STOICHIOMETRY

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

STOICHIOMETRY

Elements Measure

Stoichiometry
Calculate quantities of substances in chemical reactions

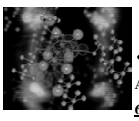
For a balanced chemical equation, the Coefficients show:
 # formula units that react
mole ratio of reactants & products
(with molar mass) # grams of reactants & products

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mole Map (One Chemical Entity)



Avagadro's
$\frac{6.02 \times 10^{23} \text{ fu}}{\text{mole}}$

Molar Mass
g / mole

Atomic Units **Moles** **Grams**

Avogadro's Number: From Memory
Molar Mass: Calculated from Periodic Table
Let the Units Drive the Solution!

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Stoichiometry (For Two Chemical Entities)

Think Molar Ratio

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Molecule – Molecule Stoichiometry

$2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$

Molecular Interpretation:

2 *molecules* C_2H_6 (ethane) react with 7 *molecules* O_2 to form 4 *molecules* CO_2 & 6 *molecules* H_2O

Burning fossil fuels is major contributor to global warming

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Molecule – Molecule Stoichiometry

$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$

How many O_2 molecules react with 308 molecules NH_3?

Given (known) = 308 molecules NH_3
Wanted = # molecules O_2

308 molecules NH_3 = # molecules O_2

Need "per" expression (from balanced chemical reaction) to convert molecules of ammonia to molecules oxygen

$$308 \text{ molecules } NH_3 \times \frac{5\ O_2 \text{ molecules}}{4\ NH_3 \text{ molecules}} = 385\ O_2 \text{ molecules}$$

From Coefficients of BALANCED Reaction

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mole – Mole Stoichiometry

$2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$

Molar Interpretation:

2 *moles* C_2H_6 (ethane) react with 7 *moles* O_2 to form 4 *moles* CO_2 & 6 *moles* H_2O

Burning fossil fuels is major contributor to global warming

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mole – Mole Stoichiometry

$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$

How many moles H_2O are formed from 4 moles NH_3?

Given (known) = 4 moles NH_3
Wanted = # moles H_2O

Need "per" expression (from balanced chemical reaction) to convert molecules of ammonia to molecules oxygen

$$4 \text{ mole } NH_3 \times \frac{6\ H_2O \text{ moles}}{4\ NH_3 \text{ moles}} = 6\ H_2O \text{ moles}$$

From Coefficients of BALANCED Reaction

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Stoichiometry: Per Expressions

$2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$

Relating C_2H_6 (ethane) to other components

$\frac{2 \text{ moles } C_2H_6}{7 \text{ moles } O_2}$ $\frac{2 \text{ moles } C_2H_6}{4 \text{ moles } CO_2}$ $\frac{2 \text{ moles } C_2H_6}{6 \text{ moles } H_2O}$

2 moles of C_2H_6 corresponds to:
7 moles O_2
4 moles CO_2
6 moles H_20

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Stoichiometry: Per Expressions

$2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$

"per expressions" (Conversion factors)
based on coefficients of balanced equation

$\frac{2\ \text{moles}\ C_2H_6}{7\ \text{moles}\ O_2}$ $\frac{2\ \text{moles}\ C_2H_6}{6\ \text{moles}\ H_2O}$ $\frac{2\ \text{moles}\ C_2H_6}{4\ \text{moles}\ CO_2}$

$\frac{7\ \text{moles}\ O_2}{2\ \text{moles}\ C_2H_6}$ $\frac{7\ \text{moles}\ O_2}{4\ \text{moles}\ CO_2}$ $\frac{7\ \text{moles}\ O_2}{6\ \text{moles}\ H_2O}$

$\frac{4\ \text{moles}\ CO_2}{2\ \text{moles}\ C_2H_6}$ $\frac{4\ \text{moles}\ CO_2}{7\ \text{moles}\ O_2}$ $\frac{4\ \text{moles}\ CO_2}{6\ \text{moles}\ H_2O}$

$\frac{6\ \text{moles}\ H_2O}{2\ \text{moles}\ C_2H_6}$ $\frac{6\ \text{moles}\ H_2O}{7\ \text{moles}\ O_2}$ $\frac{6\ \text{moles}\ H_2O}{4\ \text{moles}\ CO_2}$

Molar Ratio
Relates Any 2
Chemical Entities

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Stoichiometry: Per Expressions

Always has the form:

$\frac{\text{Moles wanted in next step}}{\text{Moles canceled in previous step}}$

Relates moles (never grams) chemical entities via coefficients of the balanced chemical reaction

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mole – Mole Stoichiometry

How many moles of oxygen are required to burn 2.4 moles ethane?

$2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$

Given = 2.4 moles ethane
Wanted = moles oxygen

Use "per" expression from the balanced reaction

$2.4\ \text{moles ethane} \times \frac{7\ \text{moles oxygen}}{2\ \text{moles ethane}} = 8.4\ \text{moles}\ O_2$

Just another unit "cancelation"

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mole – Mole Stoichiometry

Ammonia is formed from its elements.
How many moles of hydrogen are needed to produce 4.2 moles ammonia?

Write equation: $N_2 + H_2 \rightarrow NH_3$

Balance Equation: $N_2 + 3\,H_2 \rightarrow 2\,NH_3$

Add "per expression" to move from given to wanted:

$$4.2 \text{ moles } NH_3 \times \frac{3 \text{ moles } H_2}{2 \text{ moles } NH_3} = \#\text{ moles } H_2$$

Do the math:

$$4.2 \text{ moles } NH_3 \times \frac{3 \text{ moles } H_2}{2 \text{ moles } NH_3} = 6.3 \text{ moles } H_2$$

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mole – Mole Stoichiometry

How many moles of C_2H_4 can be oxidized by 1.35 mol O_2?

$$C_2H_4 + 3\,O_2 \rightarrow 2\,CO_2 + 2\,H_2O$$

Given = 1.35 moles oxygen
Wanted = moles ethylene

1.35 mol O_2 = moles C_2H_4

Convert moles given to moles wanted via "per" expression

$$1.35 \text{ mol } O_2 \times \frac{1 \text{ mole } C_2H_4}{3 \text{ mole } O_2} = \text{moles } C_2H_4$$

Units correct; do the math

$$1.35 \text{ mol } O_2 \times \frac{1 \text{ mole}}{3 \text{ mole } O_2} = 0.450 \text{ moles } C_2H_4$$

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mass – Mass Stoichiometry

Types of problems that coefficients + molar mass solve:

grams (given) → moles (wanted)
moles (given) → moles (wanted)
moles (given) → grams (wanted)
grams (given) → grams (wanted)

"Per" Expression" (Molar Ratio)
Molar Mass
Grams → Moles → Moles → Grams
Molar Mass
Given Wanted

Just another
What is known?
What is wanted?
How do I get there by "canceling units"?
Type problem

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mass – Mole Stoichiometry

How many moles of oxygen are needed to form 43.7 g H_2O?

$C_2H_4 + 3\ O_2 \rightarrow 2\ CO_2 + 2\ H_2O$

Given = 43.7 grams water
Wanted = moles oxygen

43.7 g H_2O = moles O_2

Molar mass: water: 18.02 g/mole

Set up linear string of per expressions:

$$43.7\ g\ H_2O \times \frac{1\ mole\ H_2O}{18.02\ g} \times \frac{3\ mole\ O_2}{2\ mole\ H_2O} = moles\ O_2$$

Units correct; do the math:

$$43.7\ g\ H_2O \times \frac{1\ mole\ H_2O}{18.02\ g} \times \frac{3\ mole\ O_2}{2\ mole\ H_2O} = 3.64\ moles\ O_2$$

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

Let the units drive the solution

LPT

Mole – Mass Stoichiometry

How many grams of CO_2 form by burning 0.739 mole C_2H_4?

$C_2H_4 + 3\ O_2 \rightarrow 2\ CO_2 + 2\ H_2O$

Given = 0.739 mole ethylene
Wanted = grams carbon dioxide

0.739 mol C_2H_4 = # g CO_2

Molar Mass carbon dioxide: 44.01 g/mole

Set up linear string of per expressions:

$$0.739\ mol\ C_2H_4 \times \frac{2\ mol\ CO_2}{1\ mol\ C_2H_4} \times \frac{44.01\ g}{1\ mole\ CO_2} = \#\ g\ CO_2$$

Units correct; do the math:

$$0.739\ mol\ C_2H_4 \times \frac{2\ mol\ CO_2}{1\ mol\ C_2H_4} \times \frac{44.01\ g}{1\ mole\ CO_2} = 65.0\ g\ CO_2$$

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

Let the units drive the solution

LPT

Mass – Mass Stoichiometry

How many grams of oxygen required to burn 155 g ethane?

$2\ C_2H_6 + 7\ O_2 \rightarrow 4\ CO_2 + 6\ H_2O$

Molar masses: ethane: 30.07 g/mole ; oxygen: 32.00 g/mole

Start with given (g) and convert to moles using molar mass:

$$155\ g\ C_2H_6 \times \frac{1\ mole\ C_2H_6}{30.07\ g} = \#\ g\ O_2$$

Convert moles known to moles wanted with "per expression"

$$155\ g\ C_2H_6 \times \frac{1\ mole\ C_2H_6}{30.07\ g} \times \frac{7\ Moles\ O_2}{2\ Moles\ C_2H_6} = \#\ g\ O_2$$

Convert moles oxygen to grams oxygen using molar mass:

$$155\ g\ C_2H_6 \times \frac{1\ mol\ C_2H_6}{30.07\ g} \times \frac{7\ Mol\ O_2}{2\ Mol\ C_2H_6} \times \frac{32.00\ g}{1\ mol} = \#\ g\ O_2$$

Units correct; do the math:

$$155\ g\ C_2H_6 \times \frac{1\ mol\ C_2H_6}{30.07\ g} \times \frac{7\ Mol\ O_2}{2\ Mol\ C_2H_6} \times \frac{32.00\ g}{1\ mol} = 577\ g\ O_2$$

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Mass – Mass Stoichiometry

How many grams of Al must react with O_2 to form 43.6 grams of Al_2O_3?

$$4\ Al + 3\ O_2 \rightarrow 2\ Al_2O_3$$

Given = 43.6 grams Al_2O_3

Wanted = grams Al

Molar masses: Al = 26.98 g/mole; Al_2O_3 = 101.96 g/mole

Set up linear string of per expressions:

$$43.6\ g\ Al_2O_3 \times \frac{1\ mole\ Al_2O_3}{101.96\ g} \times \frac{4\ moles\ Al}{2\ moles\ Al_2O_3} \times \frac{26.98\ g\ Al}{1\ mole} = \#\ g\ Al$$

Units correct; do the math:

$$43.6\ g\ Al_2O_3 \times \frac{1\ mole\ Al_2O_3}{101.96\ g} \times \frac{4\ moles\ Al}{2\ moles\ Al_2O_3} \times \frac{26.98\ g\ Al}{1\ mole} = 23.1\ g\ Al$$

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

Let the units drive the solution

LPT

If the density of water is 1.00 g/mL, how many mL of H_2O are produced when 6.70 moles of HNO_3 reacts with KOH?

$$HNO_{3(aq)} + KOH_{(aq)} \rightarrow KNO_{3(aq)} + H_2O_{(l)}$$

$$6.70\ mol\ HNO_3 \times \frac{1\ mol\ H_2O}{1\ mol\ HNO_3} \times \frac{18.02\ g\ H_2O}{1\ mol\ H_2O} \times \frac{1\ mL\ H_2O}{1.00\ g\ H_2O} = 121\ mL$$

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT

Generalized Pathway

"Per" Expression" (Molar Ratio)

Grams → Moles → Moles → Grams

Molar Mass (Grams → Moles) | Molar Mass (Moles → Grams)

Given **Wanted**

Entry & Exit Points Depend On

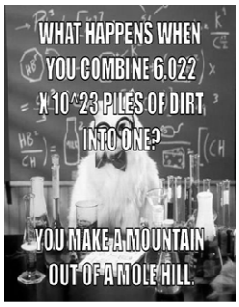
Given

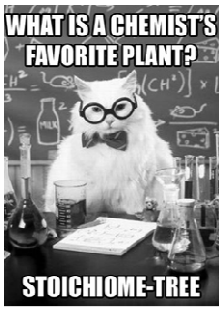
Wanted

Let the units drive the solution

Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT





Copyright Larry P. Taylor, Ph.D. All Rights Reserved

LPT