN^-
dichromate	$Cr_2O_7^{2-}$
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	$S_2O_3^{2-}$

Cations	
ammonium	NH_4^+
hydronium	H_3O^+

REFERENCES

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Haynes, WM (ed) 2016, *CRC Handbook of Chemistry and Physics*, 97th ed, CRC Press, Boca Raton, US.