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MASS & ENERGY BALANCE PRACTICE EXERCISES

POLITEKNIK KUCHING SARAWAK

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PREFACE

Mass & Energy Balance Practice Exercises is the first module that was published in 2025 based on the Mass and Energy Balance Course by the Department of Petrochemical Engineering, Politeknik Kuching Sarawak. This module emphasized Chapter 1 of the Mass and Energy Balance Course, ' Processes and Process Variables'.

This module aims to help the students identify questions, keywords, formulas, and problem-solving steps.

In short, the editors are grateful to the Department of Petrochemical Engineering, Politeknik Kuching Sarawak for giving them this valuable opportunity.

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ABSTRACT

MASS & ENERGY BALANCE PRACTICE EXERCISES

by

HAFIZAH BINTI NAIHI AND DR. MUHAMAD NAZRI BIN ABU SHAH

Mass & Energy Balance Practice Exercises is a book that provides students with some mass and energy balance example problems together with the solutions. This book focuses on the topic, "Processes and Process Variables" which is Chapter 1 of the Mass and Energy Balance Course in the Diploma of Engineering Process (Petrochemical) at Politeknik Kuching Sarawak. This book is also intended as a college- or university-level text for students in chemical engineering and similar disciplines.

This book consists of some practice questions along with the solution. The detailed solution steps that had been carried out were used to guide and teach students the series of integrated calculations of the problems. This book acts as a teaching aid for lecturers, specifically lecturers in the Department of Petrochemical Engineering, Politeknik Kuching Sarawak, and can be used as a reference by students all over the world. There is enough information supplied in the text of the problem for the students to carry out the calculation themselves before they can compare their answer version to the answer in the text of the solution. This is a good exercise for the students to measure their understanding based on the number of correct answers that they have obtained. Also, it is a challenge for the students to solve the problems correctly as illustrated in the solution text. The solution text illustrates every step taken in a calculation and it is the student's responsibility to trace from where and why particular numbers are produced.

Keywords: Mass, Energy, Balance, Calculation, Answer

TABLE OF CONTENTS

***Example 1-1* Dimensions and Units**

Pay attention to the mathematical operation

Add each of the following:

a) 25 pounds + 15 grams — Dimension: Mass

b) 3 horsepower + 600 watts — Dimension: Power

SOLUTION

Hint: The numerical operation can be performed if the units of the quantities are the same.

a) Since 1 pound = 453.593 grams,

Cancel out the same unit

$$\frac{25 \text{ pounds}}{} \times \frac{453.593 \text{ g}}{1 \text{ pound}} = 11339.83 \text{ g}$$

Addition operation

25 pounds + 15 grams

Same unit

= 11339.83 g + 15 g

= 11354.83 g

Your answer may be in grams or pounds depending on your desired unit

b) Since 1 hp = 746 watts

Cancel out the same unit

$$\frac{3\ \text{hp}}{} \times \frac{746\ \text{watts}}{1\ \text{hp}} = 2238\ \text{watts}$$

Addition operation

3 horsepower + 600 watts

Same unit

= 2238 watts + 600 watts

= 2838 watts

Your answer may be in hp or watts depending on your desired unit

Let's try!

a) 5 ft × 10 in. (Ans. 600 in.)

b) 20 bar - 1 atm (Ans. 18.738 atm)

c) 30 m^3 ÷ 400 L (Ans. 75 L)

Guided Practice

a) 5 ft × 10 in.

1st step: Identify the unit given in the question

- ft and in.

2nd step: Identify the desired units

- in.

3rd step: Determine the relationship between the units and identify appropriate unit conversion factors

- Same dimension: Length
- 1 ft = 12 in.

4th step: Cancel out the undesired unit

$$\frac{5\ \cancel{\text{ft}}}{} \times \frac{12\ \text{in.}}{1\ \cancel{\text{ft}}}$$

5th step: Perform mathematical operation

$$\frac{5\ \text{ft}}{} \times \frac{12\ \text{in.}}{1\ \text{ft}} = 60\ \text{in.}$$

Therefore,

5 ft × 10 in. = 60 in. × 10 in. = 600 in.

Self-Practice

Now your turn to answer questions b and c.

b)

c)

***Example 1-2* Conversion of Units and Conversion Factors**

a) How many liters of milk would fill a container that measures 100 in^3?

b) Convert 405 dm to km.

c) 200 lb_m of wastewater is flowing at a rate of 5 ft/s through a pipe. What is the kinetic energy of this wastewater in lb_f.ft?

SOLUTION

Hint: Line up conversion factors so units can be canceled out.

a) Convert 100 in^3 to L

Dimension: Volume

Cancel out the same unit

$$100\ in^3 \times \frac{2.54\ cm^3}{in^3} \times \frac{1\ L}{1000 cm^3} = 0.254\ L$$

b) Deci. to kilo.

Cancel out the same unit

$$405\ dm \times \frac{10^{-1}\ m}{1\ dm} \times \frac{1\ km}{10^3\ m} = 0.0405\ km$$

c) Kinetic energy = K = ½ mv^2

Leave the desired units: $lb_f.ft$

$$K=\frac{1}{2}\times\frac{200\ lb_m}{}\times\left(\frac{5\ ft}{s}\right)^2\times\frac{1\ lb_f}{32.174\ lb_m.ft/s^2}=77.702\ lb_f.ft$$

Let's try!

a) A fuel cell has a mass of 145.2 lb_m. Determine the weight of the fuel cell in lb_f and N. (Ans. 145.2 lb_f and 645.88 N)

Weight and mass

b) 106 days to milliseconds (Ans. 9.16×10^9 ms)

c) 8.8×10^{-5} mg to μg (Ans. 8.8×10^{-2} μg)

Use SI prefixes

d) 50.61 $lb_m.ft/min^2 \rightarrow kg.cm/s^2$ (Ans. 0.1944 $kg.cm/s^2$)

Conversion between systems of units

Guided Practice

a) A fuel cell has a mass of 145.2 lb_m. Determine the weight of the fuel cell in lb_f and N.

1st step: Identify the formula that relate weight and mass

- W=mg

2nd step: Identify desired unit

- lb_f and N

3rd step: Identify appropriate conversion factors for conversion between systems of units

W=mg

$$W=\frac{145.2\ lb_m}{}\times\frac{1kg}{2.20462lb_m}\times\frac{9.8066m}{s^2}\times\frac{1N}{1kg.m/s^2}$$

and

$$W=\frac{145.2\ lb_m}{}\times\frac{32.174ft}{s^2}\times\frac{lb_f}{32.174lb_m.ft/s^2}$$

Remember: The value of the gravitational acceleration (g) in each system of units is as below:

4th step: Cancel out the undesired unit

$$W=\frac{145.2\ \cancel{lb_m}}{}\times\frac{1\cancel{kg}}{2.20462\cancel{lb_m}}\times\frac{9.8066m}{\cancel{s^2}}\times\frac{1N}{1\cancel{kg}.m/\cancel{s^2}}$$

and

$$W=\frac{145.2\ \cancel{lb_m}}{}\times\frac{32.174\cancel{ft}}{\cancel{s^2}}\times\frac{lb_f}{32.174\cancel{lb_m}.\cancel{ft}/\cancel{s^2}}$$

g =9.8066 m/s^2

=980.66 cm/s^2

=32.174 ft/s^2

5th step: Perform mathematical operation

W=645.88 N and W=145.2 lb_f

Self-Practice

Now your turn to answer questions b, c and d.

b)

c)

d)

***Example 1-3* Mole Fraction and Mass Fraction**

a) A liquid mixture contains 40 wt% butane C_4H_{10}, 35 wt% hexane C_6H_{14}, and 25 wt % pentane C_5H_{12}. What is the mole fraction of each component in the mixture? Hexane, butane, and pentane have molecular weights of 86.18 kg/kmol, 58.12 kg/kmol, and 72.15 kg/mol, respectively.

b) The composition of dry air is 21 mole % O_2 and 79 mole % N_2. What is the mass percent of each gas in the air?

SOLUTION

a) ***Hint: The basis of the total mixture is assumed to be 100 kg. The mass of each component in a mixture is then calculated given the mass percent composition.***

Component	Mass percent (%)	Mass (kg)	Molecular weight (kg/kmol)	No. of moles (mol)	**Mole fraction**
Butane	40	m=40%x100 =40	58.12	n= m/MW =40/58.12 =0.6882	$x_i = n/n_T$ =0.6882/1.4408 =**0.4777**

Hexane	35	35	86.18	0.4061	**0.2819**
Pentane	25	25	72.15	0.3465	**0.2405**
Total	100	m_T=100		n_T=1.4408	1.00

b) ***Hint: The basis of the total air is assumed to be 100 moles. The mole of each gas in the dry air is then calculated given the mole percent composition.***

Component	Mole percent (%)	No. of moles (mol)	Molecular weight (g/mol)	Mass (g)	Mass fraction	**Mass percent (%)**
O_2	21	n=21%x100 =21	32	m= nxMW =21x32 =672	x_i= m/m_T =672/2899.8 =0.2317	**23.17**
N_2	79	79	28.2	2227.8	0.7683	**76.83**
Total	100	n_T=100		m_T=2899.8	1.00	100

Let's try!

a) An aqueous solution contains 35% w/w solution of NaCl in 50 g of water. Calculate the mole fraction and mole percent of sodium chloride in the solution. (Ans. 0.14225 and 14.23%)

b) 50.0 g of water H_2O, and 5.0 g of sodium hydroxide NaOH are added together to produce a solution. Determine the mole fractions of each substance. (Ans. x_{H2O}=0.9569 and x_{NaOH}= 0.04306)

Guided Practice

a) An aqueous solution contains 35% w/w solution of NaCl in 50 g of water. Calculate the mole fraction and mole percent of sodium chloride in the solution.

1st step: Find mass of NaCl

$$0.35=\frac{x}{x+50}$$

$$x=26.923g$$

2nd step: Find no. of moles of NaCl and H_2O

$$n_{NaCl}=\frac{m}{MW}=\frac{26.923g}{58.44g/mol}=0.46069\ mol$$

$$n_{H2O}=\frac{m}{MW}=\frac{50g}{18g/mol}=2.7778\ mol$$

Total moles=n_T=3.2385 mol

3rd step: Calculate the mole fraction

$$x_{NaCl}=\frac{n_{NaCl}}{n_T}=\frac{0.46069}{3.2385}=0.14225$$

4th step: Calculate the mole percent

Mole percent of NaCl

$=x_{NaCl}\times 100\%$

$=0.14225\times 100\%=14.23\%$

Self-Practice

Now your turn to answer questions b.

b)

PAST YEAR QUESTION

***Example 1-4* Density and Specific Gravity**

The specific gravity for Ethylene glycol, $C_2H_6O_2$ is 1.1088. Calculate its density in

a) g/cm^3

b) lb_m/ft^3

c) kg/m^3

If no temperatures for the substance are cited, assume the temperature for a), b) and c) cases are the same and the reference compound is water.

SOLUTION

Hint: Multiply the specific gravity of a substance to the reference density in any units

Remember: The density ρ_{ref} of a reference substance (water) is as below:

ρ_{ref} (4°C)
$=1.000\ g/cm^3$
$=1000\ kg/m^3$
$=62.43\ lb_m/ft^3$

a) $\rho_{C_2H_6O_2}=SG\times\rho_{ref}$

$$\rho_{C_2H_6O_2}=1.1088\times 1.000\frac{g}{cm^3}=1.1088\frac{g}{cm^3}$$

a) $\rho_{C_2H_6O_2}=SG\times\rho_{ref}$

$$\rho_{C_2H_6O_2}=1.1088\times 62.43\frac{lb_m}{ft^3}=69.22\frac{lb_m}{ft^3}$$

b) $\rho_{C_2H_6O_2}=SG\times\rho_{ref}$

$$\rho_{C_2H_6O_2}=1.1088\times 1000\frac{kg}{m^3}=1108.8\frac{kg}{m^3}$$

Let's try!

a) Calculate the mass in kg of 666 litre of Dimethyl carbonate. The specific gravity of Dimethyl carbonate is 1.06360. (Ans. m=708.36 kg)

b) Calculate the density in lb_m/ft^3 and the volume in ft^3 of 486 kg of mercury. Given that the specific gravity of mercury at 20°C as 13.6. (Ans. ρ=849.048 $\frac{lb_m}{ft^3}$ and V=1.2619 ft^3)

Guided Practice

a) Calculate the mass in kg of 666 L of Dimethyl carbonate. The specific gravity of Dimethyl carbonate is 1.06360.

1st step: Calculate the density of the Dimethyl carbonate

$\rho_{C_3H_6O_3}=SG\times\rho_{ref}$

$\rho_{C_3H_6O_3}=1.06360\times1000\,\frac{kg}{m^3}=1063.6\,\frac{kg}{m^3}$

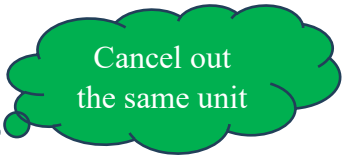
2nd step: Determine the relationship between density and mass.

$$Density=\frac{Mass}{Volume}$$

$$\rho=\frac{m}{V}$$

3rd step: Calculate mass with density and volume.

$m=\rho V$



$m=1063.6\,\frac{kg}{m^3}\times666\,L\times\frac{1m^3}{1000L}$

$m=708.36\,kg$

Self-Practice

Now your turn to answer questions b.

b)

***Example 1-5* Average Molecular Weight**

a) A gas mixture used as an artificial atmosphere for divers containing 80% O_2 (MW=32 g/mol) and 20% He (MW=4g/mol). Calculate the mole fraction of each component and the average molecular weight of the mixture.

The average molecular weight of a mixture is the ratio of the mass of a sample of the mixture to the number of moles of all species in the sample.

SOLUTION

Hint: A convenient basis of 100 moles is often a good choice for a gas.

Basis: 100 moles

Component	Mole percent (%)	No. of moles (mol)	**Mole fraction**	Molecular weight (g/mol)	Mass (g)
O_2	80	n=80%x100 =80	$x_i = n/n_T$ =80/100 =0.8	32	m= nxMW =80x32 =2560
He	20	20	0.2	4	80
Total	100	n_T=100	1.0		m_T=2640

Average molecular weight, $\bar{M} = \frac{\text{Total mass}}{\text{Total mol}} = \frac{2640}{100} = 26.4$ g/mol

b) Calculate the average molecular weight of a liquid mixture that has the following compositions: Methanol CH_3OH 60% (MW= 32.04 g/mol), Ethanol C_2H_6O 30% (MW= 46.068 g/mol), and water H_2O 10% (MW=18) by weight.

Hint: A convenient basis of 100 g is often a good choice for liquids.

Basis: 100 g

Component	Mass percent (%)	Mass (g)	Molecular weight (g/mol)	No. of moles (mol)
Methanol	60	m=60%x100 =60	32.04	n =m/MW =60/32.04 =1.8727
Ethanol	30	30	46.068	0.6512
Water	10	10	18	0.5556
Total	100	m_T=100		n_T=3.0795

Average molecular weight, $\bar{M}=\frac{\text{Total mass}}{\text{Total mol}}=\frac{100}{3.0795}=32.47$ g/mol

Let's try!

a) Spray paints contain 50% Acetone C_3H_6O (MW=58.08 g/mol), 20% Xylene C_8H_{10} (MW=106.16 g/mol), 25% Propane C_3H_8 (MW=44.097 g/mol) and 5% Toluene C_7H_8 (MW=92.14 g/mol) on a mole basis. Calculate the average molecular weight of the gas mixture. (Ans. 65.9 g/mol)

b) DMC-MeOH mixture was produced in methanolysis reaction. The liquid mixture contains 35% Methanol CH_3OH (MW= 32.04 g/mol), 15% Ethylene glycol C_2H_6O (MW= 62.07 g/mol), and 50% Dimethyl carbonate $C_3H_6O_3$ (MW=90.08 g/mol) by weight. Calculate the average molecular weight of the liquid mixture. (Ans. 52.93 g/mol)

Guided Practice

a) Spray paints contain 50% Acetone C_3H_6O (MW=58.08 g/mol), 20% Xylene C_8H_{10} (MW=106.16 g/mol), 25% Propane C_3H_8 (MW=44.097 g/mol) and 5% Toluene C_7H_8 (MW=92.14 g/mol) on a mole basis. Calculate the average molecular weight of the gas mixture.

1st step

Basis: 100 moles

Component	Mole percent (%)	No. of moles (mol)	Molecular weight (g/mol)	Mass (g)
Acetone	50	n=50%x100 =50	58.08	m= nxMW = 50x58.08 = 2904
Xylene	20	20	106.16	2123.2
Propane	25	25	44.097	1102.43
Toluene	5	5	92.14	460.7
Total	100	n_T=100		m_T=6590.33

2nd step

3rd step

4th step

Average molecular weight, $\bar{M}=\frac{\text{Total mass}}{\text{Total mol}}=\frac{6590.33}{100}=65.9$ g/mol

Self-Practice

Now your turn to answer questions b.

b)

PAST YEAR QUESTION

***Example 1-6* Concentrations**

a) 93.52 g NaCl is dissolved in 800 ml of water. The resulting solution has a density of 1.117 g/mL. Given the density of water is 1 g/mL. Calculate

i. the mole fraction of NaCl and water

ii. the mass percent of the NaCl

iii. the molality of the solution

iv. the molarity of the solution

SOLUTION

$$m_{H20}=V\times\rho$$

$$m_{H20}=800mL\times\frac{1g}{mL}=800g$$

$$n_{H20}=\frac{m}{MW}=\frac{800g}{18g/mol}=44.44\ mol$$

$$n_{NaCl}=\frac{m}{MW}=\frac{93.52g}{58.44g/mol}=1.6003\ mol$$

i. the mole fraction of NaCl and water

$$X_{NaCl}=\frac{mol\ NaCl}{total\ mol}=\frac{1.6003moles}{(1.6003+44.44)moles}=0.0348$$

$$X_{H2O}=\frac{mol\ H20}{total\ mol}=\frac{44.44moles}{(1.6003+44.44)moles}=0.9652$$

ii. the mass percent of the NaCl

$$\text{Mass percent} = \frac{\text{g NaOH}}{\text{total g solution}} \times 100\%$$

$$\text{Mass percent} = \frac{93.52\text{g NaOH}}{(93.52+800)\text{g solution}} \times 100\% = 10.47\%$$

iii. the molality of the solution

$$m = \frac{\text{mol NaCl}}{\text{kg H20}} = \frac{1.6003\text{ mol}}{0.8\text{kg}} = 2\text{ m}$$

iv. the molarity of the solution

$$V_{solution} = (800+93.52)\text{g} \times \frac{1\text{mL}}{1.117\text{g}} \times \frac{1\text{L}}{1000\text{mL}} = 0.7999\text{L}$$

$$M = \frac{\text{mol NaCl}}{\text{L solution}} = \frac{1.6003\text{ mol}}{0.7999\text{L}} = 2\text{ M}$$

b) Express 100 ppb mercury concentration in molarity.

Hint: 100 ppb: 100 g Hg/10^9 g solution

The molarity formula:

$$\text{Molarity, M}=\frac{\text{moles of solute, n}}{\text{liters of solution, V}}=\frac{\text{mol}}{\text{L}}$$

The moles of the Hg:

$$n=\frac{m}{MW}$$

$$n=\frac{100\ \text{g}}{200.59\ \text{g/mol}}=0.4985\text{mol}$$

The volume of the solution:

$$V=\frac{m}{\rho}$$

$$V=\frac{10^9\ \cancel{\text{g}}}{}\times\frac{\cancel{\text{mL}}}{1\cancel{\text{g}}}\times\frac{1\text{L}}{1000\cancel{\text{ml}}}=10^6\text{L}$$

The molarity of the solution:

$$\text{Molarity, M}=\frac{\text{moles of solute, n}}{\text{liters of solution, V}}=\frac{0.4985\text{mol}}{10^6\text{L}}=4.985\times10^{-7}\text{M}$$

Let's try!

a) Determine the molarity of 10% w/w ethanol (density 0.983 g/mL). (Ans. 2.135M)

b) Express 20 ppm Cu concentration in molarity. (Ans.3.147×10^{-3}M)

Guided Practice

a) Determine the molarity of 10% w/w ethanol (density 0.983 g/mL).

10%: 10 g ethanol/100 g solution

1st step: Identify the molarity formula

$$\text{Molarity, M}=\frac{\text{moles of solute, n}}{\text{liters of solution, V}}=\frac{\text{mol}}{\text{L}}$$

2nd step: Calculate the moles of the ethanol

$$n=\frac{m}{MW}$$

$$n=\frac{10\ g}{46.068\ g/mol}=0.2171 mol$$

3rd step: Calculate the volume of the solution

$$V=\frac{m}{\rho}$$

$$V=\frac{100\ \cancel{g}}{}\times\frac{\cancel{mL}}{0.983\cancel{g}}\times\frac{1L}{1000\cancel{ml}}=0.1017L$$

4th step: Perform mathematical operation

$$\text{Molarity, M}=\frac{\text{moles of solute, n}}{\text{liters of solution, V}}=\frac{0.2171 mol}{0.1017L}=2.135M$$

Self-Practice

Now your turn to answer questions b.

b)

PAST YEAR QUESTION

Past Year Questions

QUESTION 1

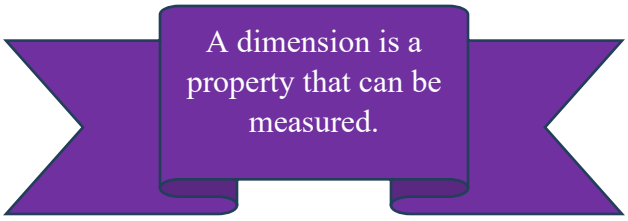
(a) State **FOUR (4)** dimensions in basic concept of measurement. [4 marks]

Length

Time

Mass

Temperature



(b) The specific gravity of formaldehyde is 0.815.

i). Calculate the mass in kg of 3550 ml of formaldehyde. [5 marks]

The density of the reference substance (water)

$$\text{Density benzene} = SG(\rho_{ref}) = 0.815(1000 kg/m^3)$$

$$= 815 kg/m^3$$

Leave the desired units: kg

Cancel out the same unit

$$\text{mass} = \frac{815 kg}{m^3} \left| \frac{3550 ml}{} \right| \frac{1 m^3}{10^6 ml}$$

$$= 2.893 kg$$

ii). Calculate the volumetric flow rate in ml/min corresponding to a mass flow rate of 65.0 Ib_m formaldehyde/hr. [4 marks]

Remember!

Volumetric flow rate, $\dot{V} = \frac{\text{Mass flow rate, } \dot{m}}{\text{Density, } \rho}$

$$\dot{V} = \frac{65\text{lbm}}{\text{hr}} \left| \frac{\text{m}^3}{815\text{kg}} \right| \frac{1\text{kg}}{2.20462\text{lbm}}$$

Cancel out the same unit

$$= \frac{0.0362\text{m}^3}{\text{hr}} \left| \frac{10^6\text{ml}}{1\text{m}^3} \right| \frac{1\text{hr}}{60\text{min}}$$

Leave the desired units: ml/min

$$= 603.33\text{ml/min}$$

c) The following contains 687.6 gram of pentane, C_5H_{12}. Given the atomic weight of carbon, C is 12.0 g/mol and hydrogen, H is 1.0 g/mol. Avogadro's number is 6.02×10^{23}.

i). Calculate the number of mole pentane, C_5H_{12}. [4 marks]

Molecular weight of butane = 5(12)+12(1) =72 g/mol

Cancel out the same unit

Leave the desired units: mol

$$\text{Mol of pentane} = \frac{687.6\text{g}}{} \times \frac{\text{mol}}{72\text{ g}} = 9.55\text{ mol}$$

Remember!

No. of moles, $\dot{n} = \frac{\text{Mass of substance, m}}{\text{Molecular Weight}}$

ii). Calculate the mass in gram (g) of H_2. [4 marks]

Remember!

Mass of substance, m=No. of moles, ṅ × Molecular Weight

1 mol C_5H_{12} → 6 mol H_2

9.55 mol C_5H_{12} → 6×9.55mol H_2

Refer to c(i)'s answer

=57.3 mol H_2

The subscripts of an empirical formula are whole numbers and represent the mole ratio of the elements in the compound.

$$\text{Mass of } H_2 = 57.3 \text{ mol} \times \frac{2(1)\text{g}}{\text{mol}} = 114.65 \text{ g}$$

iii). Calculate the number of atom C. [4 marks]

Refer to c(i)'s answer

1 mol C_5H_{12} → 5 mol C

9.55 mol C_5H_{12} → 5×9.55 mol C

=47.75 mol of C

Avogadro's number

Atom C = $47.75 \times 6.02 \times 10^{23}$

= 2.87×10^{25}

PAST YEAR QUESTION COLLECTION

Return to subtopic 1.3

Return to subtopic 1.4

Return to subtopic 1.5

Return to subtopic 1.6

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BIOGRAPHY

Pn Hafizah binti Naihi and Dr Muhamad Nazri bin Abu Shah are currently posted as lecturers in the Department of Petrochemical Engineering, JKPK at the Politeknik Kuching Sarawak. Both authors have received their undergraduate degrees in chemical engineering and specialize in teaching diploma students in the Department of Petrochemical Engineering, Politeknik Kuching Sarawak.

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