

# UWO **CHEM 1302**

**Fall 2024, Chapter 1 Notes**



# Table of Contents

## Chapter 1. Stoichiometry Review

### 1.1. Introduction to Chemical Equations and Balancing

1.1.1. Balancing Reactions

1.1.2. Reaction Stoichiometry

1.1.3. Example

1.1.4. Polyatomic Ions

1.1.5. Example

1.1.6. Practice

### 1.2. Atoms, Molecules, and the Mole!

1.2.1. Moles

1.2.2. Example

1.2.3. Practice

1.2.4. Practice

### 1.3. Stoichiometry

1.3.1. Intro to Stoichiometry

1.3.2. Stoichiometry: Putting it All Together

1.3.3. Example

1.3.4. Example

1.3.5. Practice

1.3.6. Practice

### 1.4. Limiting Reagents

1.4.1. Introduction to Limiting Reagents

1.4.2. Example

1.4.3. Example

1.4.4. Example

1.4.5. Practice

### 1.5. Percent Yield

1.5.1. Percent Yield

1.5.2. Example

1.5.3. Practice

1.5.4. Practice

# 1. Stoichiometry Review

## 1.1 Introduction to Chemical Equations and Balancing

1.1.1

### Balancing Reactions

Reactions must be balanced before the stoichiometry can be analyzed.

**What makes a reaction balanced?**

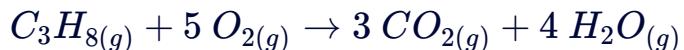
The number of \_\_\_\_\_ of each type on the \_\_\_\_\_ must equal the number of atoms of each type on the \_\_\_\_\_ of the reaction.

*Example:*

Unbalanced:

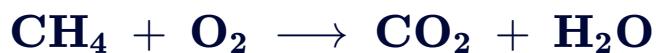


Balanced:



## Balancing Chemical Reactions

### Unbalanced Reaction



The **subscripts** tell us the ratio of different atoms in one molecule.

*Example:* One CH<sub>4</sub> molecule has 4 hydrogen atoms and 1 carbon atom

#### WATCH OUT!

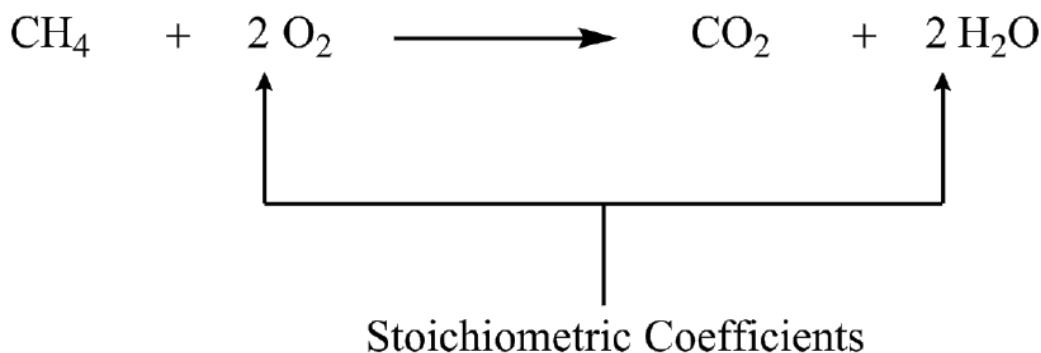
Sometimes you could be given unbalanced equations and you are expected to balance them!  
We **need to use the balanced equation for calculations** in order to get the correct answer!

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## Steps to Balance Chemical Equations

1. Balance **elements that only appear once** on the reactant side and once on the product side (typically elements not including C, N, H, O)
2. **Group polyatomic ions** and balance them as a group (not as separate elements, e.g. balance  $\text{NO}_3$  as 1  $\text{NO}_3$  group, not 1 N and 3 O)
3. **Balance all other elements**, starting with the least common elements to the most common elements
4. Make sure all **coefficients are whole numbers** AND are represented in the **simplest integer ratio possible**
5. **Check** to make sure all elements are balanced on each side of the chemical equation

## Balanced Reaction



- The **stoichiometric coefficients** of the balanced equation tell us that we need \_\_\_\_\_ oxygen molecules for each methane ( $\text{CH}_4$ ) molecule and we produce \_\_\_\_\_ waters for every methane consumed.
- It also tells us that for every 1 mole of methane used we produce \_\_\_\_\_ mole of  $\text{CO}_2$ .



### WIZE CONCEPT

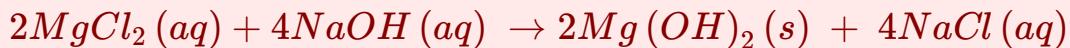
Multiply coefficients by subscripts to see exactly how much of an atom we have on each side.

**! WATCH OUT!**

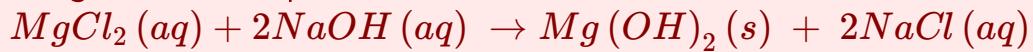
We want the **lowest possible coefficients**.

**Example:**

If I balanced an equation and got:



The **greatest common factor** that can go into each coefficient is 2 so we need to divide each coefficient by 2 to get the lowest possible numbers!



## Example: Balancing a Chemical Reaction

Balance the following equation:



### WIZE CONCEPT

The physical state of each chemical compound is often included in chemical equations:

(s) = solid

(l) = liquid

(g) = gas

(aq) = aqueous

## Polyatomic Ions

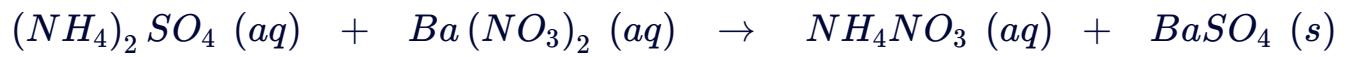
**Note:** There is no need to memorize the following table. It is just included here so you have an idea about what a polyatomic ion is!

Polyatomic Ion Cheatsheet			
<b>Ion</b>	<b>Name</b>	<b>Ion</b>	<b>Name</b>
$\text{NH}_4^+$	Ammonium	$\text{MnO}_4^-$	Permanganate
$\text{NO}_2^-$	Nitrite	$\text{CrO}_4^{2-}$	Chromate
$\text{NO}_3^-$	Nitrate	$\text{Cr}_2\text{O}_7^{2-}$	Dichromate
$\text{SO}_3^{2-}$	Sulfite	$\text{O}_2^{2-}$	Peroxide
$\text{SO}_4^{2-}$	Sulfate	$\text{O}_2^-$	Superoxide
$\text{HSO}_4^-$	Hydrogen sulfate *	$\text{C}_2\text{O}_4^{2-}$	Oxalate
$\text{HSO}_3^-$	Hydrogen sulfite	$\text{HC}_2\text{O}_4^-$	Hydrogen Oxalate
$\text{OH}^-$	Hydroxide	$\text{HCO}_2^-$	Formate
$\text{CN}^-$	Cyanide	$\text{S}_2\text{O}_3^{2-}$	Thiosulfate
$\text{PO}_4^{3-}$	Phosphate	$\text{HS}_2\text{O}_3^-$	Hydrogen Thiosulfate
$\text{HPO}_4^{2-}$	Hydrogen Phosphate	$\text{BrO}_4^-$	Perbromate
$\text{H}_2\text{PO}_4^-$	Dihydrogen Phosphate	$\text{BrO}_3^-$	Bromate
$\text{CO}_3^{2-}$	Carbonate	$\text{BrO}_2^-$	Bromite
$\text{HCO}_3^-$	Hydrogen Carbonate **	$\text{BrO}^-$	Hypobromite
$\text{ClO}^-$	Hypochlorite	$\text{IO}_4^-$	Periodate
$\text{ClO}_2^-$	Chlorite	$\text{IO}_3^-$	Iodate
$\text{ClO}_3^-$	Chlorate	$\text{IO}_2^-$	Iodite
$\text{ClO}_4^-$	Perchlorate	$\text{IO}^-$	Hypoiodate
$\text{C}_2\text{H}_3\text{O}_2^-$	Acetate		

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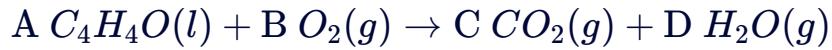
#### 1.1.5

### Example: Balance a Chemical Equation with Polyatomic Ions



## Practice: Balancing the Combustion of Furan

Choose the answer that balances the reaction shown below:



A = 2; B = 9 ;C = 8; D = 4

A = 1; B = 3 ;C = 5; D = 2

A = 1; B = 1 ;C = 1; D = 1

A = 4; B = 25 ;C = 20; D = 10

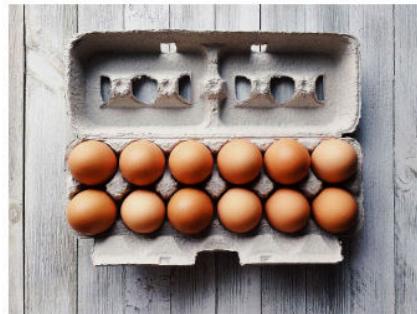
## 1.2

# Atoms, Molecules, and the Mole!

1.2.1

## Moles

When someone says they want a dozen donuts, roses, or eggs we know they mean they want 12. A **mole** in chemistry also tells us the amount of something.



- Just like how a dozen of something = 12, 1 mole of something =  $6.02 \times 10^{23}$  molecules
- $6.02 \times 10^{23}$  is referred to as **Avagadro's number ( $N_A$ )**

**i** WIZE TIP

You should memorize Avagadro's number since it is not always provided on exams! We'll soon see that you need to know it to solve problems :)

$$N_A = 6.02 \times 10^{23} \text{ molecules/mole}$$

We use the unit "**moles**" to help make very small amounts more measurable. A mole is just like any other unit!

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There are 2 Equations Related to Moles:

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

$$n = \frac{N}{N_A}$$

$n$ =# of moles

$m$ =mass (g)

$M$ =molar mass (g/mol)

$N$ =# of molecules or atoms

$N_A$ =Avagadro's number=6.02x10<sup>23</sup> molecules

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### Example #1:

If we are told that a sample of CO<sub>2</sub>(s) weighs 11g, how many moles are present?

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## Example #2

We have 2 moles of CO<sub>2</sub> present in our sample, how many molecules are there?

---

### Example #3

How many oxygen atoms there in 1 mole of CO<sub>2</sub>?

#### 1) Find Number of Molecules In the Sample

#### 2) Find the Number of O atoms in the Sample

In each molecule there are \_\_\_\_\_ O atoms.

Therefore to find the number of O atoms:

# of molecules in sample x \_\_\_\_\_ O atoms/molecule =# of O atoms

# of O atoms= \_\_\_\_\_

---

#### 1.2.2

## Example: Calculate the Number of Molecules of Ethyl Mercaptan

The volatile liquid ethyl mercaptan,  $C_2H_6S$ , is one of the most odoriferous substances known. It is added to natural gas to make gas leaks detectable. ( $d = 0.84 \text{ g/mL}$ ;  $MW = 62.1 \text{ g/mol}$ )

1. How many  $C_2H_6S$  molecules are contained in a  $3.0 \mu L$  sample?

---

2. In the same 3.0  $\mu\text{L}$  sample, how many C and H atoms are there?

1.2.3

## Practice: Converting Mass to Number of Atoms

Calculate the number of nitrogen atoms in 2.25 g of bismuth(III) nitrate.

a)  $1.03 \times 10^{22}$  atoms

b)  $1.03 \times 10^{21}$  atoms

c)  $3.43 \times 10^{21}$  atoms

d)  $3.43 \times 10^{22}$  atoms

1.2.4

## Practice: Finding the Number of Moles of Iron

Calculate the number of moles of iron atoms in 14.1 g of iron oxide,  $\text{Fe}_2\text{O}_3$

A) 0.177 mol

B) 0.0821 mol

C) 0.0906 mol

D) 0.0451 mol

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## 1.3 Stoichiometry

1.3.1

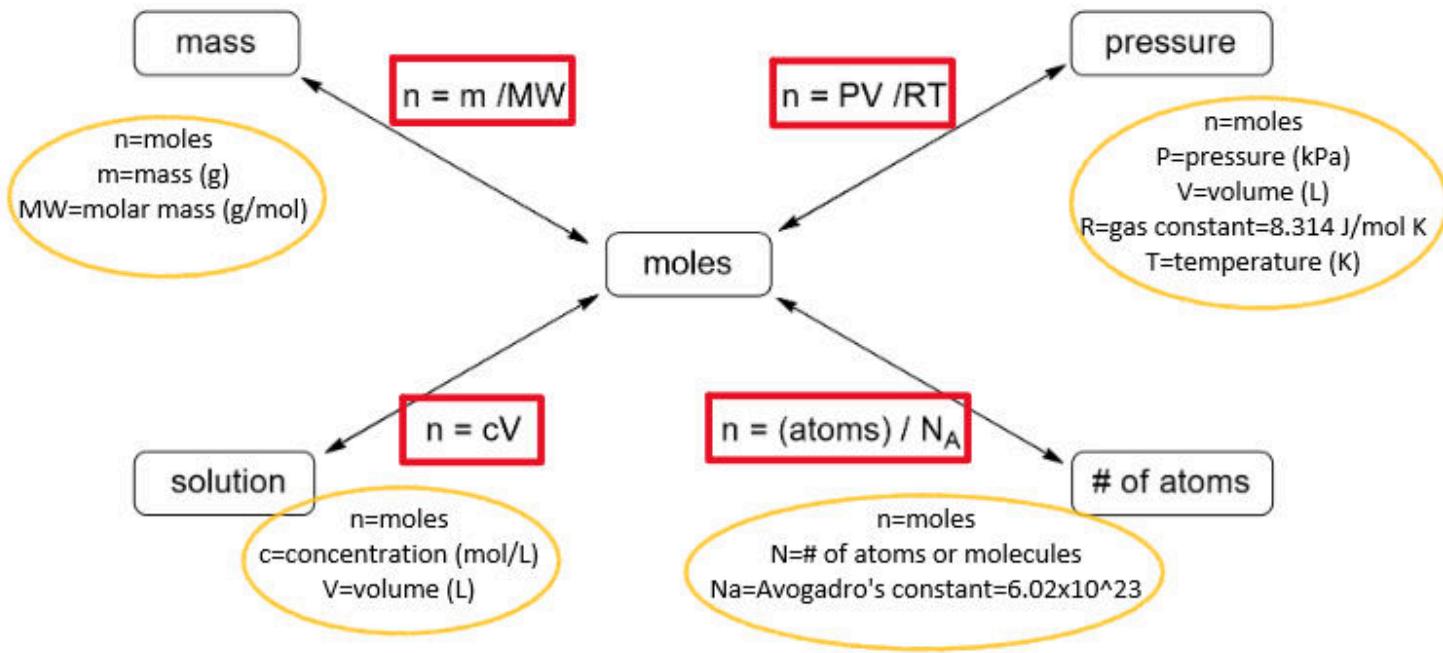
### Intro to Stoichiometry

**Stoichiometry** allows us to predict the quantities of products or reagents across a chemical reaction.

Typically this is done in a few steps:

1. Calculating the number of moles of the reagents
2. Calculating the number of moles of the products using the stoichiometric ratio
3. Calculating the mass or pressure of the products.

Moles are the central unit!



In addition we can convert between mass and volume of a pure substance by looking at it's **density**,

$$\delta = m/V$$

## Stoichiometry of a Reaction

We use the **coefficients** of the **balanced reaction** along with the our equations that convert mass, volume, and concentration into moles to predict the quantities of reactants and products in a chemical reaction.

To answer any stoichiometry problem, focus on converting to and from moles!

### General Steps to Solving a Stoichiometry Problem:

1. Convert the values given in the problem about a reactant or product to a **number of moles**
2. Use the **stoichiometric coefficients** from the **balanced** reaction to **find the number of moles of the unknown** you are being asked for
3. Convert the number of moles of your unknown to a mass, or whatever quantity you are being asked for

## Example

2.6g of sodium metal (Na) reacts with water to form NaOH and H<sub>2</sub> according to the unbalanced reaction below. Once the reaction is complete how many grams of NaOH are formed?



### i WIZE TIP

On an exam, your prof will NOT specify if an equation is balanced or unbalanced.

**Always double check that the equation is balanced. If it's not, balance the equation before continuing!**

The equation must be balanced in order to get the correct answer!

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### Step 1: Balance the reaction



### Step 2: Find the number of moles of sodium

$$n_{\text{Na}} = \frac{m}{MW} = \frac{2.6 \text{ g}}{22.990 \text{ g/mol}} = 0.113 \text{ mol}$$

### Step 3: Find the number of moles of NaOH

$$n_{\text{NaOH}} = n_{\text{Na}} \times \frac{\text{coefficient NaOH}}{\text{coefficient Na}} = 0.113 \text{ mol} \times \frac{2}{2} = 0.113 \text{ mol}$$

### Step 4: Convert the number of moles of NaOH to a mass

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

$$m_{\text{NaOH}} = n \times MW = 0.113 \text{ mol} \times 39.997 \text{ g/mol} = 4.520 \text{ g} = 4.5 \text{ g}$$

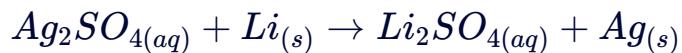
## Example: Converting Mass of Reactant to Mass of Product

Calculate the mass of hydrogen gas produced if 0.550 g of iron powder is reacted with an excess amount of sulfuric acid.



## Example: Solution Stoichiometry to Determine Mass of Product

Lithium metal was added to a 25mL of a 1.3M solution of  $\text{Ag}_2\text{SO}_4$ . The unbalanced chemical reaction is shown below.

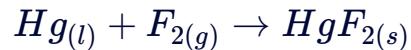


Once the reaction has gone to completion, what mass of silver metal is produced?

- a) 0.0070 g
- b) 7.0 g
- c) 3.5 g
- d) 0.0035 g

## Practice: Calculate the Mass of Product

16.0 mL of Hg (mp = -38.8°C, density = 13.56 g/mL) reacts with fluorine gas and the reaction goes to completion as shown below.



Once the reaction has gone to completion, what mass of mercury fluoride,  $\text{HgF}_2$ , is produced?

A) 1.48 g

B) 514 g

C) 142 g

D) 258 g

1.3.6

## Practice: Stoichiometry Calculations Application

A solution that is 183mM (millimolar) NaCl(aq) is isoosmotic with plasma. This means that cells don't swell or shrink when in this solution. How many grams of sodium chloride are required to make 150mL of isoosmotic NaCl(aq)? The molar mass of NaCl is 58.44g/mol.

0.2g



1.6g



2.2g



4.9g



---

## 1.4

# Limiting Reagents

1.4.1

## Introduction to Limiting Reagents

Anytime **reactant species are in limited supply** and not present in perfectly proportional amounts, a chemical reaction will have a **limiting reagent** which will be totally **consumed before any other reactant**

The quantity of the limiting reagent available directly **determines the maximum number of product molecules** that can be formed!

## Let's Consider an Example:

When making smores (yum!!) the "reaction" looks something like:



If I had 10 graham crackers, 6 pieces of chocolate, and 6 marshmallows, what would be the limiting reagent? In other words, what would I run out of first? And how many smores could I make?

- The "chemistry way" to figure this out would be to take the # of moles of each reactant and divide by its stoichiometric coefficient:

Graham crackers:  $10/2=5$

Pieces of chocolate:  $6/1=6$

Marshmallows:  $6/1=6$

- Now, to figure out the limiting reagent, look at which of the above numbers are the smallest!!
  - 5 is smallest, therefore Graham crackers are the limiting reagent!!

Now how many smores could we make?

We know graham crackers will determine how much product we get since we'll run out of the crackers first.

$$\text{moles of graham cracker} \times \frac{1 \text{ mol smores}}{2 \text{ moles graham cracker}} = \text{moles of smores}$$

---

$10 \times (1/2) = 5$  moles of smores created!

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 **WIZE CONCEPT**

It is necessary to **determine the limiting reagent** whenever we are **given the amounts of two or more reactants** in a chemical reaction.

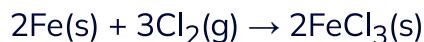
The limiting reagent is **totally consumed in the reaction. Any other reactant is in excess.**

Limiting reagent stops the reaction by **running out first.**

The **quantity of the limiting reagent** available directly **determines the maximum number of products molecules** that can be formed

## Example: Determine the Mass of Product in a Limiting Reagent Problem

Iron and chlorine gas react to form iron (III) trichloride. If 110 g of iron and 105 g of chlorine gas are reacted, which species is the limiting reagent? What is the maximum mass of  $\text{FeCl}_3$  that can be formed?



 **WIZE TIP**

### Steps for Solving Limiting Reagent Problems:

**Step 1** – Write & **balance** the equation.

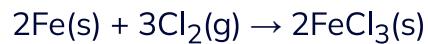
**Step 2** – Calculate **moles of each reactant**.

**Step 3** – Use the molar ratios of the present reactants (from the balanced equation) to determine the limiting reactant (LR).

- Take the **# of moles of each reactant** from step 2 and **divide by the stoichiometric coefficient** for that reactant
  - **Smallest value** from this calculation tells us the **LR**

**Step 4** – From the limiting reactant, use the **molar ratio** (from the balanced equation) to **calculate moles of the desired product**.

**Step 5** – Convert moles to the desired units (density, molarity, grams, etc...)



**Step 1 – Write & balance the equation.**

Is the equation given balanced? \_\_\_\_\_

**Step 2 – Calculate moles of each reactant.**

i) Find moles of Fe

ii) Find moles of Cl<sub>2</sub>

**Step 3 – Use the molar ratios of the present reactants (from the balanced equation) to determine the limiting reactant.**

Therefore the limiting reagent is \_\_\_\_\_ ! (because it had the smallest number)

---

**Step 4 – From the limiting reactant, use the molar ratio (from the balanced equation) to calculate moles of the desired product.**

- The maximum mass of  $\text{FeCl}_3$  that is formed depends on how much we have (LR).

**Step 5 – Convert moles to the desired units (density, molarity, grams, etc...)**

---

#### 1.4.3

### Example: What is the Limiting Reagent?

2.0 g of aqueous Barium hydroxide ( $\text{Ba}(\text{OH})_2(\text{aq})$ , 171.32 g/mol) and 1.5 g of liquid hydrogen bromide ( $\text{HBr}(\text{l})$ , 80.91g/mol) react together to give aqueous barium bromide ( $\text{BaBr}_2(\text{aq})$ ) and liquid water ( $\text{H}_2\text{O}(\text{l})$ ). Which species would be the limiting reagent of this reaction?

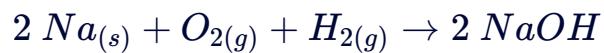
## Example: How Many Grams of the Excess Reagent Will Remain?

The reaction between  $P_4$  and  $Br_2$  is very exothermic and produces  $PBr_5$  as the only product. If 7.0 g of  $P_4$  react with 12.0 g of  $Br_2$  how many grams of the excess reagent will remain?

- a) 0.4 g
- b) 4.7 g
- c) 6.1g
- d)11.1 g

## Practice: What is the Limiting Reagent

If 12 g of sodium is mixed with 0.64 g of H<sub>2</sub> and 17 g of O<sub>2</sub> which reagent will be limiting in the reaction shown below?



A) Na

B) O<sub>2</sub>

C) H<sub>2</sub>

D) None, they will all be completely consumed

## 1.5 Percent Yield

1.5.1

### Percent Yield

So far we have been assuming that the reaction proceeds 100% to products. In reality, this is rarely the case!

When we are doing experiments in the lab we often lose some of our product by spilling it or residues of it get left on glassware and spatulas.



So far we have been calculating the **theoretical yield**.

**Theoretical Yield** - the maximum amount of product produced based on the quantity of the limiting reagent (e.g. the amount of product produced in a calculation).

**Actual Yield** - the actual amount of product produced in the reaction (e.g. the amount of product obtained in a laboratory experiment).

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

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## Test Your Understanding

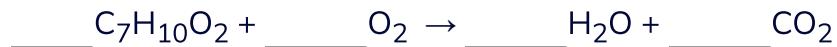
- 1) In a lab, you measure your product and record 5.222g. This is the \_\_\_\_\_ yield.
- 2) If everything went 100% perfectly according to the reaction we would get the \_\_\_\_\_ yield
- 3) If I determined the limiting reagent, and then calculated the number of moles of product and the mass of product based on this, I've just calculated the \_\_\_\_\_ yield

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#### 1.5.2

## Example: What is the Percent Yield

When 49.00 g of a hydrocarbon fuel with formula  $\text{C}_7\text{H}_{10}\text{O}_2$  is reacted with excess oxygen, a total of 21.56 g of water is collected. What was the percent yield of the reaction?



---

1.5.3

### Practice: Calculate Moles Given Percent Yield

If the yield for the following reaction is 45%, how many moles of  $\text{KClO}_3$  are needed to produce 1 mol of  $\text{O}_2$ ?



A) 0.4 moles

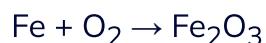
B) 1.1 moles

C) 1.5 moles

D) 4.6 moles

## Practice: Limiting Reagent & Percent Yield

Iron oxidizes when exposed to oxygen to form iron oxide according to the following equation:



352g of pure iron is exposed to 12.0 mols of  $\text{O}_2$ , and after a period of time 46.7 g of iron oxide (rust) is collected.

### Part 1

What is the limiting reagent in this reaction?

A) Fe

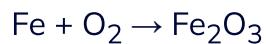
B)  $\text{O}_2$

C)  $\text{Fe}_2\text{O}_3$

D) There is no limiting reagent

## Practice: Limiting Reagent & Percent Yield

Iron oxidizes when exposed to oxygen to form iron oxide according to the following equation:



352g of pure iron is exposed to 12.0 mols of  $\text{O}_2$ , and after a period of time 46.7 g of iron oxide (rust) is collected.

### Part 2

What is the percent yield?

A) 2.2%

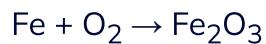
B) 8.8%

C) 9.4%

D) 33.1 %

## Practice: Limiting Reagent & Percent Yield

Iron oxidizes when exposed to oxygen to form iron oxide according to the following equation:



352g of pure iron is exposed to 12.0 mols of  $\text{O}_2$ , and after a period of time 46.7 g of iron oxide (rust) is collected.

### Part 3

How many Fe atoms are present in the rust produced?

A)  $0.89 \times 10^{17}$  atoms

B)  $1.77 \times 10^{23}$  atoms

C)  $3.56 \times 10^{23}$  atoms

D)  $4.33 \times 10^{23}$  atoms