



2021 AUSTRALIAN SCIENCE OLYMPIAD EXAM  
**CHEMISTRY**

**TO BE COMPLETED BY THE STUDENT. USE CAPITAL LETTERS.**

<b>Student Name:</b> .....	
<b>Home Address:</b> .....	
.....	<b>Post Code:</b> .....
<b>Telephone:</b> (.....) .....	<b>Mobile:</b> .....
<b>E-Mail:</b> .....	<b>Date of Birth:</b> ...../...../.....
<input type="checkbox"/> Male <input type="checkbox"/> Female <input type="checkbox"/> Unspecified <b>Year 10</b> <input type="checkbox"/> Year 11 <input type="checkbox"/> Other: .....	

<b>Name of School:</b> .....	<b>State:</b> .....
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<b>Examiners Use Only:</b>		

2021 AUSTRALIAN SCIENCE OLYMPIAD EXAM  
**CHEMISTRY**

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*Time Allowed*

*Reading Time: 10 minutes*

*Examination Time: 120 minutes*

**INSTRUCTIONS**

- *Attempt all questions in ALL sections of this paper.*
- Permitted materials: non-programmable, non-graphical calculator, pens, pencils, erasers and a ruler.
- Marks will not be deducted for incorrect answers.

**MARKS**

▪ SECTION A	15 multiple choice questions	30 marks
▪ SECTION B	3 short answer questions	30 marks each
	Total marks for the paper	120 marks

***Integrity of Competition***

*If there is evidence of collusion or other academic dishonesty, students will be disqualified. Markers' decisions are final.*



**SECTION A: MULTIPLE CHOICE**  
**USE THE ANSWER SHEET PROVIDED**

- Which of the following lists species in order of increasing ionic radius?
  - $\text{Cs}^+$ ,  $\text{Rb}^+$ ,  $\text{Na}^+$
  - $\text{S}^{2-}$ ,  $\text{Cl}^-$ ,  $\text{K}^+$
  - $\text{O}^{2-}$ ,  $\text{Na}^+$ ,  $\text{Ba}^{2+}$
  - $\text{I}^-$ ,  $\text{Cl}^-$ ,  $\text{Br}^-$
  - $\text{Sr}^{2+}$ ,  $\text{Rb}^+$ ,  $\text{Br}^-$
  
- Which of the following pairs of compounds will form a precipitate when  $0.1 \text{ mol L}^{-1}$  solutions of each are mixed?
  - $\text{AgNO}_3$  and  $\text{Ba}(\text{NO}_3)_2$
  - $\text{K}_2\text{SO}_4$  and  $\text{Cu}(\text{NO}_3)_2$
  - $\text{Ca}(\text{NO}_3)_2$  and  $\text{KBr}$
  - $\text{NaOH}$  and  $\text{CuCl}_2$
  - $\text{CuCl}_2$  and  $\text{NH}_4\text{NO}_3$
  
- A component of diesel fuel is the hydrocarbon  $\text{C}_{12}\text{H}_{24}$ , with density  $0.790 \text{ g mL}^{-1}$ . What volume of  $\text{CO}_2$  (measured at  $25 \text{ }^\circ\text{C}$  and  $100 \text{ kPa}$ ) is produced from the complete combustion of  $2.00 \text{ L}$  of  $\text{C}_{12}\text{H}_{24}$  in excess oxygen?
  - $2.79 \text{ L}$
  - $3.53 \text{ L}$
  - $1400 \text{ L}$
  - $2790 \text{ L}$
  - $3530 \text{ L}$

4. Which of the following compounds has a trigonal pyramidal geometry?
- A.  $\text{NCl}_3$
  - B.  $\text{CH}_2\text{Cl}_2$
  - C.  $\text{COCl}_2$
  - D.  $\text{CH}_4$
  - E.  $\text{BCl}_3$
5. When the given amounts of each reagent are mixed together, which of the following will release the **largest** mass of  $\text{CO}_2$ ?
- A. 0.3 mol  $\text{CuCO}_3$  and 0.1 mol  $\text{H}_2\text{SO}_4$
  - B. 0.2 mol  $\text{CuCO}_3$  and 0.3 mol  $\text{HCl}$
  - C. 0.2 mol  $\text{CuCO}_3$  and 0.2 mol  $\text{H}_2\text{SO}_4$
  - D. 0.3 mol  $\text{CuCO}_3$  and 0.3 mol  $\text{HCl}$
  - E. 0.1 mol  $\text{CuCO}_3$  and 0.3 mol  $\text{H}_2\text{SO}_4$
  - F. 0.1 mol  $\text{CuCO}_3$  and 0.2 mol  $\text{HCl}$
6. Biological tissue samples are often stained with dyes, which are coloured organic salts.
- Basic dyes consist of a coloured cation and a colourless anion.
  - Acidic dyes consist of a coloured anion and a colourless cation.

Which of the following dyes are acidic? Select all that apply.

- A.  $\text{C}_{21}\text{H}_{22}\text{N}_3\text{Cl}$
- B.  $\text{C}_{25}\text{H}_{33}\text{N}_2\text{O}_2\text{Cl}$
- C.  $\text{C}_{16}\text{H}_{17}\text{N}_2\text{ClS}$
- D.  $\text{C}_{19}\text{H}_{17}\text{N}_2\text{NaO}_5\text{S}$
- E.  $\text{C}_{33}\text{H}_{43}\text{N}_3\text{Na}_2\text{O}_8\text{S}_2$

7. What is the total number of valence electrons in the  $\text{PO}_2^{3-}$  ion?
- A. 15
  - B. 17
  - C. 20
  - D. 30
  - E. 34
8. Which of the following molecules contains 29.67% sulfur by mass?
- A.  $\text{SF}_4$
  - B.  $\text{SO}_2\text{Cl}_2$
  - C.  $\text{SOCl}_2$
  - D.  $\text{SF}_6$
  - E.  $\text{S}_2\text{F}_{10}$
9. Which of the following lists substances in order of increasing boiling point?
- A.  $\text{CO}_2$ ,  $\text{PCl}_3$ ,  $\text{CaO}$
  - B.  $\text{PCl}_3$ ,  $\text{CaO}$ ,  $\text{CO}_2$
  - C.  $\text{CaO}$ ,  $\text{CO}_2$ ,  $\text{PCl}_3$
  - D.  $\text{CaO}$ ,  $\text{PCl}_3$ ,  $\text{CO}_2$
  - E.  $\text{CO}_2$ ,  $\text{CaO}$ ,  $\text{PCl}_3$
  - F.  $\text{PCl}_3$ ,  $\text{CO}_2$ ,  $\text{CaO}$

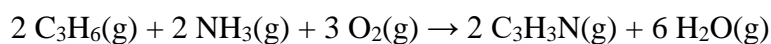
10. First ionisation energy is defined as the energy required to remove one mole of electrons from one mole of gaseous ions. Which of the following lists elements in order of increasing first ionisation energy?

- A. C, F, N, Li
- B. C, N, Li, F
- C. Li, C, N, F
- D. Li, N, F, C
- E. F, N, C, Li
- F. F, Li, N, C

11. How many atoms are present in a 1.0 kg sample of  $C_2H_4O$ ?

- A.  $1.4 \times 10^{22}$
- B.  $9.6 \times 10^{22}$
- C.  $1.4 \times 10^{25}$
- D.  $9.6 \times 10^{25}$
- E.  $9.6 \times 10^{28}$

12. Acrylonitrile ( $C_3H_3N$ ) can be synthesised industrially according to the following chemical equation:



When 100 kg of  $C_3H_6$ , 50 kg of  $NH_3$  and 125 kg of  $O_2$  are mixed, which of these reactants is present in excess? **Select all that apply.**

- A.  $C_3H_6$
- B.  $NH_3$
- C.  $O_2$

13. Which of the following is both an empirical formula and a molecular formula?

- A.  $C_3F_6$
- B.  $C_3F_8$
- C.  $C_4F_6$
- D.  $C_4F_8$
- E.  $C_4F_{10}$

14. A 1.620 g of  $\mathbf{XF}_6$  can be produced from 1.000 g of element  $\mathbf{X}$ .

Which of the following could be element  $\mathbf{X}$ ?

- A. W
- B. Se
- C. Mo
- D. Rh
- E. U

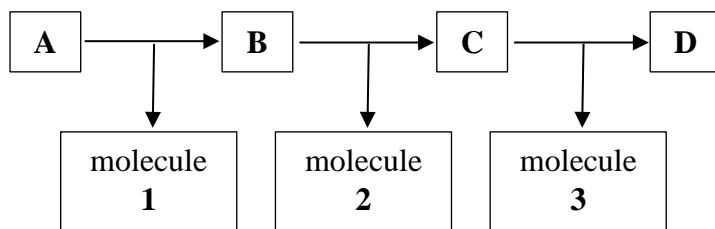
15. Of the following elements, which has the highest **third** ionisation energy?

- A. Ar
- B. Si
- C. Mg
- D. Al
- E. Cl



### Question 16

Thermogravimetric analysis involves measuring the mass of a sample as it is heated. Compound **A** decomposes with increasing temperature to give a sequence of compounds **B**, **C** and **D**, all of which contain calcium. At each stage, a small molecule is also given off (denoted molecules 1, 2 and 3 respectively), which results in the mass of each successive compound being smaller.



The mass of each compound, expressed as a percentage of the original mass of **A**, is recorded in the table below.

Compound	Percentage of original mass of <b>A</b> remaining
A	100.0
B	87.67
C	68.50
D	38.38

It is known that compound **B** is calcium oxalate,  $\text{CaC}_2\text{O}_4$ .

(a) Calculate the molar mass of compound **A**.

(b) Calculate the molar mass of molecule **1**.

(c) Identify the formula of molecule **2**.

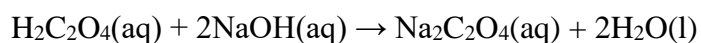
(d) Identify the formula of Compound **C**.

(e) Identify the formula of Compound **D**.

A solution is prepared by dissolving 1.946 g of oxalic acid dihydrate ( $\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ , molar mass  $126.068 \text{ g mol}^{-1}$ ) in water and making the solution up to 250.0 mL in a volumetric flask.

(f) Calculate the concentration of the oxalic acid solution (in  $\text{mol L}^{-1}$ ).

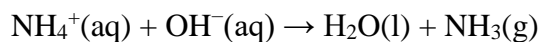
Oxalic acid reacts with sodium hydroxide to produce sodium oxalate and water, according to the following chemical equation:



20.00 mL of the oxalic acid solution above requires 18.57 mL of a sodium hydroxide solution for complete reaction.

(g) Calculate the concentration of the sodium hydroxide solution (in  $\text{mol L}^{-1}$ ).

The ammonium ion content of a salt can be determined using the following procedure. A 1.988 g sample of an ammonium salt is placed in a flask and heated with 50.00 mL of 0.5493 mol L<sup>-1</sup> potassium hydroxide solution (a known excess). The ammonium and hydroxide ions react to produce water and ammonia, which is expelled from the flask by evaporation:



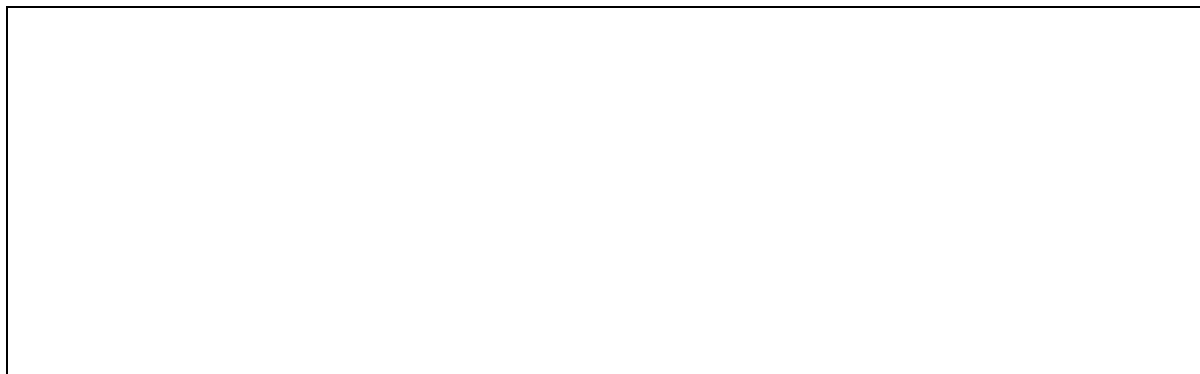
The potassium hydroxide remaining in the flask after all of the ammonia is expelled is determined with 0.1032 mol L<sup>-1</sup> hydrochloric acid, 23.89 mL of which is required for complete reaction.

(h) Calculate the amount (in mol or mmol) of hydrochloric acid added.

(i) Calculate the amount (in mol or mmol) of potassium hydroxide added in the original 50.00 mL sample.

(j) Calculate the amount (in mol or mmol) of ammonium ions in the 1.988 g ammonium salt sample.

- (k) Calculate the percentage by mass of ammonium ions in the 1.988 g ammonium salt sample.



In the absence of volumetric glassware, it is possible to use only mass measurements to determine the composition of solutions.

KHP ( $\text{KC}_8\text{H}_5\text{O}_4$ ) is an acid commonly used in such determinations.

(l) Calculate the molar mass of KHP (in  $\text{g mol}^{-1}$ )

20.58 g of KHP ( $\text{KC}_8\text{H}_5\text{O}_4$ ) is dissolved in water, giving a solution with a mass of 118.48 g.

(m) Calculate the mass of water (in g) that must have been added to the KHP to make the 118.48 g solution.

A solution of sodium hydroxide is also prepared. 4.471 g of this sodium hydroxide solution reacts completely with 5.979 g of the KHP solution above. Sodium hydroxide reacts in a 1:1 mole ratio with KHP.

In a similar reaction, 4.359 g of the sodium hydroxide solution reacts completely with a 5.925 g sample of vinegar (containing acetic acid,  $\text{CH}_3\text{COOH}$ ). Sodium hydroxide reacts in a 1:1 mole ratio with acetic acid.

(n) Calculate the mass (in g) of the KHP solution required to react completely with 4.359 g of the sodium hydroxide solution

- (o) Calculate the amount of pure KHP (in mol or mmol) required to react completely with 4.359 g of the sodium hydroxide solution.

- (p) Calculate the percentage by mass of acetic acid present in the vinegar sample.

- (q) If the density of the sodium hydroxide solution is  $1.045 \text{ g mL}^{-1}$ , calculate the concentration of the sodium hydroxide solution (in  $\text{mol L}^{-1}$ ).

### Question 17

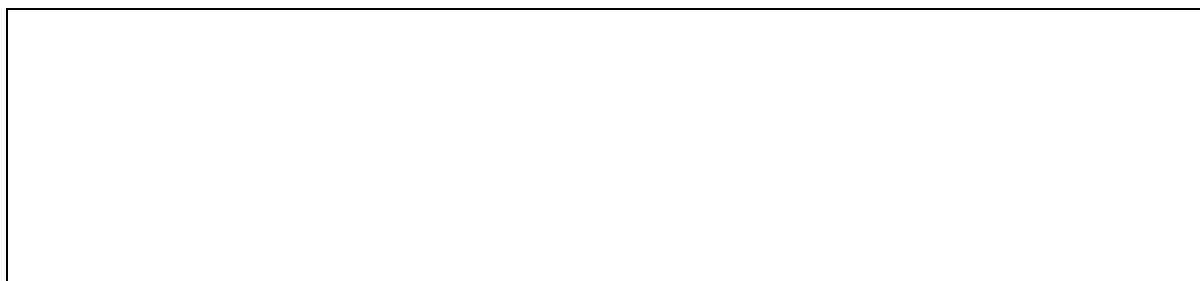
The following question will explore the role symmetry has to play in chemistry, and how it affects the physical and chemical properties of molecules.

We start by revising the basics of Lewis structures.

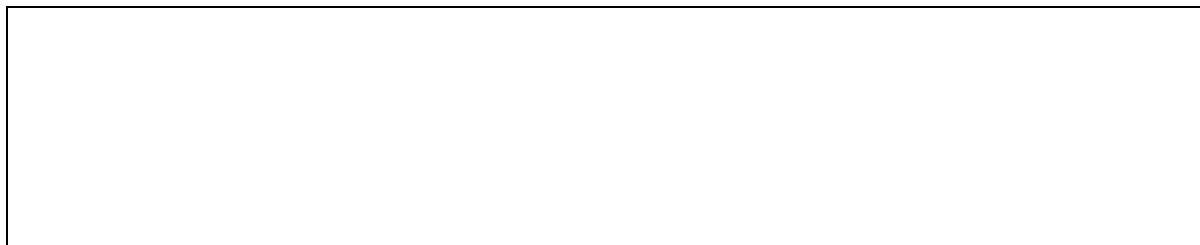
(a) Draw a correct Lewis structure for  $F_2$ .



(b) Draw a correct Lewis structure for  $H_2S$ .



(c) Draw a correct Lewis structure for  $HCN$ .



(d) Draw a correct Lewis structure for  $NO_2^+$ .

