Junior Chemistry Challenge
2024

Time allowed: 45 min

Instructions:

- Answer all the questions.
- Answer in blue or black ink.
- Diagrams and graphs should be drawn in pencil.
- The marks for each question are shown in brackets.
- Calculators are permitted.
- Do not start until you are instructed to do so.
- A Periodic Table is provided on the first page.

Name: _____ Year: _____

Question:	1	2	3	Total
Max:	10	15	15	40
Mark:				

1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.94	4 Be Beryllium 9.012											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.085	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078		21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.97	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62		39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium [97]	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 ln Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	53 Te Tellurium 127.60	53 I Iodine 126.904	54 Xe Xenon 131.293
55 Cs Cesium 132.905	56 Ba Barium 137.327	* 57 - 70	71 Lu Lutetium 174.967	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	78 lr Iridium 192.217	79 Pt Platinum 195.084	80 Au Gold 196.997	81 Hg Mercury 200.592	81 TI Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	** 89 - 102	103 Lr Lawrencium [262]	104 Rf Rutherfordium [267]	105 Db Dubnium [270]	106 Sg Seaborgium [269]	107 Bh Bohrium [270]	108 Hs Hassium [270]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [281]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [293]	118 Og Oganesson [294]

*Lanthanide series	57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium [145]	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.045
**Actinide series	89 Ac Actinium [227]	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium [237]	94 Pu Plutonium [244]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium [251]	99 Es Einsteinium [252]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [259]

1. Please circle the correct answer. There is **only one** correct answer to each question.

   (a) An oxide of copper has the formula Cu_xO_4 and contains only Cu^+, Cu^{2+}, and O^{2-} ions. What is smallest possible value of x? [1]

   A. 3

   B. 4

   C. 5

   D. 6

   E. 7

   (b) Which of the following atoms requires the smallest amount of energy to form a 1+ ion? [1]

   A. Li

   B. F

   C. He

   D. I

   E. Cs

   (c) One molecule of toluene needs to react with nine molecules of oxygen to undergo complete combustion. What is the molecular formula of toluene? [1]

   A. C_4H_6

   B. C_7H_8

   C. C_6H_{14}

   D. C_6H_6

   E. C_5H_{14}

   (d) On the pH scale, each unit on the scale represents a 10× dilution. For example, a solution of pH 2 is 10× more dilute than a solution of pH 1. [1]

   How many times more dilute is a solution of pH 1.5 compared a solution of pH 1?

   A. 0.5

   B. 5

   C. $\sqrt{10}$

   D. 1.5

   E. $10^{1.5}$

(e) The table below gives the boiling points of first three elements in Period 3.

Element	Boiling Point / °C
Na	883
Mg	1091
Al	2470

Which statement best explains this trend? [1]

A. The intermolecular forces get stronger from Na to Al and more energy is needed to overcome stronger intermolecular forces.

B. From Na to Al the metals get less reactive, so more energy is needed to boil them.

C. Al forms three bonds, Mg forms two, and Na forms one and more energy is needed to break more bonds.

D. From Na to Al an additional electron is lost to the delocalised electrons increasing the attraction between the electrons and the metal cations.

E. The atoms get heavier from Na to Al so more energy is need to make them move apart and boil.

(f) Which of the following is the formula of zinc sulphide? [1]

A. ZnS

B. $ZnSO_4$

C. Zn_2S

D. Zn_2SO_4

E. ZnS_2

(g) Consider the following reaction where a, b, c, and d are the smallest whole-numbers when this equation is balanced.

$$H_2SO_4 + a\ HI \longrightarrow b\ I_2 + c\ S + d\ H_2O$$

What is the value of b? [1]

A. 1

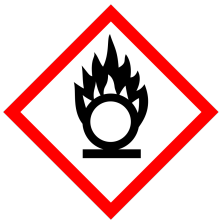
B. 2

C. 3

D. 4

E. 5

(h) Which of the following best describes this hazard symbol? [1]



A. Highly flammable.

B. Reacts vigorously with oxidising agents.

C. Explosive.

D. Extinguishes fires.

E. Reacts vigorously with reducing agents.

(i) A mixture of dyes were separated using paper chromatography. Dye X moved 1.2 cm up the chromatogram when the solvent moved 2.0 cm.

The experiment was repeated with the same mixture of dyes and the same solvent. This time the solvent moved 3.0 cm up the chromatogram.

How far did Dye X move in the second experiment? [1]

A. 1.2 cm

B. 1.8 cm

C. 0.8 cm

D. 2.0 cm

E. Cannot tell with the information given.

(j) Uranium is found as two isotopes: ^{235}U and ^{238}U. Part of the process to separate these two isotopes involves reacting uranium with fluorine to form uranium hexafluoride. To one decimal place, how much heavier is uranium-238 hexafluoride than uranium-235 hexafluoride? [1]

(A_r of F = 19)

A. 1.3%

B. 1.2%

C. 1.1%

D. 1.0%

E. 0.9%

Total for Question 1: 10

2. Many batteries are made by reacting metals together and allowing the electrons which transfer between them to go through a circuit, thus transforming their chemical energy into electrical energy.

   (a) Reactions which involve the transfer of electrons are called redox reactions. The element which loses electrons is oxidised and the element which gains electrons is reduced. These can be shown as 'half-equations', for example in the reaction between $Zn\,(s)$ and $CuSO_4\,(aq)$, which contains Cu^{2+} ions:

$$Zn\,(s) + Cu^{2+}\,(aq) \longrightarrow Zn^{2+}\,(aq) + Cu\,(s)$$

   Oxidation of Zn half-equation:

$$Zn\,(s) \longrightarrow Zn^{2+}\,(aq) + 2\,e^-$$

   Reduction of Cu^{2+} half-equation:

$$Cu^{2+}\,(aq) + 2\,e^- \longrightarrow Cu\,(s)$$

   In the following reactions give the two half-equations showing the reduction and oxidation taking place.

   i. $2\,Ag^+ + Mg \longrightarrow 2\,Ag + Mg^{2+}$ [2]

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   ii. $2\,Al + Fe_2O_3 \longrightarrow Al_2O_3 + 2\,Fe$ [2]

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   iii. $2\,Na + 2\,H_2O \longrightarrow 2\,NaOH + H_2$ [2]

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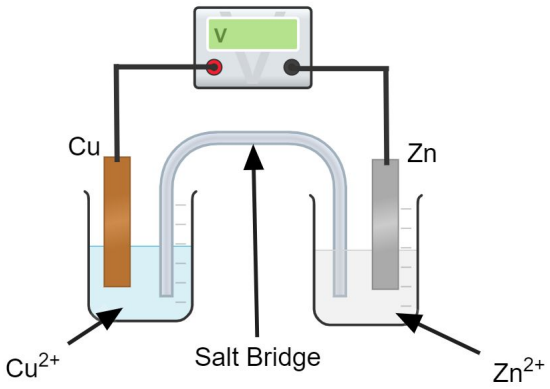
To force the electrons to go around a circuit rather than transfer directly from one atom to another, the metals are placed in two separate beakers. The beakers are connected by a 'salt bridge', a piece of filter paper soaked in an unreactive salt so ions can move from one beaker to the other. The metals are connected to a circuit. This is called an electrochemical cell.

The diagram below shows the electrochemical cell for the reaction:

$$\mathrm{Zn\,(s)} + \mathrm{CuSO_4\,(aq)} \longrightarrow \mathrm{ZnSO_4\,(aq)} + \mathrm{Cu\,(s)}$$



(b) On the diagram above draw arrows on the wires in the circuit showing the direction the electrons are travelling. [1]

(c) Suggest **two** observations about the metals and/or the solution of ions which could be seen as the reaction proceeds and the electrochemical cell produces current. [2]

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Since electrochemical cells are used as batteries, the voltage which the cell produces is often measured. Voltage is a measure of the energy per unit charge (J/C) of each transferred electron.

(d) The $\mathrm{Zn/CuSO_4}$ electrochemical cell produces 1.10 V. The battery transfers 1.204×10^{24} electrons when it is used. The charge on an electron is -1.602×10^{-19} C. How much energy in J does this battery release? [1]

(e) If the amount of Cu, Zn, $CuSO_4(aq)$, and $ZnSO_4(aq)$ in the electrochemical cell were doubled, what would happen to the voltage of the cell and why? [3]

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Different electrochemical cells were made. The beaker with the Cu metal and $Cu^{2+}(aq)$ was kept the same and the metal and solution in the other beaker were changed. The table below lists the voltages recorded on the voltmeter when different metals were combined with Cu in the electrochemical cell:

Metal/Ion solution	Voltage (V)
Li/Li^+	+3.37
Ca/Ca^{2+}	+3.21
Al/Al^{3+}	+2.00
Zn/Zn^{2+}	+1.10
Cu/Cu^{2+}	0.00
Ag/Ag^+	−0.46

(f) Suggest a voltage for the electrochemical cell if the other beaker contains Mg and an $Mg^{2+}(aq)$ solution. Justify your answer. [2]

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Total for Question 2: 15

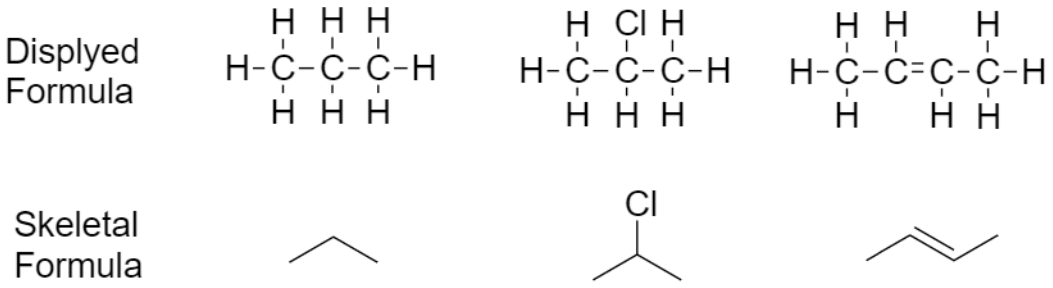
3. Organic chemistry is the chemistry of molecules which contain C and H and can contain other elements.

Carbon can form many complex molecules; therefore, chemists have invented a way of quickly and concisely drawing organic molecules, called the **skeletal formula**.

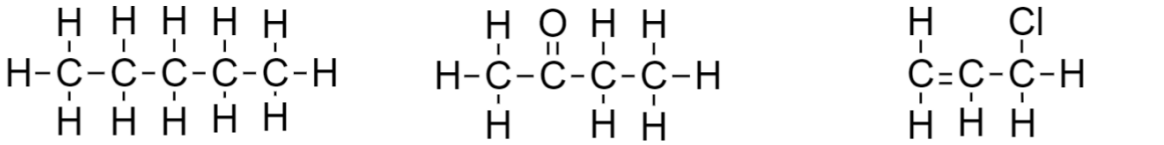
To draw the skeletal formula:

- The symbols for C and H are **not drawn** but symbols for other elements are.
- Bonds to H are **not drawn**.
- The molecules are drawn with a 120° angle between the bonds.

Example of skeletal formulae are shown below:



(a) Draw the skeletal formula in the boxes for each of the following molecules. [3]



(b) Give the molecular formula of the following molecules. [4]

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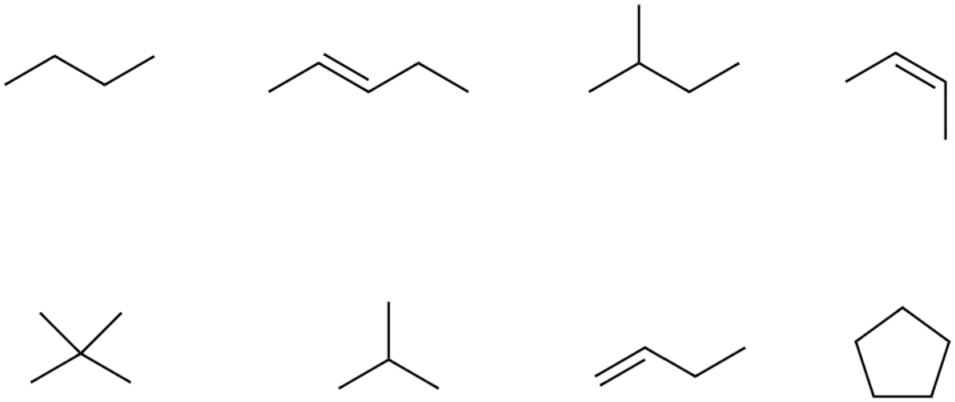
Isomers are molecules with same molecular formula but with different structures.

(c) For the eight molecules below, draw lines matching up pairs of isomers [4]



(d) Hexane (C_6H_{14}) has five isomers; one is given below. Draw the **skeletal formulae** of the four other isomers of hexane. [4]

Hexane

Isomer 1

Isomer 2

Isomer 3

Isomer 4

Total for Question 3: 15

End of Paper

Junior Chemistry Challenge is kindly supported by The Perse School, Cambridge.

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Hazard Symbol in Question 1(h) By Unknown author - EPS file rondflam.eps from UNECE web site converted with ImageMagick convert and with potrace, edited and flame redrawn in inkscape, Public Domain, https://commons.wikimedia.org/w/index.php?curid=4983851

Figure of Daniell Cell in Question 2 drawn in Chemix (https://chemix.org/)

Organic structures in Question 3 drawn in ChemDraw JS
(https://chemdrawdirect.perkinelmer.cloud/js/sample/index.html)

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