Stoichiometry

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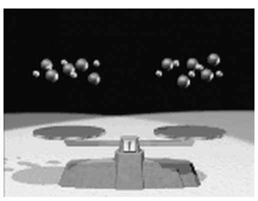
Chemical Stoichiometry

- Stoichiometry is the study of mass in chemical reactions. It deals with both reactants and products.
- It quantitatively and empirically relates the behavior of atoms and molecules in a balanced chemical equation to observable chemical change and measurable mass effects.
- It accounts for mass and the conservation of mass, just as the conservation of atoms in a balanced chemical equation.

Chemical Reactions

Atoms, Mass & Balance: eg. Zn(s) + S(s) ⟶



Stoichiometry

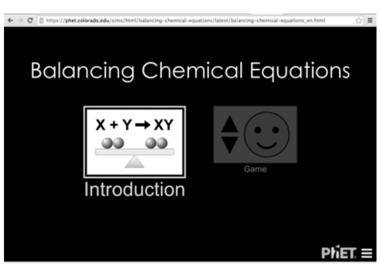
Must begin with a correctly balanced equation:

$$\_\ C_2H_5OH\ +\ \_\ O_2\ \rightarrow\ \_\ CO_2\ +\ \_\ H_2O$$

Reactants *Products*

- *C=2; H =5+1=6; O=2+1* *C=1; H=2; O=2+1*
- $\underline{\quad 1}\ C_2H_5OH\ +\ \underline{3}\ O_2\ \rightarrow\ \underline{2}\ CO_2\ +\ \underline{3}\ H_2O$

https://phet.colorado.edu/sims/html/balancing-chemical-equations/latest/balancing-chemical-equations_en.html



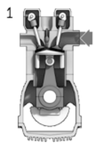
Chemical Equation

$$C_2H_5OH\ +\ 3\ O_2\ \rightarrow\ 2\ CO_2\ +\ 3\ H_2O$$

The balanced equation can be completely stated as:

- *1 mole of ethanol reacts with 3 moles of oxygen to produce 2 moles of carbon dioxide and 3 moles of water.*

Chemical Equation



All Balanced Equations relate on a molar mass basis. For example the combustion of octane:

$$2\ C_8H_{18(l)} + 25\ O_{2(g)} \longrightarrow 16\ CO_{2(g)} + 18\ H_2O_{(l)}$$

***2 moles** of octane react with **25 moles** of oxygen to produce **16 moles** of carbon dioxide and **18 moles** of water.*

The Chemical Equation: Mole & Masses

$$C_2H_5OH\ +\ 3\ O_2\ \rightarrow\ 2\ CO_2\ +\ 3\ H_2O$$

- *46g (1 mole) of ethanol reacts with 3 moles of oxygen (96g) to produce 2 moles of carbon dioxide and 3 moles of water.*
- *How many grams of carbon dioxide and water are respectively produced from 46g (1 mole) of ethanol ?*

2 mol x 44 g/mol = 88g *3 mol x 18 g/mol = 54 g*

The Chemical Equation: Moles & Masses

- $C_2H_5OH\ +\ 3\ O_2\ \rightarrow\ 2\ CO_2\ +\ 3\ H_2O$
- *How many grams of oxygen are needed to react with 15.3g of ethanol in a 12oz. beer ?*

$$15.3g_{ethanol}\ x\ mol_{ethanol}/46.0g_{ethanol} = 0.333mol_{ethanol}$$

$$0.333mol_{ethanol}\ x\ 3mol_{oxygen} / 1mol_{ethanol} = 0.999mol_{oxygen}$$

$$32.0g_{oxygen}/mol_{oxygen}\ x\ 0.999mol_{oxygen} = 32.0g_{oxygen}$$

NOTE: It takes approximately 1 hour for the biologically equivalent amount of oxygen available from cytochrome p450 to consume the alcohol in a human in 1 beer to a level below the legal limit of 0.08%.

Chemical Stoichiometry

- *Epsom salt (magnesium sulfate heptahydrate) is one of five possible hydrates: mono-, di-, tri-, hexa-, or hepta- hydrate.*
- *How can stoichiometry be used to determine, which hydrate is present in a pure unknown sample, by heating the sample in a kitchen oven at 400 º C for 45 minutes?*

$$MgSO_4 \cdot x\ H_2O_{(s)} \rightarrow MgSO_{4\ (s)} + x\ H_2O_{\ (g)}$$

Refer to % Hydrate Lab Experiment.

Mass Calculations

All Balanced Equations relate on a molar and mass basis. For the combustion of octane:

$$2\ C_8H_{18(l)} + 25\ O_{2(g)} \longrightarrow 16\ CO_{2(g)} + 18\ H_2O_{(l)}$$

*228 g of octane **(2 moles)*** *will react with 800 g of oxygen **(25 moles)** to produce **(16 moles)** 704 g of carbon dioxide and **(18 moles)** 324 g of water.*

(2 moles octane x 114 g/mol = 228 g)

Mass Calculations: Reactants ⟵ Products

Chemically Relate:

Something (S) ⟶ Another Thing (AT)

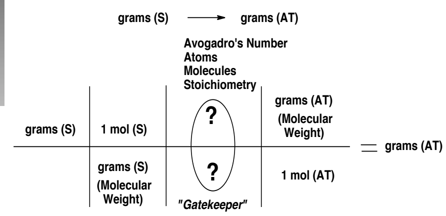
Mass (S) ⟶ Mass (AT)

grams (S) ⟶ grams (AT)

Mass Calculations: Reactants ⟷ Products

1. *Balance the chemical equation.*
2. *Convert mass of reactant or product to moles.*
3. *Identify mole ratios in balanced equation: They serve as the "Gatekeeper".*
4. *Calculate moles of desired product or reactant.*
5. *Convert moles to grams.*

Mass Calculations: Reactants ⟷ Products



QUESTION

The fuel in small portable lighters is butane (C_4H_{10}). After using a lighter for a few minutes, 1.0 gram of fuel was used. How many moles of carbon dioxide would it produce?

A. 58 moles
B. 0.017 moles
C. 1.7×10^{-24} moles
D. 0.068 moles

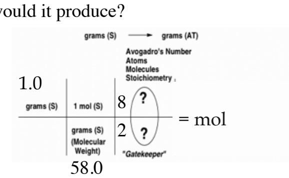
? $C_4H_{10}(g)$ + ? $O_2(g) \rightarrow$? $CO_2(g)$ + ? $H_2O(g)$

$2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g)$

ANSWER

The fuel in small portable lighters is butane (C_4H_{10}). After using a lighter for a few minutes, 1.0 gram of fuel was used. How many moles of carbon dioxide would it produce?

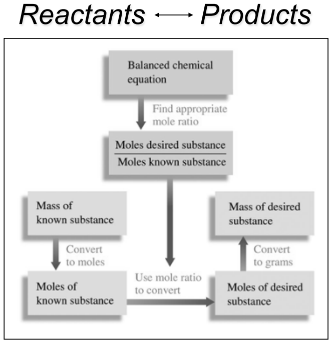
A. 58 moles
B. 0.017 moles
C. 1.7×10^{-24} moles
D. 0.068 moles



$2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g)$

The molar mass of butane: 4 × 12g/mol = 48 for carbon + 10 × 1g/mol = 10.0 for hydrogen. Total = 48.0 + 10.0 = 58.0 g/mol. Next; 1.0 gram of butane × 1 mol/58.0 g = 0.017 mol x 8 mol/2 mol =

Mass Calculations: Reactants ⟷ Products



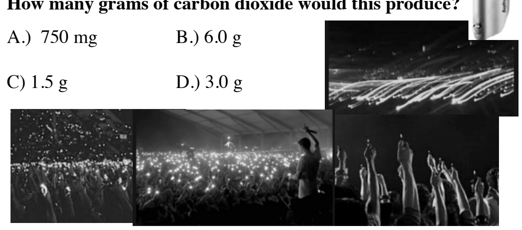
QUESTION

The fuel in small portable lighters is butane (C_4H_{10}). After using a lighter for a short time, 1.0 grams (0.068 moles) of fuel was used.

$2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g)$

How many grams of carbon dioxide would this produce?

A.) 750 mg
B.) 6.0 g
C) 1.5 g
D.) 3.0 g



ANSWER

D.) 3.0 g

2 $C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g)$

1.0 **g** $\mathbf{C_4H_{10}}$ → ? g $\mathbf{CO_2}$

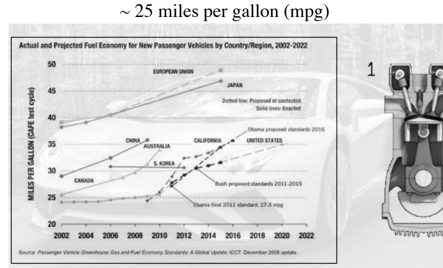
grams (S) → grams (AT)

(0.068 moles)

Avogadro's Number
Atoms
Molecules

1.0 g $\mathbf{C_4H_{10}}$ grams (S)	mol $\mathbf{C_4H_{10}}$ 1 mol (S)	8 mol CO_2	44 g $\mathbf{CO_2}$ grams (AT) (Molecular Weight)	= 3.0 g CO_2 grams (AT)
	grams (S) (Molecular Weight) 58 g $\mathbf{C_4H_{10}}$	2 mol C H	1 mol (AT) mol $\mathbf{CO_2}$	

An average mileage for an automobile in the US has been ~ 25 miles per gallon (mpg)



$2\ C_8H_{18}(g) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$
+ energy

How many pounds of carbon dioxide would be produced if you drove 25 miles in an average automobile?

$2\ C_8H_{18}(g) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$

2020 Chevrolet Spark

1.4 L, 4 cyl, Automatic (variable gear ratios)
MSRP: $16,220 - $17,320

Regular Gasoline
33 MPG combined city/highway; 30 city, 37 highway; 3.0 gal/100mi

2020 Lamborghini Aventador Coupe

Premium Gasoline
11 MPG combined city/highway; 9 city, 15 highway; 9.1 gals/100 miles

4 cyl, 1.5 L

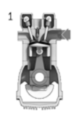
Regular Gasoline
25 MPG combined city/highway; 25 city, 26 highway; 4.0 gals/100 miles

2020 Mitsubishi Eclipse

$2\ C_8H_{18}(g) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$

1.0 **gal** $\mathbf{C_8H_{18}}$ → ? lb $\mathbf{CO_2}$

1.0 **gal** x 3.785 L/gal x 1000 mL/L x 0.70 g/mL = 2649.5 g



grams (S) → grams (AT)

Avogadro's Number
Atoms
Molecules

2649.5 g $\mathbf{C_8H_{18}}$ grams (S)	mol $\mathbf{C_8H_{18}}$ 1 mol (S)	16 mol CO_2	44 g $\mathbf{CO_2}$ grams (AT) (Molecular Weight)	= 8181 g CO_2 grams (AT)
	grams (S) (Molecular Weight) 114 g $\mathbf{C_8H_{18}}$	2 mol C_8H_{18}	1 mol (AT) mol $\mathbf{CO_2}$	18.02 lbs

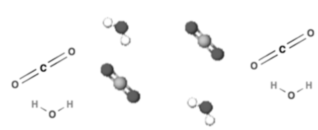
About the weight of a 7 mo. old baby

Carbon Molecules

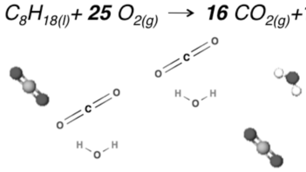
ENERGY & Life Styles

#3
https://www.youtube.com/watch?v=Q9u8vM8YjeU&list=PLE7B4FAD08F1EBCE2&index=3

Making & Breaking Bonds



$2\ C_8H_{18(l)} + 25\ O_{2(g)} \rightarrow 16\ CO_{2(g)} + 18\ H_2O_{(l)}$ + **energy**



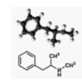
$2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(g)$

How many pounds of carbon dioxide would be produced if you drove 25 miles in a Lamborghini Aventura (11 mpg)?

18.0 **lbs** x 25 mi/11mi = 40.9 **lbs**

About the weight of a 5 yr. old child

Percent Yield



- *In synthesis as in any experimentation, it is very difficult and at most times impossible to be perfect. Therefore the actual yield (g) is measured and compared to the theoretical calculated yield (g). This is the percent yield:*
- *% Yield = actual (g) / theoretical (g) x 100*

Some DVC students may report percent yields greater than 100% in their first synthesis experiment. Hmmm?....... Why is this not theoretically possible without experimental error?

Theoretical (Yield) Mass Calculations
*Reactant → **Product***

grams (Reactant) → grams (Product)

Moles
Molar Mass

grams (R)	1 mol (R)	? mol (P)	grams (P)	= ? grams (P)
	grams (R)	? mol (R)	1 mol (P)	
	(*Divide*) by Molar Mass (R)	*"Gatekeepers" from Balanced reaction*	(*Multiply*) by Molar Mass (P)	

Theoretical (Yield) Mass Calculation

1 $C_{20}H_{24}N_2O_{(s)}$ + $H_{2\,(g)}$ → **1** $C_{20}H_{26}N_2O_{(s)}$
Ibogaine

3.03 grams ($C_{20}H_{24}N_2O$ Reactant) → **?** grams ($C_{20}H_{26}N_2O$ Product) ***Ibogaine***

308.4 g mol^{-1} Moles Molar Mass 310.4 g mol^{-1}

3.03 grams (R $C_{20}H_{24}N_2O$)	1 mol (R)	1 mol (P)	310.4 grams (P $C_{20}H_{26}N_2O$)	= **?** **3.05** grams (P)
	308.4 Grams (R $C_{20}H_{24}N_2O$)	1 mol (R)	1 mol (P)	
	(*Divide*) by Molar Mass (R $C_{20}H_{24}N_2O$)	*"Gatekeepers" from Balanced reaction*	(*Multiply*) by Molar Mass (P $C_{20}H_{26}N_2O$)	

QUESTION

- *A synthetic hydrogenation reaction produced 2.85g of Ibogaine, $C_{20}H_{26}N_2O$, a natural product with strong promise in treating heroin addiction (at least in Europe), the calculated theoretical yield was 3.05g, what is the % yield?*

A) 6.6% *B) 80.3%* *C) 93.4%* *D) 107%*

ANSWER

- *If a reaction produced 2.85g of Ibogaine, $C_{20}H_{26}N_2O$, a natural product with strong promise in treating heroin addiction, and the theoretical yield was 3.05g, what is the % yield?*

A) 6.6% *B) 80.3%* *C) 93.4%* *D) 107%*

% yield = 2.85g / 3.05g x 100
= 93.4%