## THE EMPIRICAL FORMULA

The **empirical formula** of a compound is the simplest formula, which shows the ratio of the atoms present in a compound or a molecule by mass.

The **molecular formula** of a compound is the formula, which shows the number of each kind of atoms present in the compound.

## TO CALCULATE THE EMPIRICAL FORMULAE

Example **I**
Sodium sulphate has the following composition by mass; sodium 32.4% sulphur 22.5% and oxygen 45.1%.

| Elements | Na | S | O |
|---|---|---|---|
| percentage | 32.4 | 22.5 | 45.1 |
| Relative atomic masses (RAM) | 23 | 32 | 16 |
| Moles = $\frac{percentage}{RAM}$ | $\frac{32.4}{23} = 1.4$ | $\frac{22.5}{32} = 0.7$ | $\frac{45.1}{16} = 2.8$ |
| Mole ratio (divide by smallest value) | 2 | 1 | 4 |
| Empirical formula | $Na_2SO_4$ | | |

**Example 2**
A compound contains oxygen and copper only. The molecular mass is 159.0.
What is its Empirical and molecular formula if the percentage of copper is 76

*Solution*
Percentage of oxygen = 100 – 76 = 24%

| Elements | Cu | O |
|---|---|---|
| percentages | 76 | 24 |
| Relative atomic mass | 64 | 16 |
| Number of moles = $\frac{percentage}{RAM}$ | $\frac{76}{64} = 1.875$ | $\frac{24}{16} = 1.5$ |
| Mole ratio (divide by smallest value) | $\frac{1.875}{1.5} = 1$ | $\frac{1.5}{1.5} = 1$ |

Empirical formula

CuO

Molecular formula

(CuO)n = 159

64n + 16n = 159

80n = 159

n = $\frac{159}{80}$

n = 1.987

**n = 2** (always **n** is a whole number)

Therefore molecular formula of **CuO = $Cu_2O_2$**

**Exercise**

1. A compound contains 53.3% oxygen, 6.7% hydrogen and 40% carbon. The simplest formula of compound is (C = 12, H =1 O = 16)
   A. CHO, B. $CH_2O$ C. $C_2H_2O$ $CH_2O_2$
2. The oxide of P contains 50% by mass P. Its relative molecular mass is 64. What is the formula of the oxide (P = 32, O = 16)
   A. PO, B. $PO_2$ C. $P_2O$ D. $PO_3$
3. A white powder is made of 24 percent carbon and 76 percent fluorine atoms. Its simplest formula is
   A. $CF_2$ B. $C_2F_4$ C. $CF_3$ D. $CF_4$
4. 6.6g of am element M, combine with excess oxygen to give 8.1g of oxide. The simplest formula of the oxide is (M = 65, O =16)
   A. $M_2O$ B. MO C. $MO_2$ D. $M2O_3$
5. 12.7g of metal R, reacts completely with 11.3g of oxygen to form oxide. Which one of the following is the formula of oxide of R? (R = 27, O = 16)
   A. $R_3O_2$ B. $RO_2$ C. $R_2O$ D. $R_2O_3$
6. A hydrocarbon contains 4.8g of carbon and 0.8g of hydrogen. The empirical formula of the hydrocarbon is
   A. $C_2H$ B. $CH_4$ C. $CH_2$ D. $C_6H$
7. An oxide of metal M, contains 86.6% M. the empirical formula of the oxide is (O = 16; M = 207)
   A. MO B. $M_2O$ C. $MO_2$ D. $M_2O_3$

8. 2.50g of an oxide of metal M, was reduced by hydrogen to 1.98g.
   (a) Calculate the moles of atoms of
      (i) M in oxide (M = 64)
      (ii) Oxygen in the oxide (O = 16)
   (b) Determine the molecular formula of the oxide of M. (1 ½ marks)
   (c) Name two other gases that can be used instead of hydrogen (2mark)
9. Hydrocarbon Z of molecular formula 56 consists of 85.7% of carbon by mass.
   (a) Define the term hydrocarbon (1marks)
   (b) Calculate empirical formula of Z.
   (c) Determine the molecular formula of Z.
10. A Compound Y of molecular formula = 46 consists of 52.2% carbon, 13.0% hydrogen and 34.8% oxygen by mass. (H=1, C=12, O = 16)
   (a) Calculate the empirical formula of Y

(b) Determine the molecular formula of Y

(c) Combustion of Y is highly exothermic. Suggest one use of Y.

11. A compound Y consist of 92.31% carbon and 7.69% hydrogen. The formula mass of Y is 26.

(a) Calculate the empirical formula of Y

(b) Determine molecular formula of Y

(c) Write structural formula of Y

12. A hydrocarbon, R, contains 80% carbon by mass.

(a) Calculate empirical formula of R.

(b) If the molecular mass of R is 30. Determine molecular formula of R

(c) Write the formula for complete combustion of R

13. The molecular mass of gas X is 28 and its empirical formula is $CH_2$.

(a) Determine the molecular formula of X.

(b) Write

(i) the structural formula of X

(ii) the equation for the reaction between X and bromine

(c) (i) Name any other reagent that could be used to identify X

(ii) State what would be observed if the reagent named in (c)(i) was reacted with X.

14. A compound Z of molecular formula AxBy consist of 8.57% A, 45.71% B and 45.72% of water

(a) Determine the values of x, y and n. (H= 1, O = 16, A = 27, B = 96)

(b) Write the molecular formula of Z.

15. Excess carbo monoxide was passed over 4.0g of heated oxide of iron Y, 2.8g of iron was formed.

(a) Determine the molecular formula of Y. (O = 16, Fe = 56)

(b) Write equation for the reaction between Y and carbon monoxide.

16. A compound Y, consists 52.17% carbon, 13.04% hydrogen and 34.78% oxygen. The relative molecular mass of Y is 46.

(a) Determine the

(i) Empirical formula of Y (03mark)

(ii) Molecular formula of Y (1mark)

(b) When Y was heated with concentrated sulphuric acid, a colourless gas, Z which turned bromine water colourless was evolved. Identify

(i) Y ……..

(ii) Z …….

**Answers**

Answers working

1 B

| Element | carbon | hydrogen | oxygen |
|---|---|---|---|
| percentage | 40 | 6.7 | 53 |
| RAM | 12 | 1 | 16 |
| moles | $\frac{40}{12} = 3.3$ | $\frac{6.7}{1} = 6.7$ | $\frac{53.3}{16} = 3.3$ |

| | | | | |
|---|---|---|---|---|
| | | Mole ratio | 1 | 2 | 1 |
| | | Formula | $CH_2O$ | | |

2 B

| | | |
|---|---|---|
| Element | P | O |
| percentage | 50 | 50 |
| RAM | 32 | 16 |
| moles | $\frac{50}{32} = 1.6$ | $\frac{50}{16} = 3.12$ |
| Mole ratio | 1 | 2 |
| Formula | $PO_2$ | |

3 A

| | | |
|---|---|---|
| Element | C | F |
| percentage | 24 | 76 |
| RAM | 12 | 19 |
| moles | $\frac{24}{12} = 2$ | $\frac{76}{19} = 4$ |
| Mole ratio | 1 | 2 |
| Formula | $CF_2$ | |

4 A

| | | |
|---|---|---|
| Element | M | O |
| Mass | 6.6 | 8.1 |
| RAM | 65 | 16 |
| moles | $\frac{6.6}{65} = 0.1$ | $\frac{8.1}{16} = 0.5$ |
| Mole ratio | 2 | 1 |
| Formula | $M_2O$ | |

5 D

| | | |
|---|---|---|
| Element | R | O |
| Mass | 12.7 | 11.3 |
| RAM | 27 | 16 |
| moles | $\frac{12.7}{27} = 0.47$ | $\frac{11.3}{16} = 0.7$ |
| Mole ratio | 2 | 3 |
| Formula | $R_2O_3$ | |

6 C

| | | |
|---|---|---|
| Element | C | H |
| Mass | 4.8 | 0.8 |
| RAM | 12 | 1 |
| moles | $\frac{4.8}{12} = 0.4$ | $\frac{0.8}{1} = 0.8$ |
| Mole ratio | 1 | 2 |
| Formula | $CH_2$ | |

| | | |
|---|---|---|
| 7 | | Percentage of oxygen = 100 – 86.6 = 13.4 |
| | C | |

| Element | M | O |
|---|---|---|
| percentage | 86.6 | 13.4 |
| RAM | 207 | 16 |
| moles | $\frac{86.6}{207} = 0.42$ | $\frac{13.4}{16} = 0.84$ |
| Mole ratio | 1 | 2 |
| Formula | $MO_2$ | |

8 (a)(i) Mass of metal, M = 1.98

Moles = $\frac{1.98}{65} = 0.031$

(ii) Mass of oxygen = 2.50 – 1.98 = 0.52g

Moles = $\frac{0.52}{16} = 0.032$

(b)

| Element | M | O |
|---|---|---|
| moles | 0.031 | 0.032 |
| Mole ratio | 1 | 1 |

Formula: MO

(c) Ammonia

Carbon monoxide

9. (a) Hydrocarbon is a substance that contains carbon and hydrogen only

(b) Percentage of hydrogen = 100 – 85.7 = 14.3%

| Element | C | H |
|---|---|---|
| Percentage | 85.7 | 14.3 |
| RAM | 12 | 1 |
| Moles | $\frac{85.7}{12} = 7.14$ | $\frac{14.3}{1} = 14.3$ |
| Mole ratio | 1 | 2 |

Formula: $CH_2$

(c) $(CH_2)n = 56$

$14n = 56$

$n = 4$

Molecular formula $C_4H_8$

10. (a)

| Element | C | H | O |
|---|---|---|---|
| Percentage | 52.2 | 13 | 34.8 |
| RAM | 12 | 1 | 16 |
| Moles | $\frac{52.2}{12} = 4.35$ | $\frac{13}{1} = 13$ | $\frac{34.8}{16} = 2.175$ |
| Mole ratio | 2 | 6 | 1 |

Formula: $C_2H_6O$

(b) $(C_2H_6O)n = 46$

$(12 \times 2 + 1 \times 6 + 16 \times 1)n = 46$

$n = 1$

therefore, molecular formula: $C_2H_6O$

(c) Y is used as fuel

11. (a)

| Element | C | H |
|---|---|---|
| Percentage | 92.31 | 7.69 |
| RAM | 12 | 1 |
| Moles | $\frac{92.31}{12} = 7.69$ | $\frac{7.69}{1} = 7.69$ |
| Mole ratio | 1 | 1 |

Empirical formula: CH

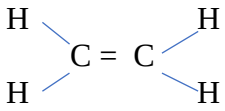
(b) $(CH)n = 26$

$13n = 26$

$n = 2$

molecular formula $C_2H_2$

(c)



12 (a) Percentage of hydrogen = 100 – 80 = 20%

| Element | C | H |
|---|---|---|
| Percentage | 80 | 20 |
| RAM | 12 | 1 |
| Moles | $\frac{80}{12} = 6.7$ | $\frac{20}{1} = 20$ |
| Mole ratio | 1 | 3 |

Formula: $CH_3$

(b) $(CH3)n = 30$

$n(12+3) = 30$

$15n = 30$

$n = 2$

molecular formula: $C_2H_6$

$2C_2H_6\ (g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$

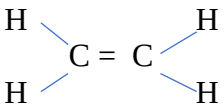
13 (a) $(CH_2)n = 28$

$14n = 28$

$n = 2$

molecular mass = $C_2H_4$

(b)(i)



(b)(ii) $C_2H_4 + Br_2 \longrightarrow C_2H_4Br_2$

(c)(i) Acidified potassium permanganate

(ii) Decolorise

14 (a) Formula mass of water, $H_2O$ = 1x2 + 16 = 18

| Components | A | B | $H_2O$ |
|---|---|---|---|
| Percentage | 8.57 | 45.71 | 45.71 |
| RAM | 16 | 96 | 18 |
| Moles | $\frac{8.57}{16} = 0.53$ | $\frac{45.71}{96} = 0.48$ | $\frac{45.72}{18} = 2.54$ |
| Mole ratio | 1 | 1 | 5 |

x = 1
y = 1
n= 5

(b) $AB.5H_2O$

15 (a) Mass of iron = 2.8g
Mass of oxygen = 4.0 – 2.8 = 1.2g

| Element | Fe | O |
|---|---|---|
| Mass | 2.8 | 1.2 |
| RAM | 56 | 16 |
| Moles | $\frac{2.8}{56} = 0.05$ | $\frac{1.2}{16} = 0.075$ |
| Mole ratio | 2 | 3 |

Formula is $Fe_2O_3$

(b) $Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g)$

16 (a)(i)

| Components | C | H | O |
|---|---|---|---|
| Percentage | 52.17 | 13.04 | 34.54 |
| RAM | 12 | 1 | 16 |
| Moles | $\frac{52.17}{12} = 4.3$ | $\frac{13.04}{1} = 13.04$ | $\frac{34.54}{16} = 2.1$ |
| Mole ratio | 2 | 6 | 1 |

Emperical formula $C_2H_6O$

(ii) $(C_2H_6O)n = 46$
46n = 46
n = 1
molecular formula is $C_2H_6O$

(b)(i) Y = Ethanol

(ii) Z =Ethene

…..End