CHEMICAL REACTIONS AND STOICHIOMETRY

Learning Objectives:

I. Chemical equation means and Balancing Equation
II. Classification of Reaction
III. Redox reaction
IV. Mole and Avogadro's number
V. Molar Mass
VI. Determination of mass of a substance and its number of moles
VII. Calculate the number of moles and mass of a reaction product?
VIII. Limiting reactant of a chemical reaction
IX. Percent yield
X. Energy Diagram
XI. Heat of the reaction and difference between exothermic and endothermic reaction

I. Balancing Chemical Equations

The study of how and why a chemical reaction occurs is a very important part of chemistry. In this section we will examine how to describe a chemical change or a reaction through equation and how to balance an equation. Balancing of chemical equation is required because of law of conservation of mass and energy. According to law of conservation of mass, matter of the universe is conserved and it can never be destroyed or created. Therefore, the total atoms present in a reaction before and after must be same. The bonded atoms are rearranged in a chemical reaction but the total mass remains same.

Just like a cooking recipe, A chemical equation contains the starting materials on left side of an arrow and the products on the right. The coefficients are written in front of the reactants and products and they tell how many molecules or moles of a substance react or are formed. States of the reactant and product substances are written with parenthesis. Solid substances are written as (s), liquid substances are written as (l) and gaseous substances are written as (g), Solutions are mainly expressed as (aq) means aqueous.

A chemical equation is balanced by placing coefficients in front of chemical formulas one at a time. Beginning with most complex formula, so that the number of atoms of each element is the same on both sides. Sometimes fractional coefficients are used to balance equation which then converted to an integer by multiplying the entire equation by a whole number. Any special reaction condition is mentioned on the top of the arrow like heat (Δ) of light (hv) etc.

Here are some examples of balanced chemical Equation.

$$4\ Fe\ (s) + 3\ O_2\ (g) \longrightarrow 2\ Fe_2O_3\ (s)$$

$$3\ H_2\ (g) + 1\ N_2\ (g) \longrightarrow 2\ NH_3\ (g)$$

Let's take the first example: Unbalanced equation

$$Fe\ (s) + O_2(g) \rightarrow Fe_2O_3(s)$$

We will count total number of atoms on each side first

Left hand side Fe-1	Right hand side Fe-2
O-2	O-3

Let's balance Fe first with putting coefficient 2 in front of Fe on the reactant side.

$$2Fe\ (s) + O_2(g) \ \rightarrow Fe_2O_3(s)$$

But the equation is still unbalanced, because the number of oxygen is not same. To make same number of oxygen on both sides, we must multiply left hand side by 3 and right hand side by 2.

$2Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

Left hand side Fe-1	Right hand side Fe-4
O-6	O-6

To make total number of Fe atom equals 4 on the left hand side, we put coefficient 4.

So the final balanced equation is:

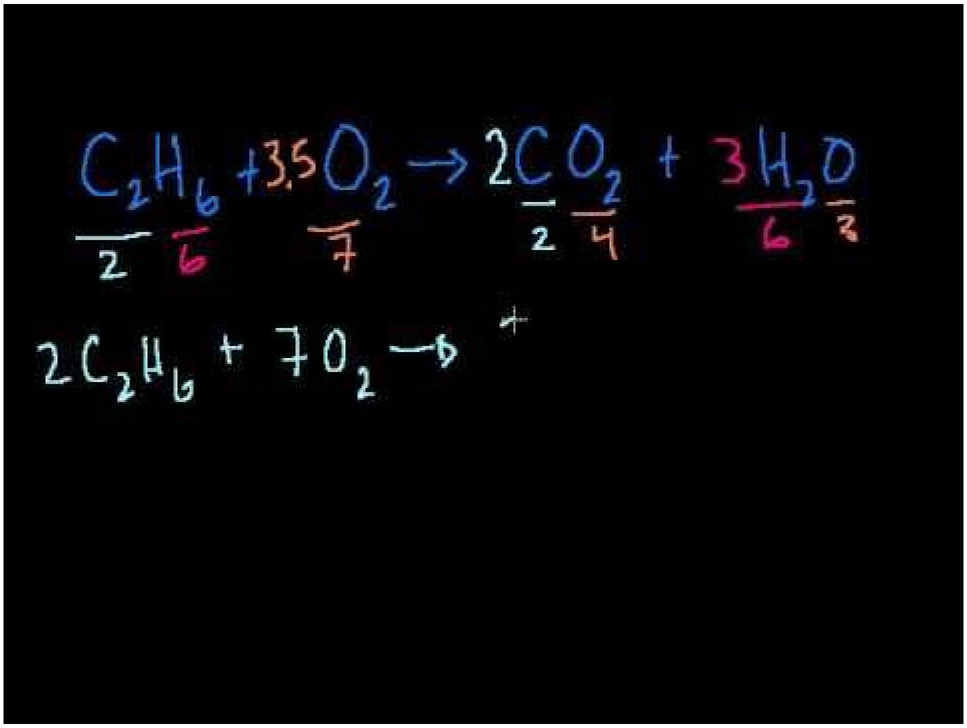
$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

$C_2H_6(g) + O_2(g) \ \rightarrow CO_2 + H_2O$
Sometimes we have to use fractional coefficients to balance an equation. For example, in the following equation, After balancing C with coefficient 2 and H with coeff. 3 on the product side, the total number of oxygen is 2*2 from CO_2 and 3*1=3 from H_2O, total seven atoms of O.
On the left hand side we have 2 atoms O. To balance O atoms we have to put coefficient 7/2.

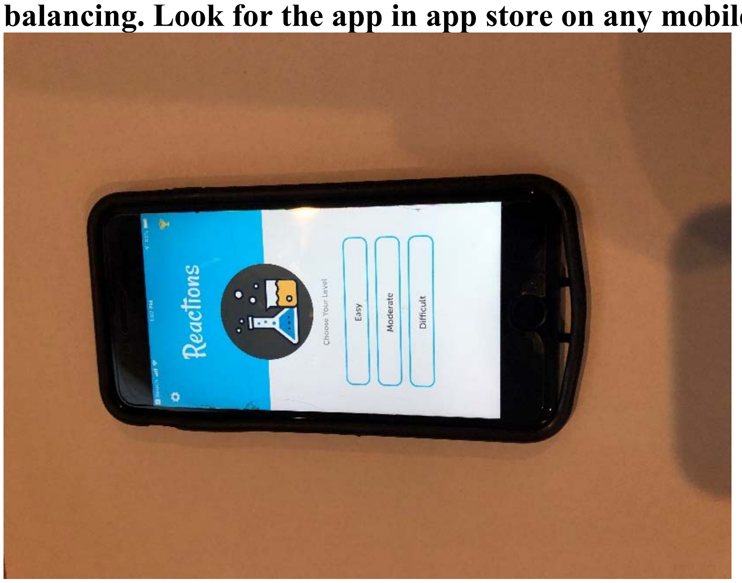
Balance equation is:

$$C_2H_6 + \frac{7}{2}O_2 \rightarrow 2CO_2 + 3H_2O.$$

https://www.youtube.com/watch?v=RnGu3xO2h74

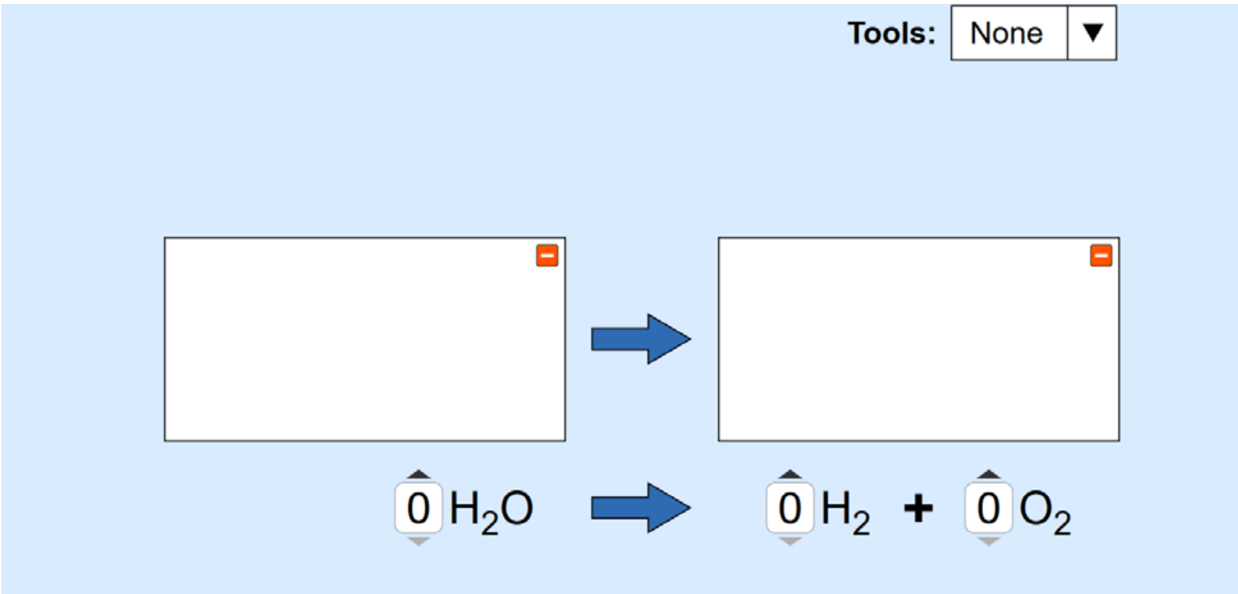


Try this Balancing app(free): "Reactions" with more than 400 equations for practicing balancing. Look for the app in app store on any mobile device.

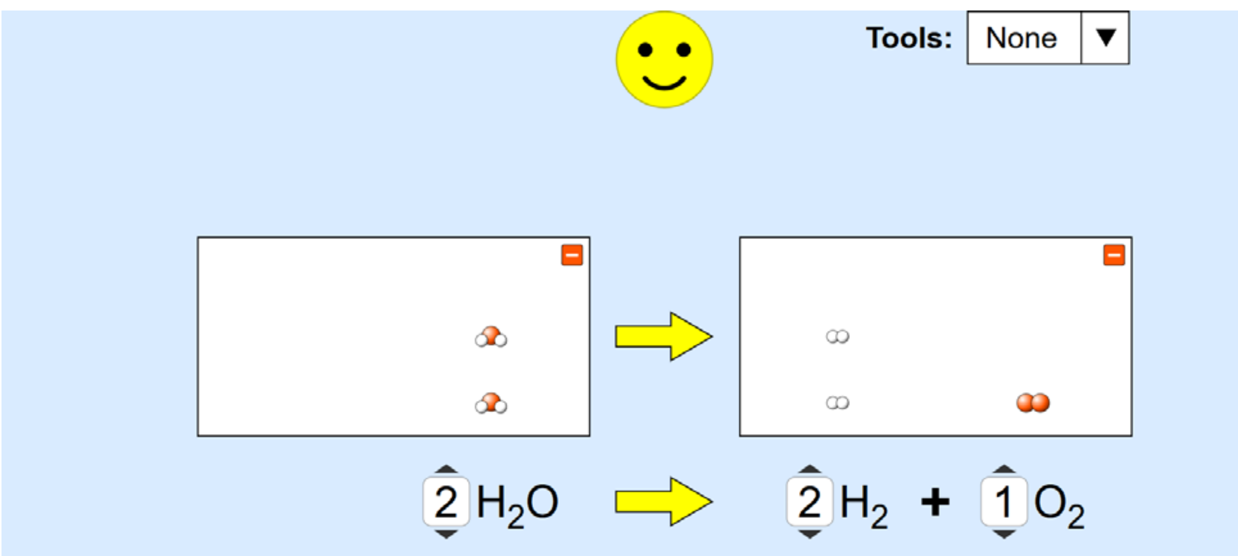


https://phet.colorado.edu/en/simulation/balancing-chemical-equations

Go to the above link and click on the activity "Introduction".
We will play with the topic, separation of water. The screen should appear like below.



On the left hand side we have H-2 O-1
On the right hand side H-2, O-2. Apparently Hydrogen is balanced but no oxygen. To balance oxygen we have use coefficient 2 in front of water . Now we have 2*2 =4 atoms H and 2 atoms of O. We adjust the number of H atoms on the right hand side by changing the coefficient equal 2 for H_2 and 1 for O_2. The equation is balanced.



[Advanced iframe src="https://phet.colorado.edu/sims/html/balancing-chemical-equations/latest/balancing-chemical-equations_en.html" width="100%" height="600"]

In case of polyatomic ion containing equations, it is always recommended to consider them as unit rather than broken down to individual atoms if they appear on both sides of the equation.

$$LiOH + H_3PO4 \rightarrow Li_2HPO4 + H_2O \text{ (unbalanced)}$$

To balance Li, we have to put coefficient 2 in front of LiOH. That will give total number H on the left hand side= 5 and O=2, keeping PO_4 unit separate from other elements. We can put coefficient 2 in front of H_2O to form 4 H and 2 O, remaining one H is present in Li_2HPO4. PO_4 unit is same on left and right hand side. So the final number of atoms look like :

Left side:		Right side:
Li -2		Li-2
O-2		O-2
H-5		H-5
PO4-1		PO4-1

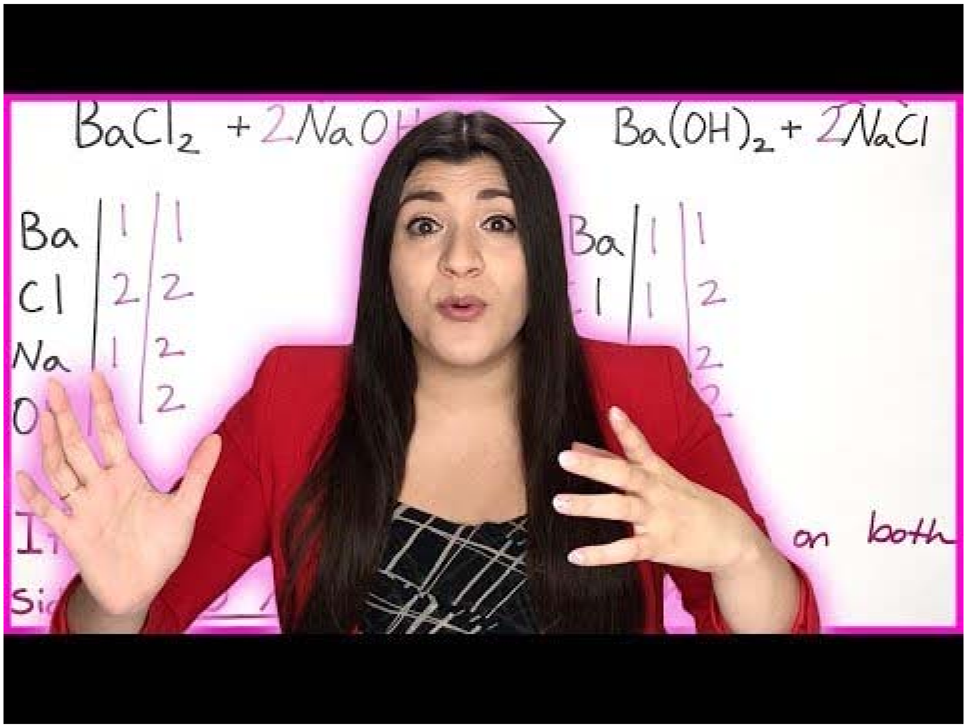
Balanced equation is

$$2LiOH + H_3PO4 \rightarrow Li_2HPO4 + 2H_2O \text{ (balanced)}$$

Always lowest number of coefficients are used to balance a chemical equation. For example, $2H_2O \rightarrow 2H_2 + O_2$, this equation can also be balanced by $4H_2O \rightarrow 4H_2 + O_2$
But we always use lowest set of whole numbers to balance an equation.

The following video might help you to understand more this topic.

https://www.youtube.com/watch?v=jy6F0Lbvjm8



Rules for balancing chemical equations:

1. Mentally, draw a box or circle around chemical formulas – you cannot change any symbol or subscript in the formula to balance equation.
   a. Example 1: You cannot change a subscript - H_2O is different than H_2O_2!!
   b. Example 2: You cannot insert coefficients in middle of formula - H_22O is not correct.
2. Count up the number of each type of atom on both sides of the equation. You might want to make a simple table to keep track as you learn how to balance equation.
3. Add coefficients to the front of the boxes to balance the equation and update your element count. **Coefficients must be whole numbers.**
4. These tips will help you balance equations
   Remember to write the seven diatomic elements (H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2) with the subscript $_2$. Once they react, they will exist as individual atoms in a molecule.

   a. If the same polyatomic ion appears both side of the reaction, put a mental box around it and treat it as a single unit
   b. In some types of ionic reactions it will help to write water as H–OH instead of H_2O.
   c. Balance the elements in compounds first. Start with metals and then balance nonmetals.
   d. Leave the reactants and products that are elements until the end.
5. When the number of atoms of each element is the same before and after the reaction, equation is balanced.

Sample Problems

Example 1

Step 1: Determine the number of each type of atom that are on the reactant and the product side of the equation:

___Mg (s) + ___HCl (aq) → ___H_2 (g) + ___$MgCl_2$ (aq)

Reactant	Atom	Product
1	Mg	1
1*	H	**2***
1*	Cl	**2***

Mg is balanced but H and Cl are not. and Cl are not.
There are twice as many products as reactants for H and Cl.dd a coefficient of 2 in front of HCl.

(*) indicates that the atoms are not balanced in the equation.

Coefficients must be used.

Step 2: Add coefficients to balance the equation. In this case, a coefficient of 2 in front of HCl will balance the equation. The rest of the coefficients are 1.

1 Mg (s) + **2** HCl (aq) → **1** H_2 (g) + **1** $MgCl_2$ (aq)

Reactant	Atom	Product
1	Mg	1
2	H	2
2	Cl	2

All atoms are balanced.
The equations is balanced.

Example 2

Step 1: Determine the number of each type of atom that are on the reactant and the product side of the equation:

___$AgNO_3$ (aq) + ___$MgCl_2$ (aq) → ___AgCl (s) + ___$Mg(NO_3)_2$ (aq)

Reactant	Atom or Unit	Product

1	Ag	1
1*	NO_3	**2***
1	Mg	1
2*	Cl	**1***

Ag and Mg are balanced but NO_3 and Cl are not. Start with the NO_3.

(*) indicates that the atoms are not balanced in the equation.

Coefficients must be used.

Step 2: Add coefficients to balance the equation. In this case, add a coefficient of 2 to balance the NO_3 and add a coefficient of 1 to the others at this point. The number of atoms have changed, updated values appear in the table.

2 $AgNO_3$ (aq) + **1** $MgCl_2$ (aq) → **1** AgCl (s) + **1** $Mg(NO_3)_2$ (aq)

Reactant	Atom or Unit	Product
2*	Ag	**1***
2	NO_3	2
1	Mg	1
2*	Cl	**1***

NO_3 and Mg are balanced but Ag and Cl are not.
There are twice as many reactants as product for both Ag and Cl.

(*) indicates that the atoms are not balanced in the equation.

Coefficients must be changed.

Step 3: Change the coefficient for AgCl to 2 to balance the equation. The number of atoms have again changed, the updated values appear in the table.

2 $AgNO_3$ (aq) + **1** $MgCl_2$ (aq) → **2** AgCl (s) + **1** $Mg(NO_3)_2$ (aq)

Reactant	Atom or Unit	Product
2	Ag	2
2	NO_3	2
1	Mg	1
2	Cl	2

All atoms are balanced.
The equation is balanced.

Pre-Activity Questions:

1. Write the name and then determine the number of atoms of each element in the following chemical formulas:

H_3PO_4	N_5O_3	$Al_2(SO_3)_3$
Name: No. of H ____________ No. of P ____________ No. of O ____________	Name: No. of N ____________ No. of O ____________	Name: No. of Al ____________ No. of S ____________ No. of O ____________

2. Use this equation to answer the following questions:

$$\mathbf{1\ Ca\ (s) + 2\ HF\ (aq) \rightarrow 1\ CaF_2\ (s) + 1\ H_2\ (g)}$$

Write a word equation for this reaction.	
Is the reaction balanced?	
Identify the coefficient(s).	
Identify the subscript(s).	
What is the state of each of the reactants?	
What will serve as evidence that a reaction has occurred?	

Simulation

1. Log onto the simulation: http://bit.ly/BalancingEquationsPhET
2. Select "Introduction".
3. Select "Make Ammonia" and then select the balance "Tool". Complete the table to count the number of each type of atom in the space provided below. Write the balanced equation next to the table.

Reaction 1 Make Ammonia	Total Number of Atoms	
	Reactants	Products
H		
N		

4.  Reset the simulation.
5. Select "Separate Water" and then select the bar graph "Tool".
6. Add coefficients until the equation is balanced. Complete the table to count the number of each type of atom in the space provided below. Write the balanced equation next to the table.

Reaction 2 Separate Water	Total Number of Atoms	
	Reactants	Products
H		
O		

7.  Reset the simulation.
8. Select "Combust Methane" and then select "None" for "Tools".
9. Add coefficients until the equation is balanced. Complete the table to count the number of each type of atom in the space provided below. Write the balanced equation next to the table.

Reaction 3 Combust Methane	Total Number of Atoms	
	Reactants	Products

C		
H		
O		

10. Select “Game” at the bottom of the page and then select “Level 1”.
11. Balance the first equation, and then use the “Check” button to see if your equation is balanced.
    a. If it is, move onto the next equation.
    b. If not, use the “Show Why” button to see the number of each type of atom and then “Try Again”.
    c. Show all of your work and write your final equation in the space provided below.

12. Continue on to Level 2 and follow the directions given for Level 1. Show all of your work and write your final equation in the space provided below.

1
2
3
4
5

13. Continue on to Level 3 and follow the directions given for Level 1. Show all of your work and write your final equation in the space provided below.

1
2
3
4
5

Questions

1. Balance the following equations:

a) $Al + O_2 \rightarrow Al_2O_3$
b) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
c) $BaCl_2 + NaNO_3 \rightarrow Ba(NO_3)_2 + NaCl$
d) $Fe_2O_3(s) + H_2(g) \rightarrow Fe(s) + H_2O(g)$
e) $CaO(s) + C(s) \rightarrow CaC_2(s) + CO_2(g)$
f) $Na_2CO_3(s) + H_2CO_3(aq) \rightarrow Na(HCO_3)_2(aq)$
g) $KNO_3(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + HNO_3(aq)$

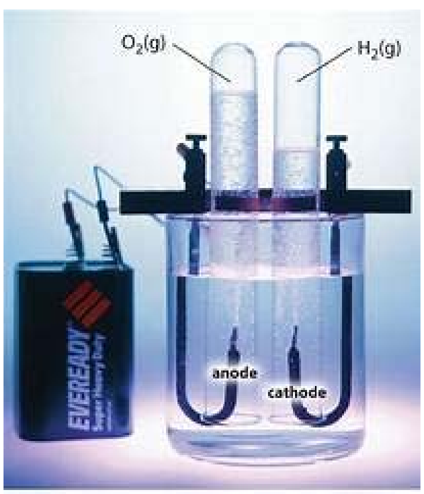
Ans: a) 4, 3, 2
b) 1, 5, 3, 4
c) 1, 2, 1, 2
d) 1, 3, 2, 3
e) 2, 5, 2, 1
f) 1, 1, 2
g) 2, 1, 1, 2

II. Classification of Reactions

Chemical reactions can be broadly classified in five categories.

1) Decomposition reaction: When one reactant breaks down to two more reactant, the reaction is called decomposition reaction

$$2H_2O \longrightarrow 2H_2 + O_2$$



anode: $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$
cathode: $2H^+(aq) + 2e^- \rightarrow H_2(g)$
overall: $2H_2O(l) \rightarrow O_2(g) + 2H_2(g)$

2) Combination reaction: When two or more reactants join together to form one single product, te reaction is called combination or synthesis reaction. Here are some example of combination reaction.

$$8Fe + S_8 \longrightarrow 8FeS$$

3) Single replacement reaction: An active element replaces another element in a compound.

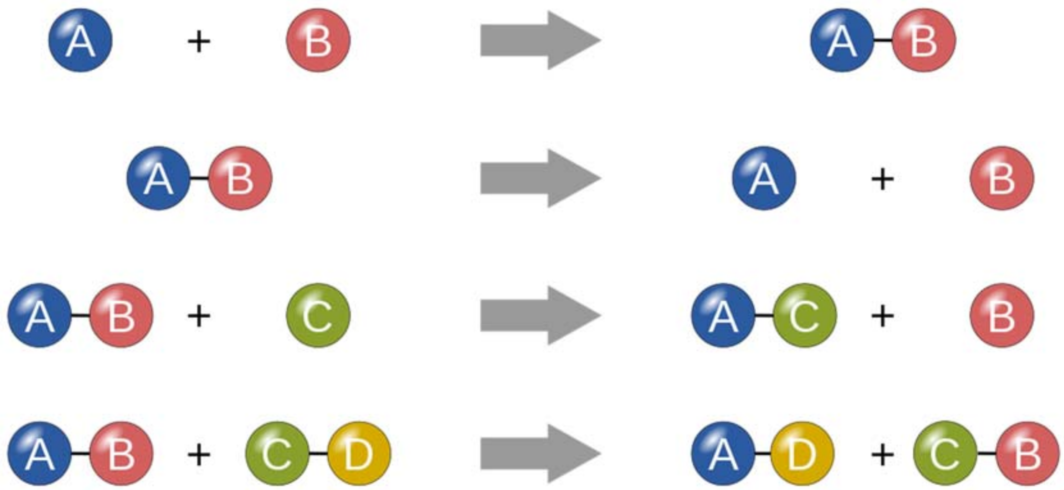
$$Mg + 2H_2O \longrightarrow Mg(OH)_2 + H_2$$

In the above example, Magnesium replaces Hydrogen from water to form Hydrogen gas and magnesium hydroxide is formed.

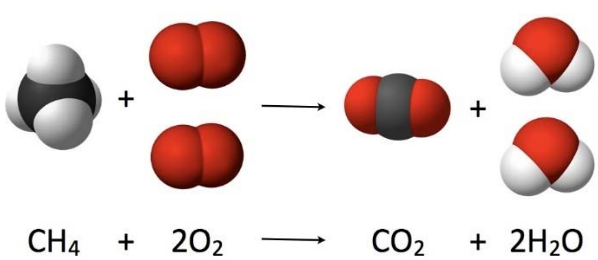
4) Double replacement Reactions: When the cations of two ionic compounds switch places to form products, the reaction is classified as

$$Pb(NO_3)_2 + 2KI \longrightarrow PbI_2 + 2KNO_3$$

In the above example when Potassium Iodide(KI) is added to colorless Lead Nitrate solution ($Pb(NO_3)_2$) , yellow precipitate of Lead Iodide (PbI_2) is formed.
Below is the generic representation of all the different types of reactions discussed .



5) Combustion reaction: When a hydrocarbon burns to produce Carbon dioxide and gaseous water, the reaction is called combustion reaction. A combustion reaction always produces heat energy along with the products.



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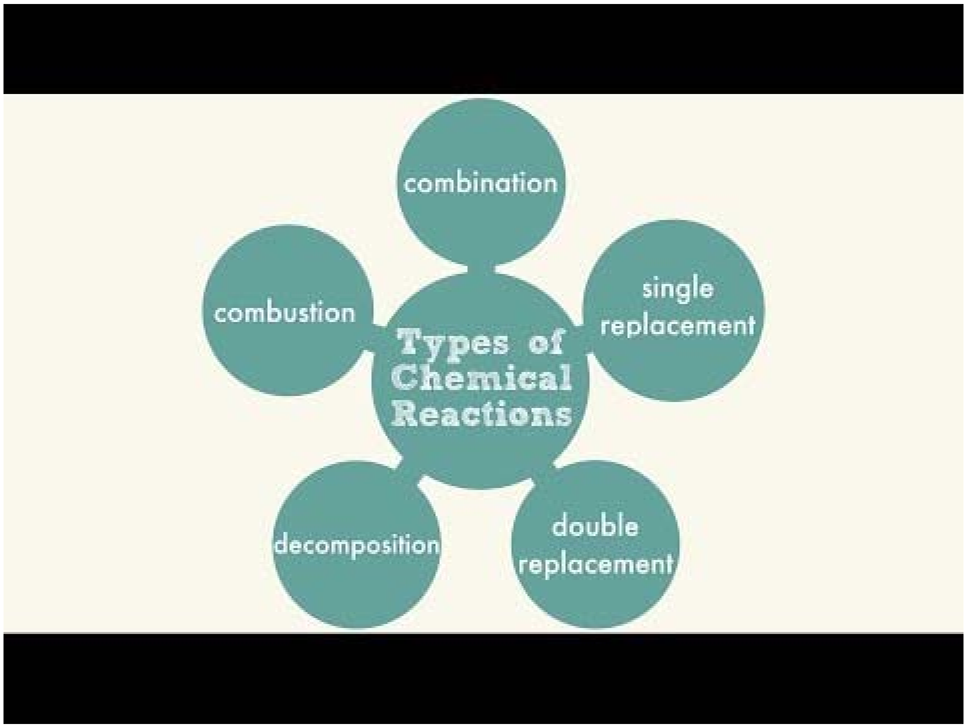
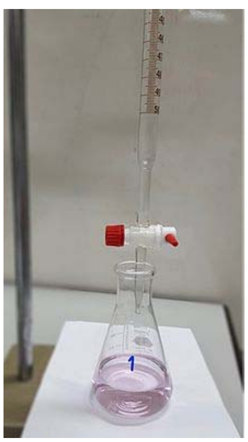


There are many other categories of reactions like acid-base reactions, precipitation reactions, etc. These reactions will be described under respective chapters. Only redox reaction is described in this chapter.




<u>Following activity has been taken from AACT</u>

Identifying Chemical Reactions

Part 1: Determine if there is a chemical reaction

	Reactants **Appearance of reactant(s)**	**Rxn** **(Yes/No)**	**Proof (List all that apply):** **Appearance of Products**
1.	Copper metal + hydrochloric acid		
2.	Zinc metal + hydrochloric acid		
3.	Potassium iodide + lead (II) nitrate		
4.	Potassium thiocyanate + iron (III) nitrate		
5.	Potassium iodide + aluminum nitrate		
6.	Ammonium dichromate		
7.	Magnesium + oxygen		

Part 2: If there is a chemical reaction then complete the word equation

1. Copper metal + hydrochloric acid →
2. Zinc metal + hydrochloric acid →
3. Potassium iodide + lead (II) nitrate →
4. Potassium thiocyanate + iron (III) nitrate →
5. Potassium iodide + aluminum nitrate →
6. Ammonium dichromate →
7. Magnesium + oxygen →

Part 3: Convert complete word equations to balanced chemical equations

1. Formula Equation:

   Balanced equation:

2. Formula Equation:

   Balanced equation:

3. Formula Equation:

   Balanced Equation:

4. Formula Equation:

   Balanced Equation:

5. Formula Equation:

   Balanced Equation:

6. Formula Equation:

   Balanced Equation:

7. Formula Equation:

   Balanced Equation:

Answer Key: Identifying Chemical Reactions

Part 1: Determine if there is a chemical reaction

	Reactants Appearance of reactant(s)	Rxn (Yes/No)	Proof (List all that apply): Appearance of Products
1.	Copper metal + hydrochloric acid Cu: solid chunks, shiny, orange-red color HCl: colorless, liquid	No	No reaction (NR) or no Rxn
2.	Zinc metal + hydrochloric acid Zn: sliver chunk, with rugged edges HCl: colorless, liquid	Yes	Gas produced – bubbles are produced in the test tube and zinc color changes and becomes darker/black.
3.	Potassium iodide + lead (II) nitrate KI: liquid and pale-yellow color $Pb(NO_3)_2$: liquid and colorless	Yes	Change in color and production of a precipitate (ppt). when liquids are mixed a bright yellow solid substance is produced.
4.	Potassium thiocyanate + iron (III) nitrate KSCN: colorless liquid $Fe(NO_3)_3$: orange-yellow liquid	Yes	Change in color – when mixed the solution becomes dark red color and resembles fake blood.

5.	Potassium iodide + aluminum nitrate KI: liquid and pale-yellow color $Al(NO_3)_3$:	No	No reaction (NR) or no Rxn
6.	Ammonium dichromate $(NH_4)_2Cr_2O_7$: bright orange fine solid crystals	Yes	Change in color, formation of a gases (reactions resemble eruption of a volcano) – sparks of light are produced, dark green fluffy solid is produced, water vapor is produced. Nitrogen gas is produced but is not seen. Larger quantity of dark green product compared to original solid.
7.	Magnesium + oxygen Mg: flat dull silver ribbon	Yes	Production of light – bright white light is produced, and Mg ribbon turns to black ash.

Part 2: If there is a chemical reaction then complete the word equation

8. Copper metal + hydrochloric acid → No reaction
9. Zinc metal + hydrochloric acid →zinc chloride + hydrogen gas
10. Potassium iodide + lead (II) nitrate → potassium nitrate + lead (II) iodide
11. Potassium thiocyanate + iron (III) nitrate → potassium nitrate + iron (III) thiocyanate
12. Potassium iodide + aluminum nitrate →No reaction
13. Ammonium dichromate →chromium (III)oxide + nitrogen gas + water vapors
14. Magnesium + oxygen → magnesium oxide

Part 3: Convert complete word equations to balanced chemical equations

8. No reaction = No balanced chemical equations

9. Formula Equation: $Zn(s) + HCl\ (aq) \rightarrow ZnCl_2\ (aq) + H_2(g)$

   Balanced equation: $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2\ (aq) + H_2(g)$

10. Formula Equation: $KI(aq) + Pb(NO_3)_2\ (aq) \rightarrow KNO_3\ (aq) + PbI_2\ (s)$
    Balanced Equation: $2KI(aq) + Pb(NO_3)_2\ (aq) \rightarrow 2KNO_3\ (aq) + PbI_2\ (s)$

11. Formula Equation: $KSCN(aq) + Fe(NO_3)_3\ (aq) \rightarrow KNO_3\ (aq) + Fe(SCN)_3\ (aq)$
    Balanced Equation: $3KSCN(aq) + Fe(NO_3)_3\ (aq) \rightarrow 3KNO_3\ (aq) + Fe(SCN)_3\ (aq)$

12. No reaction = No balanced chemical equations

13. Formula Equation: $(NH_4)_2Cr_2O_7(s) \rightarrow Cr_2O_3(g) + N_2\ (g) + H_2O(g)$
    Balanced Equation: $(NH_4)_2Cr_2O_7(s) \rightarrow Cr_2O_3(g) + N_2\ (g) + 4H_2O(g)$

14. Formula Equation: $Mg(s) + O_2\ (g) \rightarrow MgO(s)$
    Balanced Equation: $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

Questions:

1. Classify the following reactions:

a) $Fe(s) + 2FeCl_3(s) \longrightarrow 3FeCl_2(s)$
b) $3Ca(OH)_2 + 2H_3PO_4 \longrightarrow Ca_3(PO_4)_2 + 6H_2O$

Ans: a) combination, b) double displacement

III. Redox Reaction

Oxidation-Reduction or redox reactions are electron transfer reactions. Reactions in batteries and rusting are very common examples of redox reaction. Even in our body, digestion process involves redox reaction.

Oxidation results in the loss of electrons. Metals and anions tend to undergo loss of electrons. In some reactions oxidation involves addition of oxygen and removal of hydrogen. Reduction results in the gain of electrons. Nonmetals and cations tend to undergo reduction reaction. Reduction results in the loss of O atom and gain of H atoms.

A redox is a type of chemical reaction that involves a transfer of electrons between two species

The oxidation state of an element corresponds to the number of electrons, that an atom loses, gains in a chemical reaction The *reducing agent* is the reactant that is being oxidized. The *oxidizing agent* is reactant that is being reduced. Electron transfer occurs simultaneously, i.e., number of electrons gain is equal to number of electrons lost.

Oxidation state

The oxidation state is an important concept in chemistry, essential in order to understand the REDOX reactions. The oxidation state of an element corresponds to the number of electrons, that an atom loses or gains when joining with other atoms in compounds.

We can see the oxidation state also as the total number of electrons which have been removed from an element (a positive oxidation state) or added to an element (a negative oxidation state) to get to its present form or state.

Oxidation involves an increase in oxidation state

Reduction involves a decrease in oxidation state

To determine the oxidation state of an element, we can use the following rules:

- The oxidation state of an individual atom is 0. This is because it hasn't been either oxidised or reduced yet!
- The sum of the oxidation states of all the atoms or ions in a neutral compound is zero. The sum of the oxidation states of all the atoms in an ion is equal to the charge on the
- The more electronegative element in a substance is given a negative oxidation state. The less electronegative one is given a positive oxidation state. (Fluorine is the most electronegative element followed by oxygen)
- Group 1 metals have an oxidation state of +1 and Group 2 an oxidation state of +2
- The oxidation state of fluorine is -1 in compounds
- Hydrogen generally has an oxidation state of +1 in compounds
- Oxygen generally has an oxidation state of -2 in compounds

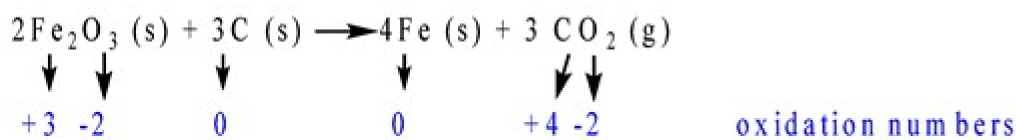
In binary metal compounds, Group 17 elements have an oxidation state of -1, Group 16 elements of -2, and Group 15 elements of -3.

How redox work

Let's get an example and understand better how redox reactions work:

$$2Fe_2O_3\ (s) + 3C\ (s) \rightarrow 4Fe\ (s) + 3\ CO_2\ (g)$$

How do we know if the above reaction is a redox? In order to be a redox, a transfer in electrons needs to happen, therefore we need to see if there is an electron transfer occurring, and we can do that by checking if any **oxidation numbers** change from the reactants to the products.



From the above figure, we can see that the oxidation numbers for carbon and iron are changing during the reaction from a transfer of electrons.

Carbon is being oxidized because it is losing electrons as the oxidation number increases from 0 to +4.
Iron is being reduced because it is gaining electrons as the oxidation number decreases from +3 to 0.

The reducing agent is the reactant that is being oxidized (and thus causing something else to be reduced), so in our case C is the **reducing agent**.

The oxidizing agent is reactant that is being reduced (and thus causing something else to be oxidized), so in our case Fe2O3, is the **oxidizing agent**.

Let's see the following reaction:

$$Al(s)+Cu^{2+}(aq)\rightarrow Al^{3+}(aq)+Cu(s)$$

$$\downarrow \quad \downarrow \qquad \downarrow \qquad \downarrow$$

$$(0) \quad (2+) \qquad (3+) \qquad (0)$$

In this reaction Al is oxidized from 0 to 3+, loss of electrons.Copper is reduced from 2+ to , gaining electrons. Al is reducing agent, copper is oxidizing agent.

Reduction half-reaction:

The reduction half-reaction shows the reactants and products participating in the reduction step. Since Cu^{2+} is being reduced to Cu(s) we can write the following:

$$Cu^{2+}(aq)\rightarrow Cu(s)$$

Which is not charge-balanced. There is a net charge of +2, plus on the reactant side and 0 on the product side. We can balance the charges by including the electrons (which have negative charge) being transferred, and then we will get our reduction half-reaction right and balanced:

$$Cu^{2+}(aq)+2e^-\rightarrow Cu(s)$$

now, if we add up the charges, including the electrons that have been transferred, we end up with an overall charge of 0 at both sides of the reductions half-reaction. The balanced half-reaction tells us that Cu^{2+} is gaining 2 electrons per copper atom to form solid Cu.

Let's do the same with the other half of the reactions:

Oxidation half-reaction: This reaction will include the oxidation of Al(s) to Al^{3+} . let's add to the half reaction the electrons that have been transferred from Al(s):

$$Al(s)\rightarrow Al^{3+}(aq)+3e^-$$

Now, we will combine the two balanced half-reactions to get the balanced overall equation. In doing so, we need to multiply the reduction half-reaction by 3 and multiply the oxidation half-reaction by 2 so both reactions involve the transfer of 6 electrons:

$$3\times[Cu^{2+}(aq)+2e^-\rightarrow Cu(s)] \quad 3\times\text{reduction half-reaction}$$

$$2\times[Al(s)\rightarrow Al^{3+}(aq)+3e^-] \quad 2\times\text{oxidation half-reaction}$$

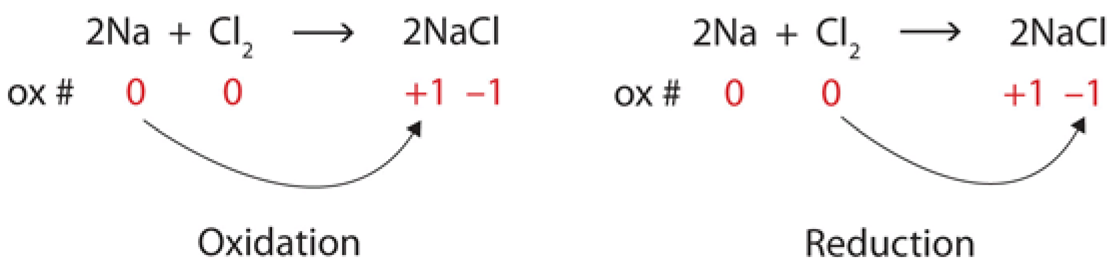
The last step of this method involves adding the half reactions together to get our overall balanced equation, and check to see if any reactants and products appear on both sides.

$$\cancel{6e^-}+3Cu^{2+}(aq) \rightarrow 3Cu(s) \qquad 3\times\text{reduction half-reaction}$$

$2Al(s) \rightarrow 2Al3+(aq)+\cancel{6e-}$ 2×oxidation half-reaction

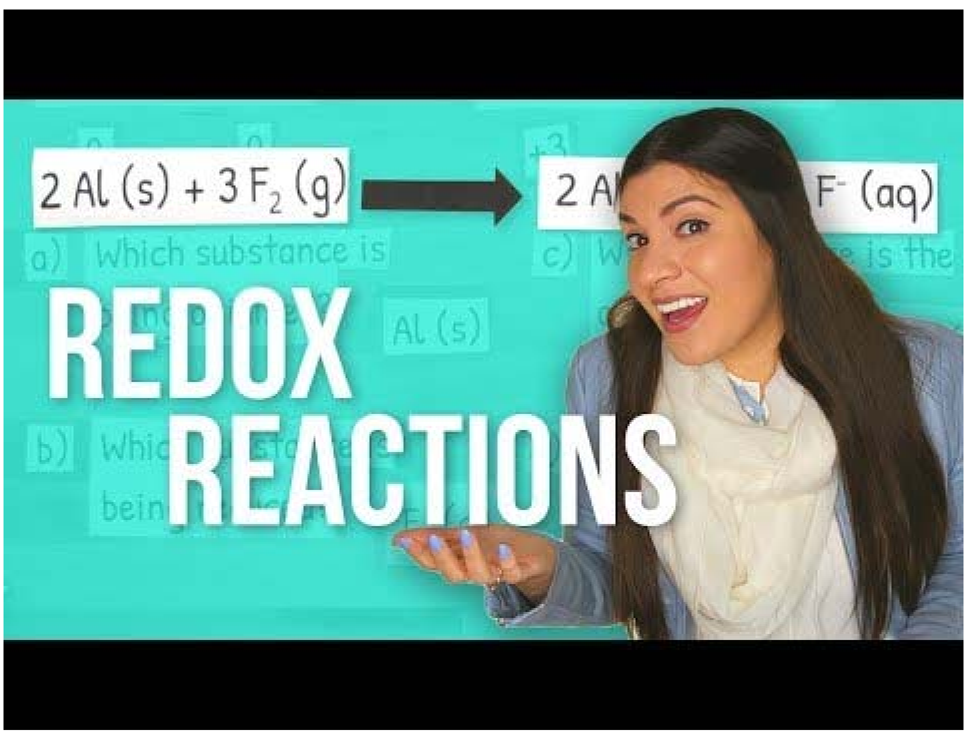
$2Al(s)+3Cu^{2+}(aq) \rightarrow 2Al^{3+}(aq)+3Cu(s)$ Overall balanced reaction

Another example:



For more example watch the following video:

https://www.youtube.com/watch?v=6gtcvqLmPo8



Questions:

1. Which substance is oxidized and which substance is reduced?

a) $Ag + Cl \rightarrow AgCl$

b) $2SO_3 \rightarrow 2SO_2 + O_2$

Ans: a) Ag is oxidized and Cl is reduced

b) S is reduced and O is oxidized.

IV. Mole and Avogadro's number

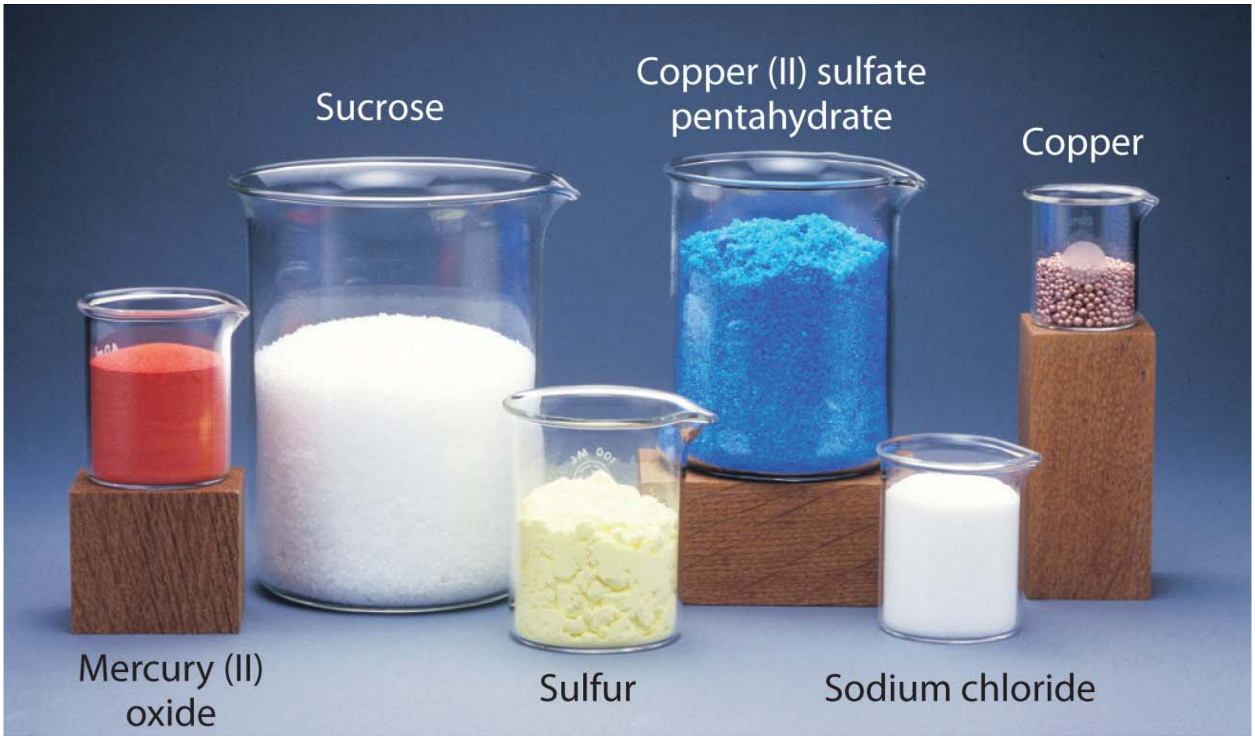
The chemical changes observed in any reaction involve the rearrangement of billions of atoms. It is impractical to try to count or visualize all these atoms, but scientists need some way to refer to the entire quantity. They also need a way to compare these numbers and relate them to the weights of the substances, which they *can* measure and observe. The solution is the concept of the mole, which is very important in quantitative chemistry.

Avogadro's Number

Amadeo Avogadro first proposed that the volume of a gas at a given pressure and temperature is proportional to the number of atoms or molecules, regardless of the type of gas. Although he did not determine the exact proportion, he is credited for the idea.

A mole is a quantity that contains $6.02 * 10^{23}$ atoms, molecules and ions.
Avogadro's number is the number of particles in a mole $6.02 * 10^{23}$

Below are some chemical compound with 1 mole of the substance:



The mole (or mol) represents a certain number of objects. The amount of a substance that contains the same number of entities as there are atoms in 12 g of carbon-12. One mole of H_2O molecules contains 6.022×10^{23} molecules. • 1 mole contains 6.022×10^{23} entities (Avogadro's number). One mole of NaCl contains 6.022×10^{23} NaCl formula units.

Exactly 12 g of carbon-12 contains 6.022 x 10 23 atoms.
*** There is a new definition of mole available at C & EN article
https://cen.acs.org/content/cen/articles/96/web/2018/11/New-definitions-kilogram-mole.html

The meaning and usefulness of the mole: number of moles of elements in a compound can also be determined from the chemical formula. For example,
the chemical formula of water is H_2O. Therefor in 1 mole of H_2O contains 2 mols of H and 1 mol of O from the subscript of the chemical formula.

Mol and number of particles can be easily calculated by using the conversion factor:

$\frac{1\text{mol}}{6.022 \times 10^{23}}$ or vice versa

Examples:

1. How many atoms are present in 3.0 mols of Ag?

Ans: Since it is mols to atoms, Avogadro's number is the conversion factor.

3.0 mols of Ag * $\frac{6.022 \times 10^{23} \text{ atoms of Ag}}{1 \text{ mol Ag}}$ = 18.067 * 10^{23} atoms or 1.8 *10^{24} atoms Ag

2. How many molecules are present in 2.93 mols of H_2O?

   Since it is mols to molecules, Avogadro's number is the conversion factor.

Ans: 2.93 mols of H_2O * $\frac{6.022 \times 10^{23} \text{ molecules of } H_2O}{1 \text{ mol } H_2O}$ = 18.067 * 10^{23} atoms or 1.8 *10^{24}

3. How many mols of Hydrogen are in 1.56 mols of CH_4?

Since it is mols from a compound to mols of an element, we will use chemical formula.

1.56 mols of CH_4 * $\frac{4 \text{ mols H}}{1 \text{ mol } CH_4}$ = 6.24 mols of H

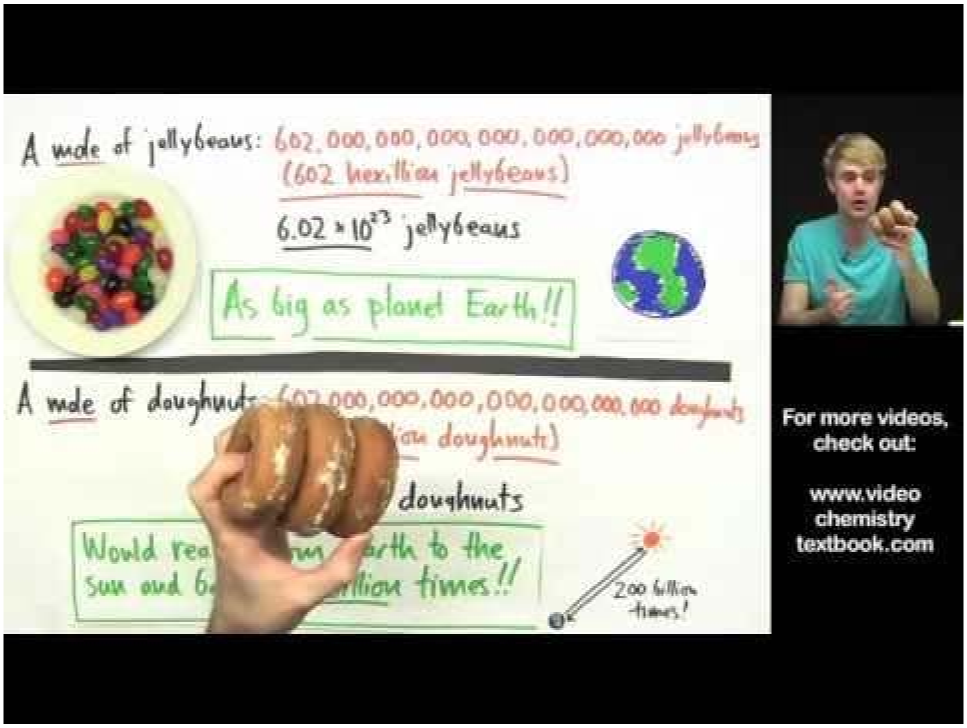
4. How many hydrogen atoms are there in 2.50 mol of glucose ($C_6H_{12}O_6$)?

We will use both chemical formula and avogadro's number to solve this problem.

2.50 mol $C_6H_{12}O_6$ * $\frac{12 \text{ mols H}}{\text{mol } C_6H_{12}O_6}$ * $\frac{6.022 \times 10^{23} \text{ atoms of H}}{1 \text{ mol H}}$ =180.66 x 10^{23} or 1.81 x 10^{23} atoms

Watch the following video:

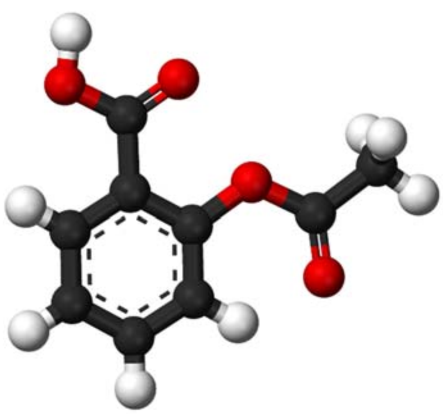
https://www.youtube.com/watch?v=wI56mHUDJgQ



Questions:

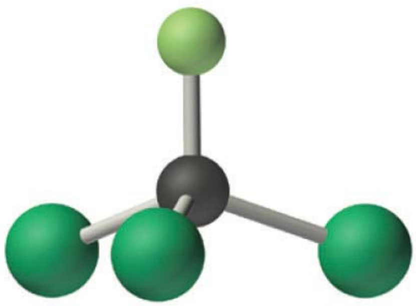
1. How many atoms are present in 5.5 mol of Fe?

2. How many mols of each element present in 2 .00 mols of the following compound? $C_9H_8O_4$ (aspirin)



3. How many oxygen atoms are present in 5.20 mol of $Al_2(SO_4)_3$?

4. How many molecules are present in 7.29 mols of the compound below?



Freon-11, CCl_3F

5. $3.11 * 10^{24}$ molecules are present in a glass of water. How many mols of H_2O are present?

Ans: 1. $3.31*10^{24}$ atoms
2. 18 mols of C, 16 mols H, 8.0 mols O
3. $3.77 *10^{25}$ atoms of oxygen
4. $4.39*10^{24}$ molecules
5. 5.17 mols

V. Molar Mass

The molar mass is the mass of one mole of a substance, reported in grams. The molar mass is numerically equal to the formula weight but the units are different (g/mol or amu).

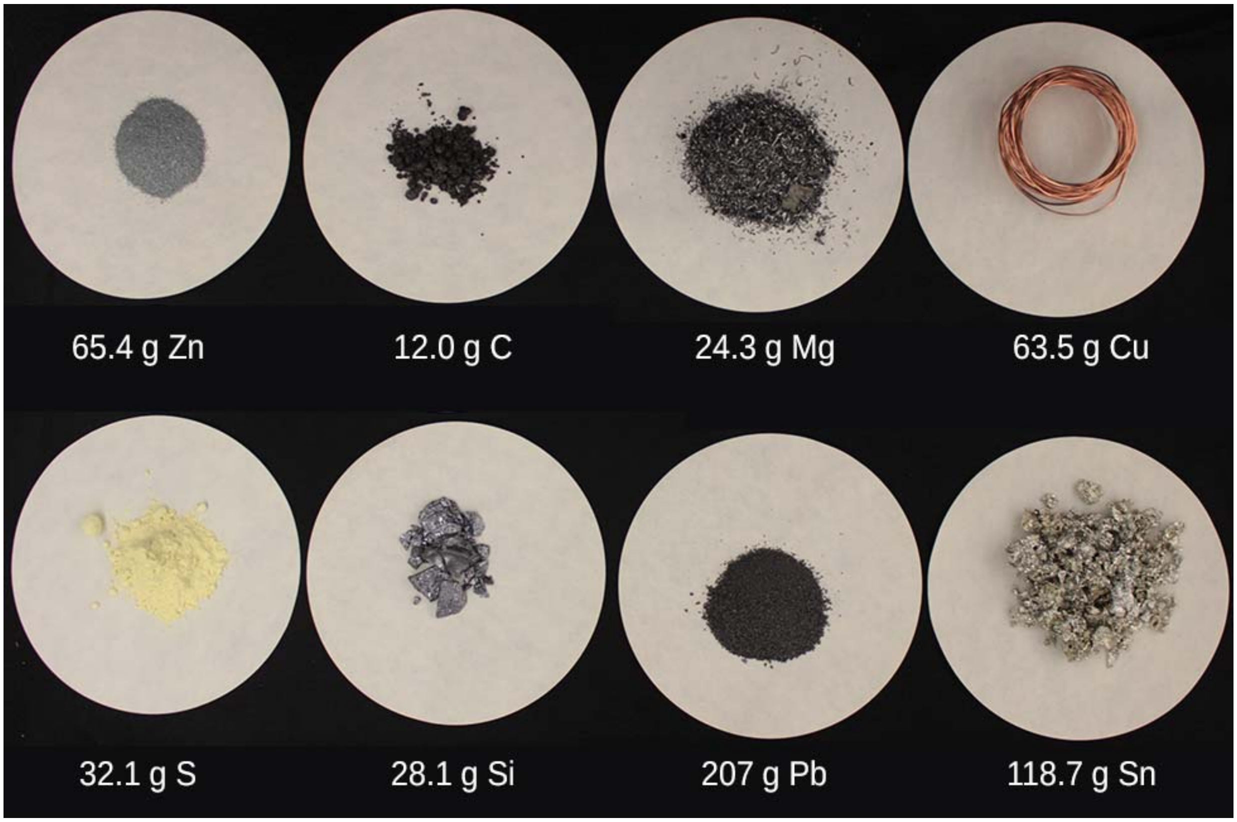
Calculation of molar mass: use the average atomic mass from periodic table. For example: molar mass of carbon 12.01 g/mol, Hydrogen 1.008 g/mol.
Below is a picture of 1 mol of different element in grams.

Molar mass of a compound is determined using the formula. Individual molar mass of the elements in a compound is taken and multiplied by its coefficients and added all together.

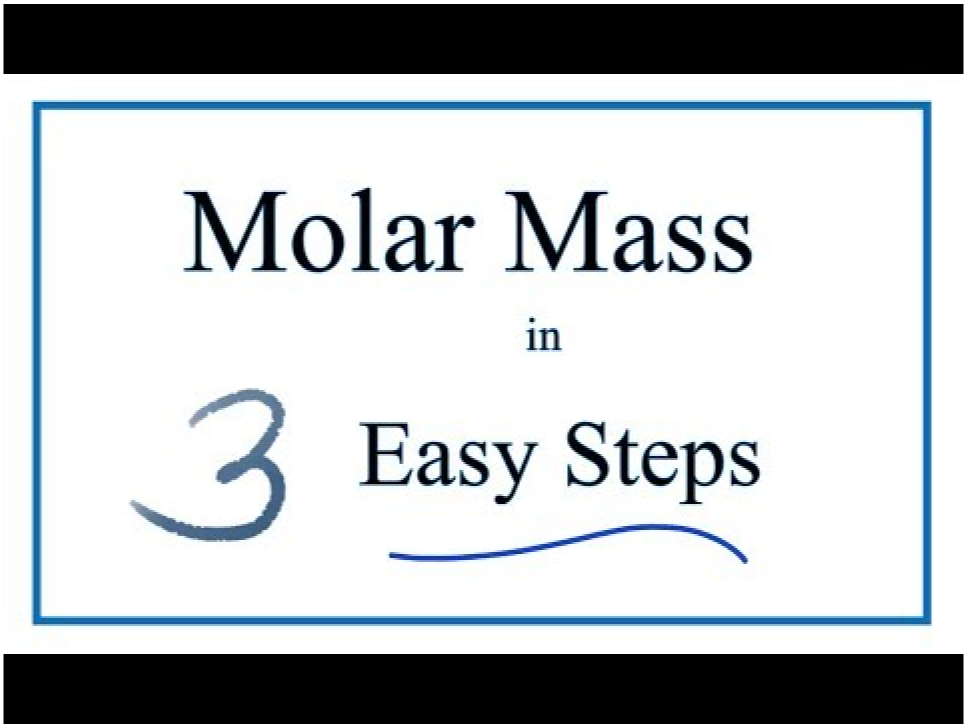
Example: Determine the molar mass of Glucose: $C_6H_{12}O_6$

Molar mass C → 6*12.01 = (72.06 g/mol)+
H →(12*1.008= (12.096 g/mol) +
O→(6* 16.00)= (96 .00g/mol)

180.16 g/mol



Watch the following video:
https://www.youtube.com/watch?v=o3MMBO8WxjY



Questions:

1. Determine the molar mass of Eu.

2. What is the molar mass of water, H_2O?

3. What is the formula weight ammonium carbonate, $(NH_4)_2CO_3$?

Ans: 1. 151.965 g/mol

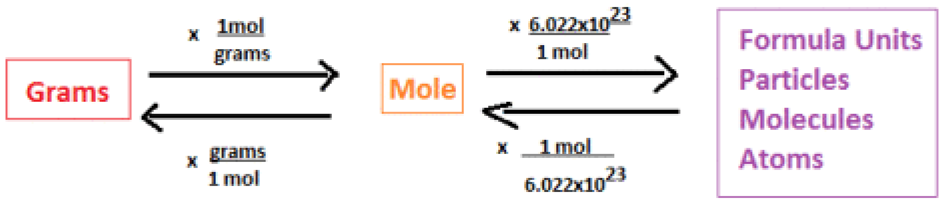
2.18.02 g/mol

3. 96.07 amu

VI. Conversion between Mass of a Substance and Moles

The molar mass is used as a conversion factor to determine how many grams are contained in a given number of moles of a substance. Similarly, the molar mass is used to determine how many moles of a substance are contained in a given number of grams

MOLE MAP



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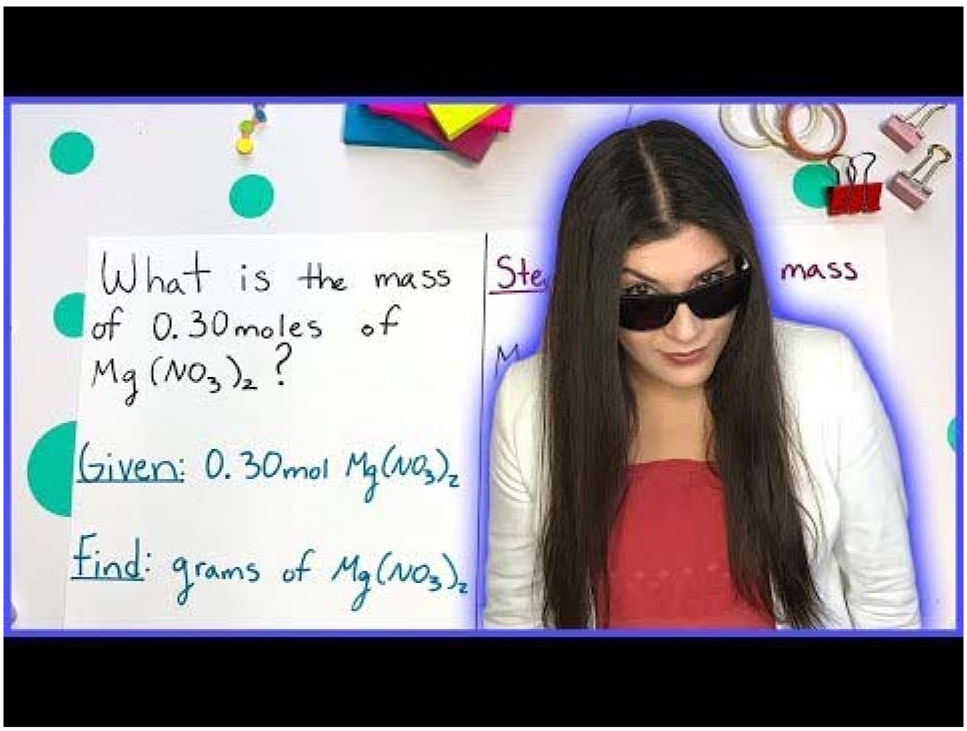


Example#1: How many mols are present in 24.02 g of Carbon?

Since it is grams to mol conversion, molar mass is the conversion factor.
According to Periodic table molar mass of C= 12.01 g/mol

$$24.02 \text{ g C} * \frac{1 \text{ mol C}}{12.01 \text{ g C}} = 2.00 \text{mols of C}$$

Example#2: How many mols are present in 54.1 g of Carbon?

Since it is grams to mols, molar mass is the conversion factor.
Molar mass of H_2O= 1.008 + 2* 16.00= 18.02 g/mol

$$54.1 \text{ g } H_2O * \frac{1\text{mol } H_2O}{18.02 \text{ g H2O}} = 3.00 \text{ mols of } H_2O$$

Example #3: How many grams are in 3.57 mols of CO_2?

Since it is mols to grams, molar mass is the conversion factor.
Molar mass of CO_2= 12.01 + (4*16.00)= 44.01 g/mol

$$3.57 \text{ mols of } CO_2 * \frac{44.01 \text{ 1g } CO_2}{1 \text{ mol } CO_2} = 157 \text{ g of } CO_2$$

Example#4 : How many atoms are present in 35.0 g of Cu?
We will use both conversion factor, molar mass and avogadro's number to solve this problem.

Pathway: $$grams \times \frac{moles}{grams} \times \frac{atoms}{moles} = atoms$$

$$35.0 \text{ g Cu} * \frac{1\text{mol Cu}}{63.5 \text{ g Cu}} * \frac{6.022 * 10^{23} \text{ atoms Cu}}{1 \text{ mol Cu}} = 3.32 * 10^{23} \text{ atoms of Cu}$$

Questions:

1. How many mols of H_2O are in 75.0 g of H_2O?

2. How many grams are in 3.46 mols of NaCl?

3. How many molecules are present in one mole of glucose, $C_6H_{12}O_6$?

4. You have a sample of 3.01×10^{23} atoms of silver. How much does this sample weigh?

5. A typical deposit of cholesterol, $C_{27}H_{46}O$, in an artery has a mass of 3.90 mg. How many molecules of cholesterol are present in this deposit?

Ans: 1. 4.16 mols H_2O

2. 202.2 g NaCl
3. $6.02 * 10^{23}$
4. 53.9 g Ag
5. $6.10 * 10^{18}$ molecules

VII. Determination of Mass and Moles of a Chemical reaction

Stoichiometry is a big word for a process that chemist's use to calculate amounts in reactions. It makes use of the coefficient ratio set up by balanced reaction equations to make connections between the reactants and products in reactions.

Stoichiometry calculates the quantities of reactants and products in a chemical reaction. The equation must be balanced!

Questions that deal with amounts in reactions are examples of reaction stoichiometry. We already have the tools necessary to solve this question. We just need to learn a new way to apply skills such as writing chemical formulas, calculating formula masses, and converting from mass to moles, particles to moles, and volume of gases to moles.

Mole to Mole Conversions- you must have the Mole Ratio. Illustration: Let's use an analogy that we can understand to begin to understand the process. The KEY to any mole conversion is the ratio of coefficients in the reaction equation.

Say I want to make a bacon double cheeseburger. Let's get our recipe together. 1 hamburger bun + 2 hamburger patties + 2 slices of cheese + 4 strips of bacon → 1 bacon double cheeseburger

Based on this recipe: 1) If I have five bacon double cheeseburgers:

a. How many hamburger buns did you use? → 5 hamburger bun

b. How many hamburger patties did you use? → 10 hamburger patties

c. How many slices of cheese did you use? → 10 slices of cheese

d. How many strips of bacon did you use? → 20 strips of bacon

2) How many bacon double cheeseburgers can you make if you start with:

a. 2 buns, 4 patties, 4 slices of cheese, 8 strips of bacon ans: 2 bacon double cheese burgers

b. 1 dozen buns, 2 dozen patties, 2 dozen slices of cheese, 4 dozen strips of bacon ans: 1 dozen bacon double cheese burgers 2

c. 1 mole of buns, 2 mol of patties, 2 mol of cheese slices, 4 mol of bacon strips ans: 1 mole of bacon double cheese burgers

d. 10 buns, 20 patties, 2 slices of cheese, 40 strips of bacon, ans: only 1 bacon double cheese burger

To think through these questions we were using the ratios set up by the reaction equation (a.k.a. recipe) We understood that to produce one complete bacon double cheeseburger we needed to have each of the above ingredients in a 1 bun to 2 patties to 2 slices of cheese to 4 slices of bacon. This ratio is called the coefficient ratio. The coefficient of a balanced chemical equation tell us the number of moles of each reactant that combine and the number of moles of each product formed. Coefficients are used to form molar ratios that serve as conversion factors relating the number of moles of reactants and products.

When the mass of a substance in a reaction must be calculated, first its number of moles is determined using mole rations, and then the molar mass is used to convert moles to grams.

If we want to make 3 sandwiches then we would just triple all of the coefficients. THIS COEFFICIENT RATIO IS KEY TO DOING STOICHIOMETRY.

Let's apply the above logic to a chemical recipe (a.k.a. chemical reaction equation)

a) : 1 H_2SO_4 + 2 NaOH → 1 Na_2SO_4 + 2 H_2O

If I use 1 mole of H_2SO_4 How many moles of sodium hydroxide do I need? 2 moles of NaOH

How many moles of sodium sulfate do I make? 1 Mole of Na_2SO_4

b) Consider the reaction $2H_2 + O_2 \rightarrow 2H_2O$. How many moles of water will be produced if there are 3.5 moles of oxygen?

pathway: mol of O_2 → 2 mol of H_2O

3.5 moles O_2 * 2 moles H_2O = 7.0 mol H_2O

c) Mole to Mass.

How many grams of water will be produced if there are 3.5 moles of oxygen?
pathway: mol of O_2 → mol of H_2O → grams of H_2O

$$3.5 \text{ mol } O_2 \rightarrow \frac{2 \text{ mol } H_2O}{1\text{mol } O_2} = 7.0 \text{ mols } H_2O$$

We need to convert mols to grams of H_2O.Here molar mass is the conversion factor.
18.02 g H_2O = 1mol H_2O

$$7.0 \text{ mols of } H_2O * \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 126 \text{ g of } H_2O \text{ or } 130 \text{ g of } H_2O.$$

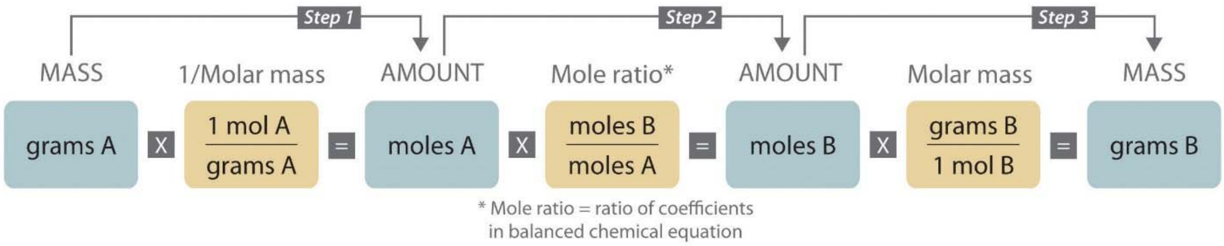
d) **Mass to Mass.** What mass of barium phosphate can be produced from 14.3 g of potassium phosphate reacting with barium nitrate?
$2K_3PO_4 + 3Ba(NO_3)_2 \rightarrow Ba_3(PO_4)_2 + 6\ KNO_3$

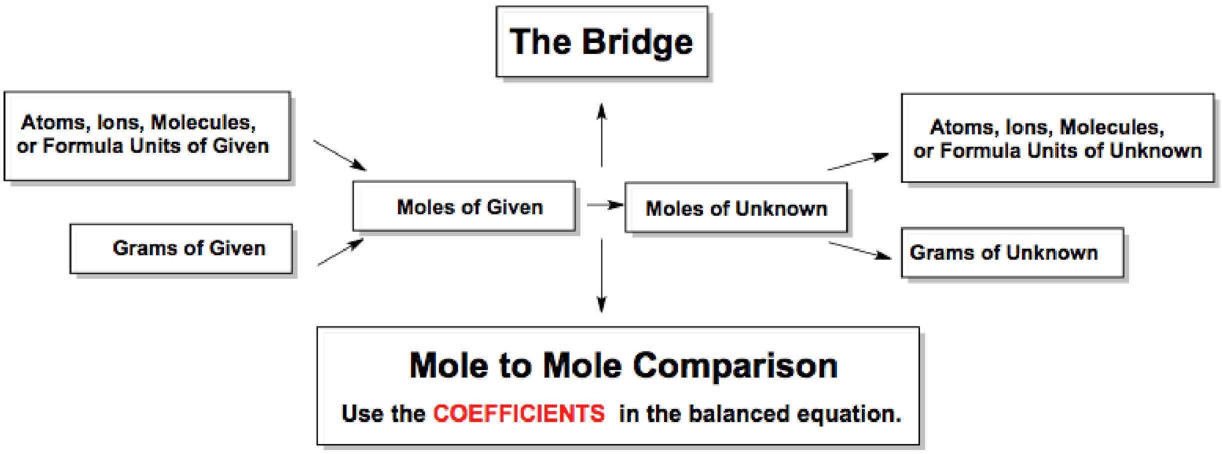
Molar mass of K_3PO4= 212.27 g/mol

Molar mass of $Ba_3(PO4)_2$= 601.93 g/mol

pathway: grams of K_3PO_4 → mol of K_3PO_4 → mol of $Ba_3(PO_4)_2$ → grams of $Ba_3(PO_4)_2$

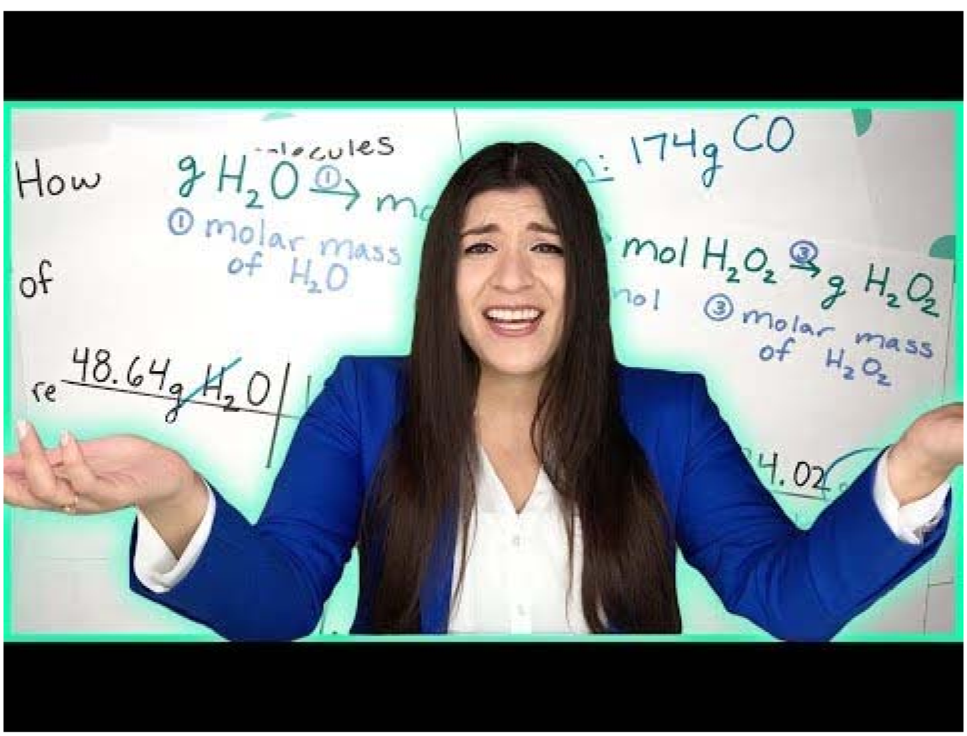
$$14.3 \text{ g } K_3PO_4 \times \frac{1 \text{ mol } K_3PO_4}{212.27 \text{ g } K_3PO_4} \times \frac{1 \text{ mol } Ba_3(PO_4)_2}{2 \text{ mol } K_3PO_4} \times \frac{601.94 \text{ g } Ba_3(PO_4)_2}{1 \text{ mol } Ba_3(PO_4)_2} = 20.2Ba_3(PO4)_2$$





Here is another video explaining how to solve step by step stoichiometry problems.

https://www.youtube.com/watch?v=lcnIiC8JZg0&t=80s



Following Activity has been taken from AACT

Air Bag Stoichiometry

Background

- **Stoichiometry**
  - mass relationships between substances in a chemical reaction
  - based on the mole ratio
- **Mole Ratio**
  - indicated by coefficients in a balanced equation

Prelab Questions

1. Have you ever had an experience with a vehicular air bag? Do you know someone who has?

2. Why would an air bag need to be inflated with an exact amount of gas?

3. What might happen if an air bag was inflated with too little gas?

4. What might happen if an air bag was inflated with too much gas?

Materials

- Calculator
- Periodic table

Problem

If exactly 59.6g of nitrogen gas is needed to inflate your air bag to the correct size, how many grams of NaN_3 would you need to decompose? (Chemical reaction must be written and balanced first)

Extension

The compound diborane (B_2H_6) was at one time considered for use as a rocket fuel. How many grams of liquid oxygen would a rocket have to carry to burn 10 kg of diborane completely? (The products are B_2O_3 and H_2O).

Individual practice problems

1. You want to help your little brother make an exploding volcano for his science class. The lava will be made from reacting baking soda ($NaHCO_3$) with vinegar ($HC_2H_3O_2$). After building the volcano, you know that you want to create about 100.0g of lava (or sodium acetate). Too little lava, and the volcano won't overflow. Too much lava would be a giant mess! Using stoichiometry and the equation below, calculate the exact amount of baking soda needed to make 100.0g of lava. Assume you have excess vinegar.

$$NaHCO_3 + HC_2H_3O_2 \rightarrow NaC_2H_3O_2 + H_2O + CO_2$$

2. Camels store the fat tristearin ($C_{57}H_{110}O_6$) in the hump. As well as being a source of energy, the fat is a source of water, because when it is used the reaction below takes place. What mass of water can be made from 1.0kg of fat?

$$2\ C_{57}H_{110}O_6 + 163\ O_2 \rightarrow 114\ CO_2 + 110\ H_2O$$

3. You want to create 12g of copper to meld into a piece of jewelry. You know that when copper (II) chloride reacts with aluminum, copper is a product. How much aluminum would you need to start your reaction with to get 12g of copper? (write and balance the reaction first)

Individual practice problems – Answers

1. You want to help your little brother make an exploding volcano for his science class. The lava will be made from reacting baking soda ($NaHCO_3$) with vinegar ($HC_2H_3O_2$). After building the volcano, you know that you want to create about 100.0g of lava (or sodium acetate). Too little lava, and the volcano won't overflow. Too much lava would be a giant mess! Using stoichiometry and the equation below, calculate the exact amount of baking soda needed to make 100.0g of lava. Assume you have excess vinegar.

$$NaHCO_3 + HC_2H_3O_2 \rightarrow NaC_2H_3O_2 + H_2O + CO_2$$

100.0g$NaC_2H_3O_2$	1 mol $NaC_2H_3O_2$	1 mol $NaHCO_3$	84.01g $NaHCO_3$
	82.04g $NaC_2H_3O_2$	1 mol $NaC_2H_3O_2$	1 mol $NaHCO_3$

= 102.4g $NaHCO_3$

2. Camels store the fat tristearin ($C_{57}H_{110}O_6$) in the hump. As well as being a source of energy, the fat is a source of water, because when it is used the reaction below takes place. What mass of water can be made from 1.0kg of fat?

$$2\ C_{57}H_{110}O_6 + 163\ O_2 \rightarrow 114\ CO_2 + 110\ H_2O$$

1.0kg $C_{57}H_{110}O_6$	1000g	1 mol $C_{57}H_{110}O_6$	110 mol H_2O	18.02g H_2O
	1 kg	891.67g $C_{57}H_{110}O_6$	2 mol $C_{57}H_{110}O_6$	1 mol H_2O

= 1.1×10^3 g H_2O

3. You want to create 12.0g of copper to meld into a piece of jewelry. You know that when copper (II) chloride reacts with aluminum, copper is a product. Given excess copper (II) chloride, how much aluminum would you need to start your reaction with to get 12.0g of copper? (write and balance the reaction first)

$$2Al + 3CuCl_2 \rightarrow 2AlCl_3 + 3Cu$$

12.0g Cu	1 mol Cu	2 mol Al	26.98g Al
	63.55g Cu	3 mol Cu	1 mol Al

= 3.40g Al

Questions:

1. What mass of bromine gas can be produced from the complete reaction of potassium bromide and 34.5 g of fluorine gas? $2KBr + F_2 \rightarrow Br_2 + 2KF$

2. Lime, CaO, is produced by the reaction $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$. What weight of CO_2 is obtained by the decomposition of 38.7 g of $CaCO_3$?

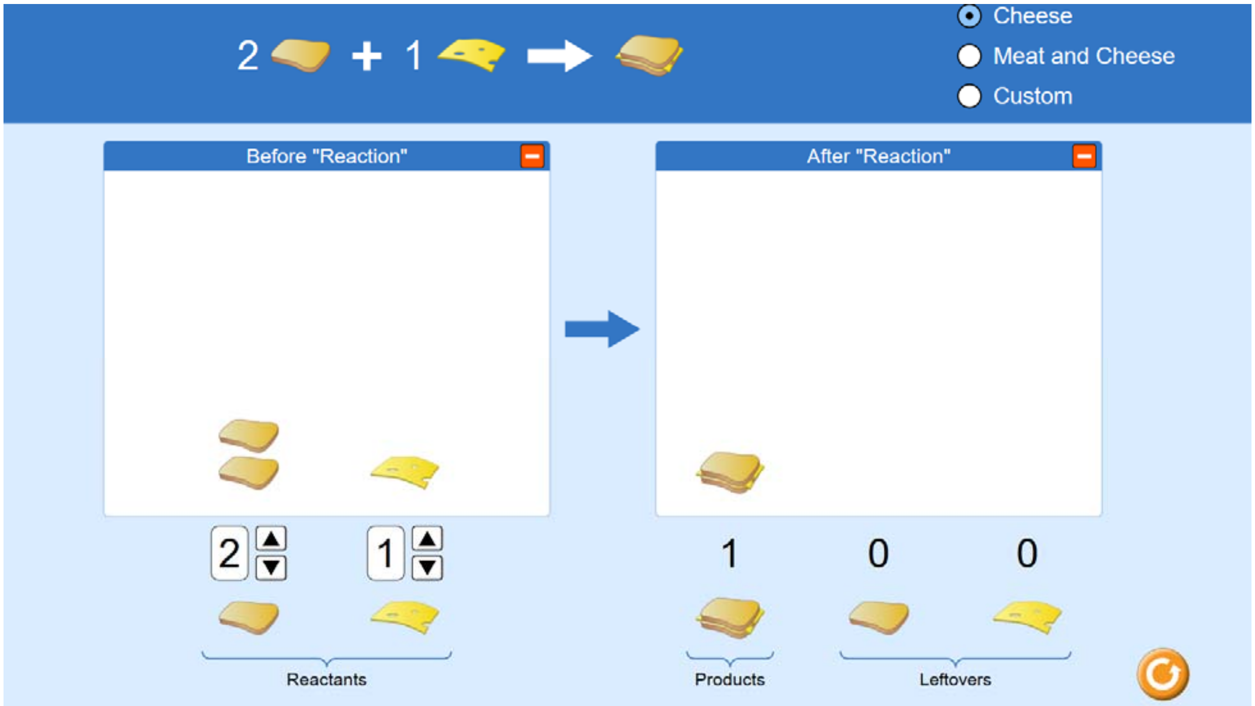
3. Given the reaction $2\ HgO(s) \rightarrow 2\ Hg(l) + O_2(g)$. What weight of elemental mercury will be obtained by the decomposition of 94.5 g of HgO?

Ans: 1. 145 g Br_2
6. 17.0 g CO_2
7. 87.5 g Hg

VIII. Limiting Reactant

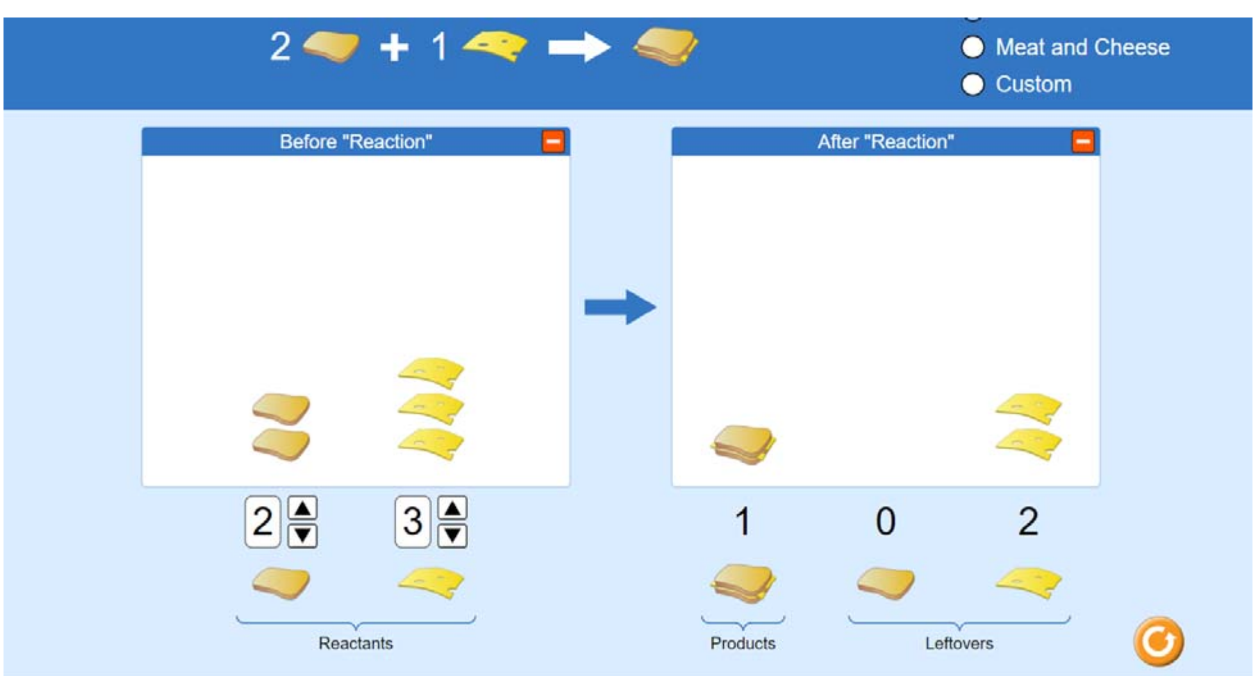
Often in a chemical reaction a reagent runs out and that stops the entire chemical reaction. Limiting reactant is a reactant that is completely used up first in a chemical reaction. The number of moles of limiting reactant determines the moles of products using the molar ratios in the balanced equation. The amount of products obtained from a limiting reagent is called theoretical yield. Theoretical yield is the max. amount of products theoretically possible in a chemical reaction according to balanced equation.

Go to the following simulation activity and find how may bread and cheese you need
https://phet.colorado.edu/sims/html/reactants-products-and-leftovers/latest/reactants-products-and-leftovers_en.html

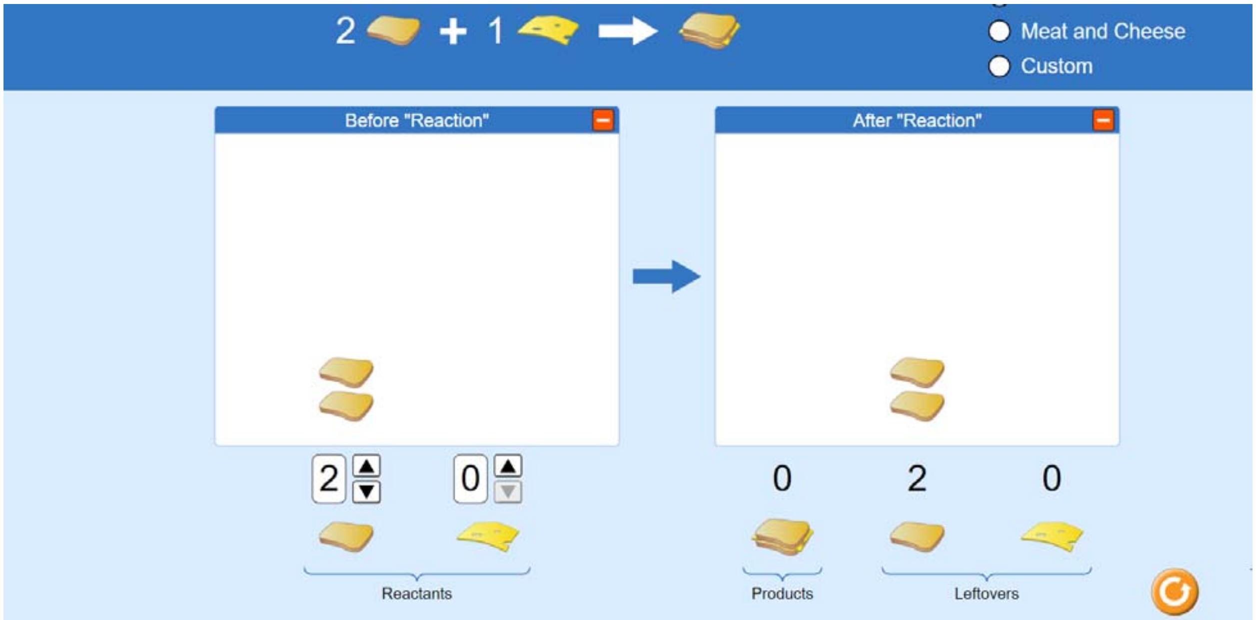


The above picture shows that following the recipe we need 2 breads and 1 slice of cheese to make a product.

Now if you increase the number of cheese slices that will be excess reagent.

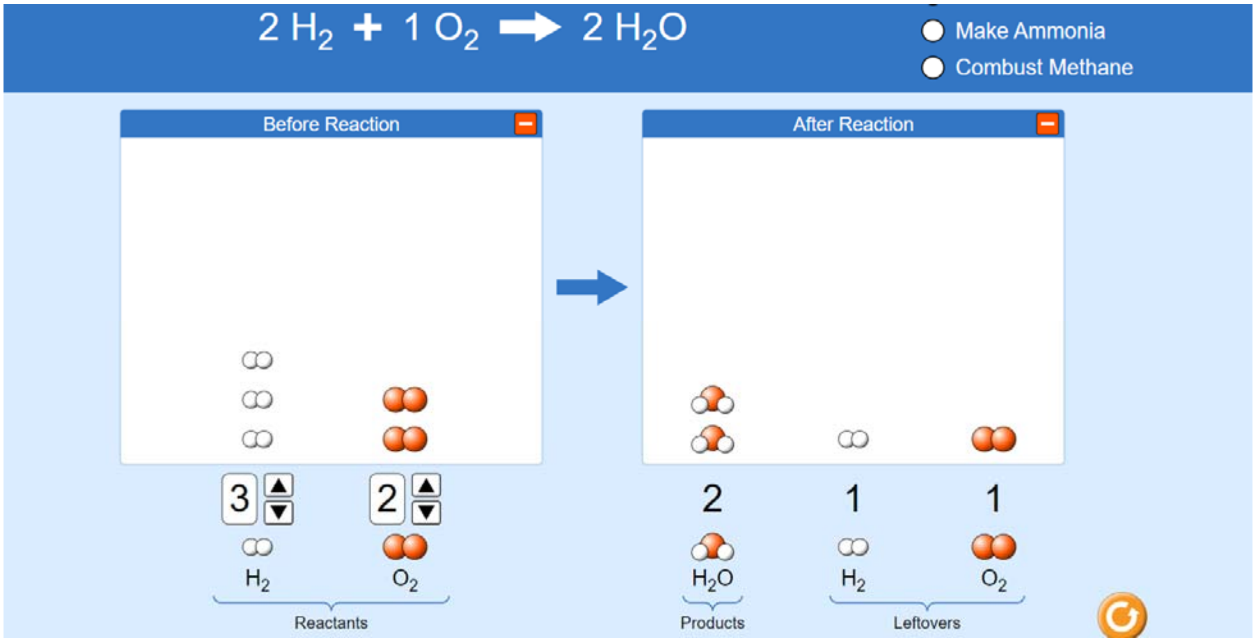


If you take less than one slice then there is no product because number of cheese slice is then limiting reagent and bread is excess.



Now we come to problems in chemical world. Can you explain the picture below?

Which one is limiting reagent? Which one is excess reagent? What is the theoretical yield of the following reaction?



Example #1: Here's a nice limiting reagent problem we will use for discussion. Consider the reaction:

$2Al + 3I_2$ ------> $2AlI_3$

Determine the limiting reagent and the theoretical yield of the product if one starts with:

(a) 1.20 mol Al and 2.40 mol iodine.
(b) 1.20 g Al and 2.40 g iodine
(c) How many grams of Al are left over in part b?

Solution for part (a):

We already have moles as the unit, so we use those numbers directly.

1) Here is how to find out the limiting reagent:

take the moles of each substance and divide it by its coefficient in the balanced equation. The substance that has the smallest answer is the limiting reagent.

Let's say that again:

to find the limiting reagent, take the moles of each substance and divide it by its coefficient in the balanced equation. The substance that has the smallest answer is the limiting reagent.

2) Resuming with the problem solution:

For aluminum: 1.20 / 2 = 0.60
For iodine: 2.40 / 3 = 0.80

3) The lowest number indicates the limiting reagent. Aluminum will run out first in part (a) of the question. Why?

1.20/2 means there are 0.60 "groupings" of 2 and 2.40/3 means there are 0.80 "groupings" of 3. If they ran out at the same time, we'd need one "grouping" of each. Since there is less of the "grouping of 2," it will run out first.

4) The second part of the question "theoretical yield" depends on finding out the limiting reagent. Once we do that, it becomes a stoichiometric calculation.

Al and AlI_3 stand in a one-to-one molar relationship, so 1.20 mol of Al produces 1.20 mol of AlI_3. If molar mass of AlI_3 is 407.99 g/mol, the theoretical yield is 1.20 mol * 407.99 g/1 mol= 489.6 g = 490. g.

Notice that the amount of I_2 does not play a role, since it is in excess.

Solution for part (b):

1) Since we have grams, we must first convert to moles. The we solve just as we did in part a just above. For the mole calculation:

aluminum is 1.20 g / 26.98 g mol^{-1} = 0.04477 mol
iodine is 2.4 g / 253.8 g mol^{-1} = 0.009456 mol

2) To determine the limiting reagent:

aluminum is 0.04477 / 2 = 0.02238
iodine is 0.009456 / 3 = 0.003152

The lower number is iodine, so we have identified the limiting reagent.

3) Finally, we have to do a calculation and it will involve the iodine, NOT the aluminum.

I_2 and AlI_3 stand in a three-to-two molar relationship, so 0.009456 mol of I_2 produces 2/3*0.009456= 0.006304 mol of AlI_3. Again, notice that the amount of Al does not play a role, since it is in excess.

From here figure out the grams of AlI_3 and you have your answer.

Solution for part (c):

Since we have moles, we calculate directly and then convert to grams.

Al and I_2 stand in a two-to-three molar relationship, so 0.009456 mol of I_2 uses 0.006304 mol of Al.

Convert this aluminum amount to grams and subtract it from 1.20 g and that's the answer.

https://www.youtube.com/watch?v=IvCPLCQ-YK0

How much $ZnCl_2$ can be produced from the reaction of 2.0 mol of Zn and 3.0 mol of HCl? Which is the limiting reagent?

$$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$$

Method #2. Determine how much of one reactant the other reactant requires to react completely. Then use the limiting reagent to determine the maximum amount of product that can be made.

Questions:

1. Find the limiting reagent in each of the following:

a) $N_2 + 3H_2 \rightarrow 2NH_3$
Starting with 28.0 g of N_2 and 2.50 g of H_2

b) $CaO + CO_2 \rightarrow CaCO_3$
Starting with 112.0 g of CaO and 66.0 g of CO_2

Ans: 1 a) H_2 b) CaO

IX. Percent Yield

It is often important to calculate percent yield in a chemical reaction to estimate the efficiency of a chemical reaction. Percent yield is defined as

Percent yield= (actual/theoretical)*100%. The actual yield is the amount of product in a chemical reaction, determined by weighing a product on a balance. Theoretical yield is a quantity calculated from a balanced chemical equation, using mole ratios and molar masses. The theoretical yield is the maximum amount of product formed in a chemical reaction from the amount of reactants used.

When we perform stoichiometric calculations to determine the amount of product produced – that is a theoretical yield. But when we actually perform the experiment in a lab setting, we usually find we do not get as much product, we usually get a smaller actual yield due to human error or other experimental error.

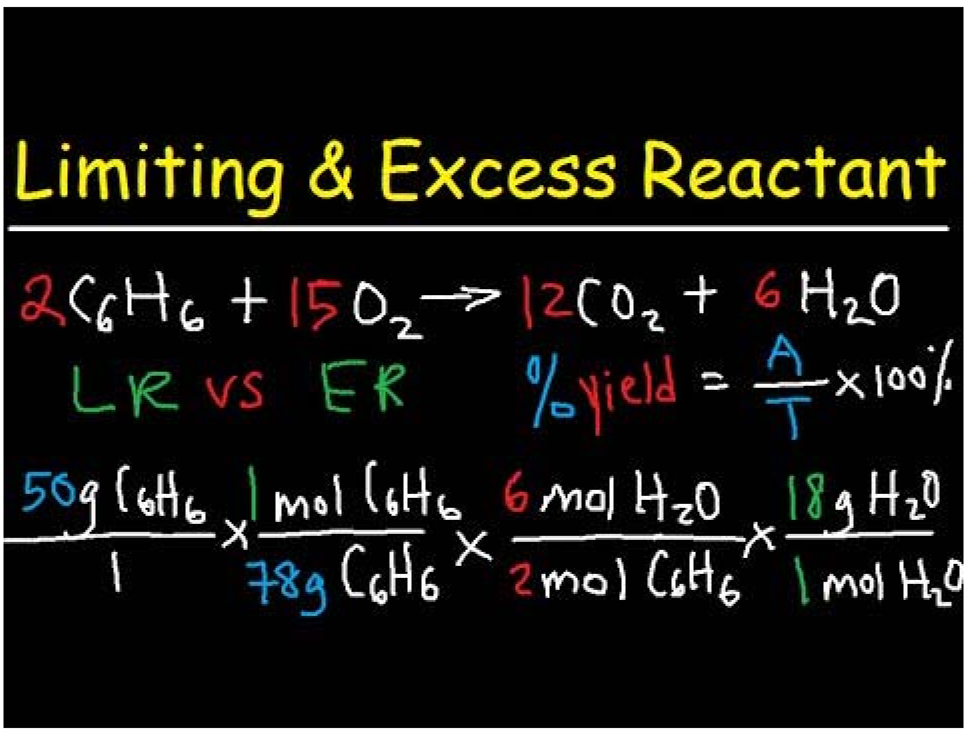
To calculate the percent yield, the actual yield and theoretical yield are needed. You prepared cookie dough to make 5 dozen cookies. The phone rings and you answer. While talking, a sheet of 12 cookies burn and you have to throw them out. The rest of the cookies are okay. What is the percent yield of edible cookies?

Theoretical yield 60 cookies possible

Actual yield 48 cookies to eat

Percent yield 48 cookies x 100 = 80% yield

https://www.youtube.com/watch?v=CK2yK_JTUH4



Examples:

1. the reaction of carbon and oxygen produces carbon monoxide. $2C(g) + O_2 (g)\ 2CO(g)$ What is the percent yield if 40.0 g CO are actually produced when 30.0 g O_2 are used? (Need to find the theoretical 1 st) 1) 25.0% 2) 75.0% 3) 76.2%

Ans: theoretical yield of CO $30.0 \text{ g } O_2 \times \dfrac{1 \text{ mol } O_2}{2 \text{ mol CO}} \times 28.01 \text{ g CO} = 52.5 \text{ g CO}$ (theoretical)

percent yield 40.0 g CO (actual) x 100 = 76.2 % yield 52.5 g CO (theoretical)

2. When N_2 and 5.00 g H_2 are mixed, the reaction produces 16.0 g NH_3. What is the percent yield for the reaction? $N_2 (g) + 3H_2 (g) \rightarrow 2NH_3 (g)$ 1) 31.3 % 2) 56.5 % 3) 80.0 %

$$N_2 (g) + 3H_2 (g) \rightarrow 2NH_3 (g)$$

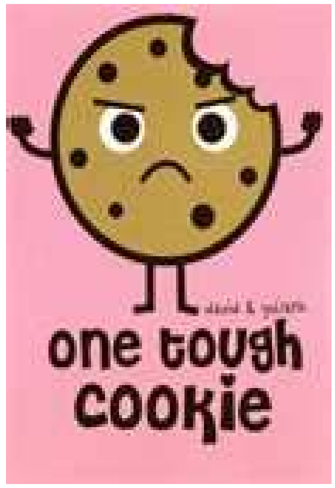
$$5.00 \text{ g } H_2 \times \frac{1 \text{ mol } H_2}{2.106 \text{ g } H_2} \times \frac{2 \text{ mol } NH_3}{3 \text{ mols } H_2} \times 17.03 \text{ g } NH_3 = 28.2 \text{ g } NH_3 \text{ (theoretical)}$$

Percent yield = 16.0 g NH_3 x 100 = 56.7 % 28.2 g NH_3

<u>The following activity has been taken from AACT</u>

Cookie Stoichiometry

Stoichiometry is a process in which the equation for a chemical reaction is used like a recipe. We will do mass to mass problems, limiting reactant problems, and percent yield problems just like we did with this cookie recipe. It will be a piece of cake!!



Original Nestle Tollhouse Cookie Recipe Ingredients:

2 1/4 cups all-purpose flour
1 teaspoon baking soda
1 teaspoon salt
1 cup (2 sticks) butter or margarine, softened
3/4 cup granulated sugar
3/4 cup packed brown sugar
1 teaspoon vanilla extract
2 large eggs
2 cups (12 oz. pkg.) NESTLÉ TOLL HOUSE Semi-Sweet Chocolate Morsels

PREHEAT oven to 375° F. COMBINE flour, baking soda and salt in small bowl. Beat butter, granulated sugar, brown sugar and vanilla extract in large mixer bowl until creamy. Add eggs one at a time, beating well after each addition. Gradually beat in flour mixture. Stir in morsels and nuts. Drop by rounded tablespoon onto ungreased baking sheets. BAKE for 9 to 11 minutes or until golden brown. Cool on baking sheets for 2 minutes; remove to wire racks to cool completely.

11 minutes, 375° Makes 60 cookies.

.

Use the above cookie recipe to answer the following questions. Be sure to show your work and cross out units.

1. Write 3 ratios that can be used from this recipe.

2. If you make 45 cookies, how many batches is this?

3. How many cups of brown sugar are needed to completely “react” with 8 eggs?

4. How many batches of cookies can be made from 1 cup of morsels?

5. If you start out with 4 eggs and 3 cups of flour, which one will run out first? This is called the “limiting reactant”.

6. Using the information from #5, how many batches can you make if you have plenty of the other ingredients?

7. Which ingredient did you use to get the answer to #6, the eggs or the flour?

8. How many cookies is this?

9. If you had enough ingredients to make a batch of cookies and you made 53 cookies (you probably ate the rest of the dough!), what is your percent yield?

Questions:

1. In a particular reaction, the theoretical yield is 37.4 g, If the actual yield is 31.2g. what is the percent yield?

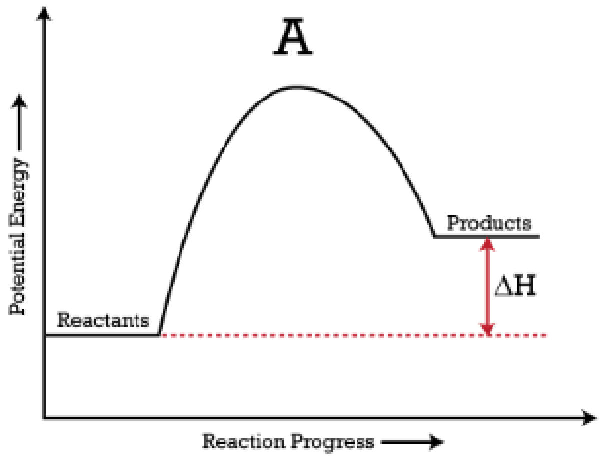
2. $2C_2H_5OH(l) \rightarrow (C_2H_5)_2O(l) + H_2O(l)$

In the above reaction, 46.0 g of C_2H_5OH produces 35.9 g diethyl ether. What is the percent yield?

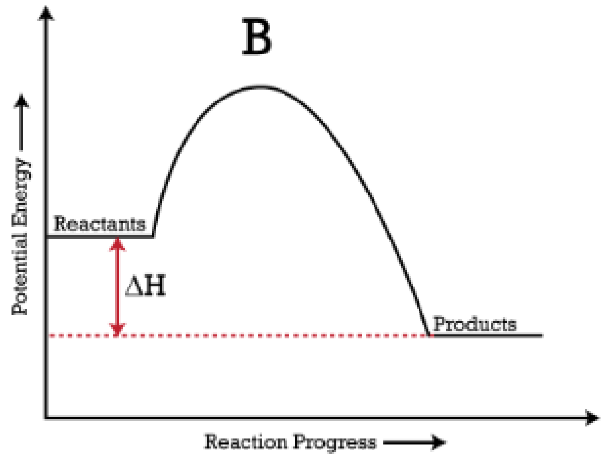
Ans: 1. 83.4% 2. 96.9%

X. Energy Diagram

A potential energy diagram illustrates the energy changes that occurs during a chemical reaction. Energy is plotted along vertical axis and reaction coordinate is plotted along horizontal axis. According to collision theory, reactant molecules collide during chemical reaction. Molecules with proper kinetic energy called activation energy and alignment successfully form the product. For every reaction there is a certain amount of activation energy required to form the product, During the chemical reaction some old bonds are broken and new bonds are formed. When the reactant reaches the intermediate stage during reaction with proper activation energy, the species is called Activated complex or transition state. The transition state is located at the top of the energy barrier that separates reactants from products on the potential energy diagram. Also, the reaction can release the heat or absorb the heat during the chemical reaction. This quantity of heat is called heat of the reaction or enthalpy(ΔH). When the reaction is releasing heat, product enegy level is below reactant energy level, since the total energy in a chemical reaction is always conserved.



Endothermic



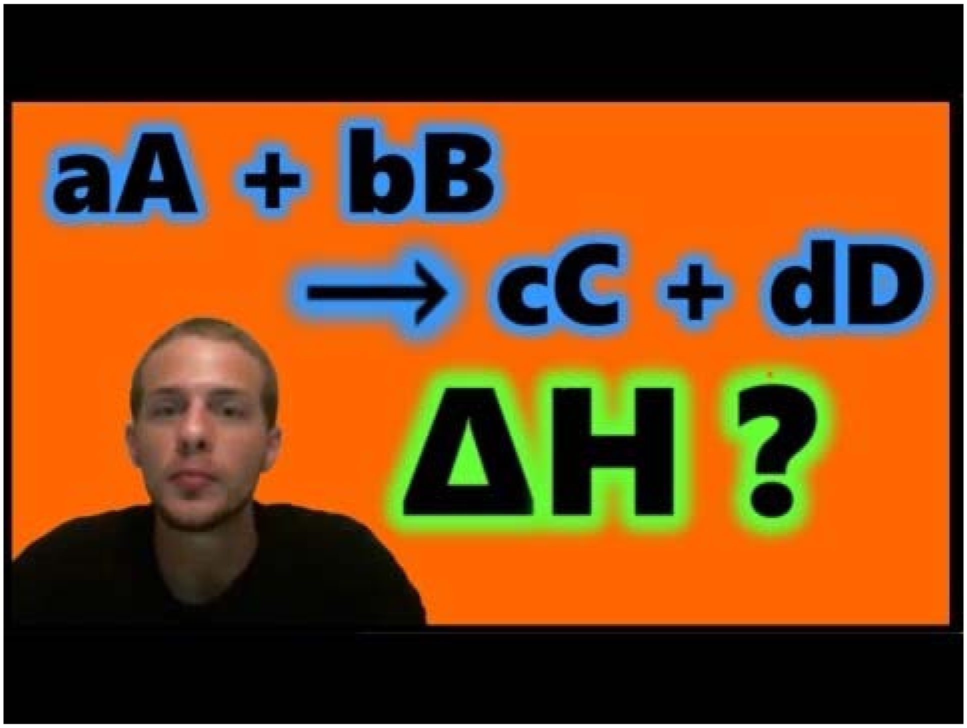
Exothermic

XI. Heat Energy and Stoichiometry

The heat of reaction is also called enthalpy change and symbolized by ΔH, the energy absorbed or released in a reaction. In an endothermic reaction, energy is absorbed. Sign of ΔH is positive If written separately, on the reactant side if mentioned in the reaction. On the energy diagram products are on the higher energy level than the reactants. It means reactants bonds are stronger than products bond.

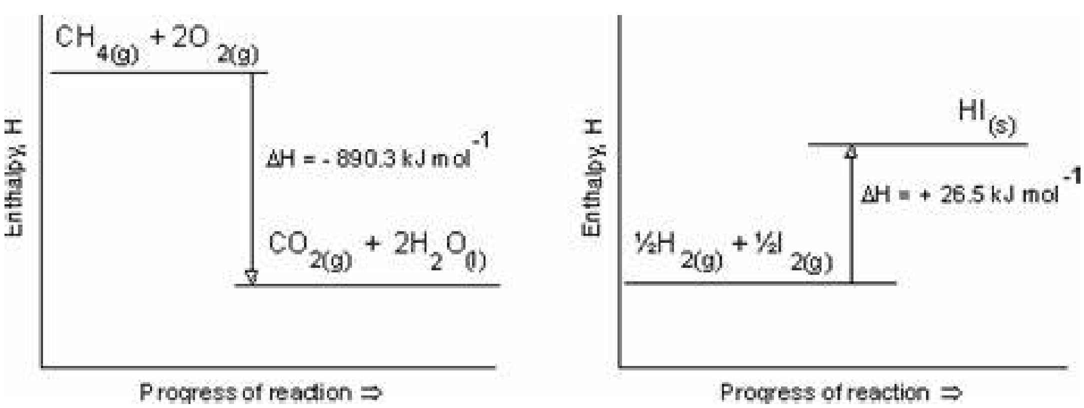
In an exothermic reaction, energy is released. Sign of ΔH is negative if written separately, on the product side if mentioned in the reaction. On the energy diagram products are on the lower energy level than the reactants. It means products bonds are stronger than reactants bonds.

https://www.youtube.com/watch?v=H4wRTbayj4o



$N_2 + 3H_2 \rightarrow 2\ NH_3(g) + 92.5\ kJ$
$2\ NaHCO_3 + 129\ kJ \rightarrow Na_2CO_3 + H_2O + CO_2$

The above two reactions are examples of exothermic and endothermic reaction. The diagram below is the enthalpy diagram for exo- and endothermic reaction.



A balanced chemical equation gives the enthalpy value. The magnitude of enthalpy is proportional to the amount of substance.

In example #1, if 222.4 g of N_2 reacts, how many kilojoules of heat will be released?

We can use the balanced equation coefficients to find the amount of heat.

$$222.4 \text{ g } N2 * \frac{1 \text{ mol } N_2}{28.00 \text{ g } N_2} * \frac{-92.5 \text{ KJ}}{1 \text{ mol } N_2} = -74.0 \text{ kJ}$$

Similarly in endothermic reaction, energy is absorbed and similar calculation can be performed.

Questions:

1. Metabolism of one mole of glucose, $C_6H_{12}O_6$, releases 670 kcal. How much heat is released by the combustion of 0.300 moles of glucose?

2. Below is the combustion reaction of propane, C_3H_8. Is the reaction exothermic or endothermic? How much heat is involved by the combustion of 1.20 moles of propane?

$$C_3H_8 + O2 \rightarrow 3CO_2 + 4H_2O + 531 \text{ kcal}$$

Ans: 1. 201 kcal 2. Exothermic, 637 kcal released

Practice Questions: Chapter 5

Indicate the answer choice that best completes the statement or answers the question.

1. How many moles of marble, $CaCO_3$, are there in a 275 g piece of marble?

   a. 4.57×10^{-22} b. 0.364

   c. 2.75 d. 275

2. Ethanol is produced industrially by the acid catalyzed reaction of ethylene with water. The balanced equation for this reaction is:

$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(l)$

If water is present in excess, how many grams of ethanol can be produced from 7.24 mol of ethylene?

   a. 7.24 g b. 14.5 g

   c. 203 g d. 334 g

3. Which of the following is true of **<u>all</u>** combustion reactions?

   a. They are exothermic.

   b. They produce carbon dioxide.

   c. both a and b

   d. neither a nor b

4. When an acid is added to a solution, no gas is formed. Which of the following ions cannot be in the solution?

   a. CO_3^{2-} b. PO_4^{3-}

   c. SO_4^{2-} d. none of these

5. Which of the following is true of the reaction: $O_2(g) \rightarrow 2\ O(g)$?

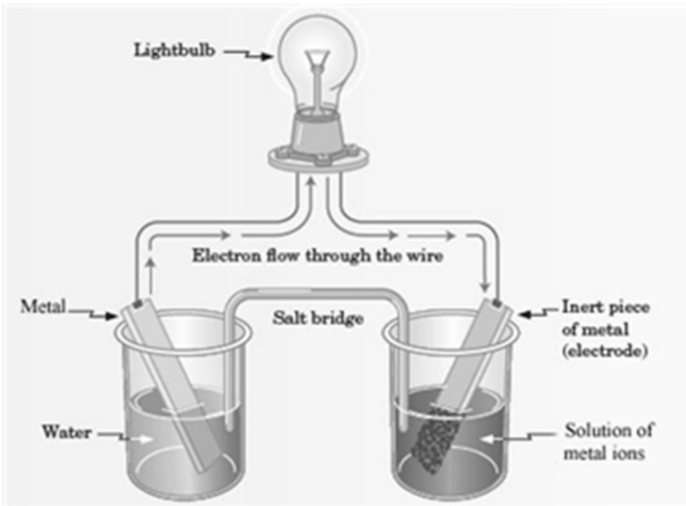
   a. It is endothermic.

   b. It is exothermic.

   c. It is neither endothermic nor exothermic.

d. None of these, the reaction cannot occur.

Consider the following representation of a voltaic cell.



This voltaic cell is represented by the following reaction:
$Mg(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Mg^{2+}(aq)$

6. What is the identity of the "Metal" shown in the diagram?

a. Mg b. Cu

c. Mg^{2+} d. Cu^{2+}

7. What is the molecular weight of sucrose, $C_{12}H_{22}O_{11}$?

a. 180.2 amu b. 319.6 amu

c. 342.3 amu d. 360.4 amu

8. The molecular weight of ethylene glycol is 62.0 g. What is the mass of one molecule of ethylene glycol?

a. 9.70×10^{21} g b. 62.0 g

c. 0.0161 g d. 1.03×10^{-22} g

9. The balanced equation for burning octane is: $2\ C_8H_{18}(g) + 25\ O_2(g) \rightarrow 18\ H_2O(g) + 16\ CO_2(g)$. What weight of oxygen is required to completely burn 19.8 g of octane?

a. 28.1 g b. 34.7

c. 69.5 d. 139 g

In the image are several types of burners used in many chemistry laboratories.

10. Whether these burners use natural gas, propane or butane as a fuel, which of the following is true?
    a. The reactions are classified as combustion reactions.
    b. The reactions are classified as redox reactions.
    c. The reactions are classified as exothermic.
    d. All of the these statements are correct.

11. Which of the following is true regarding mass relationships in a chemical reaction?
    a. To determine mass relationships in a chemical reaction, you first need to know the balanced chemical equation for the reaction.
    b. To convert from grams to moles and vice versa, you need to use Avogadro's number as a conversion factor.
    c. Both a and b are true.
    d. Both a and b are false.

12. Which of the following is reduction?

a. gain of electrons	b. loss of hydrogen
c. gain of oxygen	d. none of these

13. Which of the following are the products of the incomplete combustion of a hydrocarbon such as methane, CH_4, or propane, C_3H_8?

a. $CO(g) + H_2O(g)$	b. $CO(g) + H_2O_2(l)$
c. $CO_2(g) + H_2O(g)$	d. $CO_2(g) + H_2O(l)$

14. When a solution of Cu(II) chloride, $CuCl_2$, is added to a solution of potassium sulfide, K_2S, a black precipitate of copper sulfide, CuS, forms. Which of the following is the total ionic equation for this reaction?

a. $CuCl_2(aq) + K_2S(aq) \rightarrow CuS(s) + 2\ KCl(aq)$

b. $Cu^{2+}(aq) + Cl_2^{2-}(aq) + K_2^{2+}(aq) + S^{2-}(aq) \rightarrow CuS(s) + K_2^{2+}(aq) + Cl_2^{2-}(aq)$

c. $Cu^{2+}(aq) + 2\ Cl^{-}(aq) + 2\ K^{+}(aq) + S^{2-}(aq) \rightarrow CuS(s) + 2\ K^{+}(aq) + 2\ Cl^{-}\ (aq)$

d. $Cu^{2+}(aq) + S^{2-}(aq) \rightarrow CuS(s)$

15. Which of the following compounds has the largest formula weight?

a. KCl b. NaCl

c. MgF_2 d. BF_3

16. Which of the following is true of a voltaic cell?

a. The anode is the positive electrode and place where reduction occurs.

b. The anode is the positive electrode and place where oxidation occurs.

c. The cathode is the positive electrode and place where reduction occurs.

d. The cathode is the positive electrode and place where oxidation occurs.

17. The atomic weight of copper is less than that of silver. If you have a 10 g sample of each of these metals, which of the following is true?

a. You have fewer of atoms of copper than of silver.

b. You have equal numbers of atoms of copper and silver.

c. You have more atoms of copper than of silver.

d. There is insufficient information to determine which of the above is true.

18. A person drinks 1.50×10^3 g of water, H_2O, per day. How many moles is this?

a. 0.0120 b. 8.33

c. 83.3 d. 1.20×10^2

19. Lime, CaO, is produced by the reaction $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$. What weight of CaO is obtained by the decomposition of 38.7 g of $CaCO_3$?

a. 15.5 g b. 17.0 g

c. 21.7 g d. 23.2 g

20. What is the molar mass of glucose, $C_6H_{12}O_6$?

a. 60.05 amu b. 180.2 amu

c. 60.05 g d. 180.2 g

21. Which of the following is true of a conventionally balanced chemical equation?

a. The number of molecules on the left equal the number of molecules on the right.

b. The coefficients are all integers.

c. Both a and b are true.

d. Both a and b are false.

22. In a particular experiment to prepare a compound, the theoretical yield is 34.7 g. If the actual yield is 31.2 g, what is the percent yield?

a. 0.899% b. 11.1%

c. 89.9% d. 93.0%

23. Solutions of sugars such as glucose react with Ag^+(aq) to produce Ag(s). In this reaction glucose functions as which of the following?

a. the reducing agent

b. the oxidizing agent

c. both the reducing agent and the oxidizing agent

d. neither the oxidizing agent nor the reducing agent

24. Diethyl ether can be made from ethanol. The reaction is:

$2\ C_2H_5OH(l) \rightarrow (C_2H_5)_2O(l) + H_2O(l)$

The percent yield of diethyl ether in one experiment was 94.0% and actual yield was 68.6 g. How much ethanol did the chemist use in this experiment?

a. 45.4 g b. 73.0 g

c. 80.2 g d. 90.7 g

25. Metabolism of one mole of glucose, $C_6H_{12}O_6$, releases 6.70×10^2 kcal. How much heat is released by the combustion of 50.0 g of glucose?

a. 186 kcal b. 201 kcal

c. 2.23×10^3 kcal d. 2.41×10^3 kcal

26. In the reaction $CH_2O(g) + O_2(g) \rightarrow HCOOH(g) + H_2O(g)$ which species is oxidizing agent?

a. $CH_2O(g)$ b. $O_2(g)$

c. HCOOH(g) d. $H_2O(g)$

27. When solutions of $AgNO_3$ and NaOH react, the balanced molecular equation is:

$2\ AgNO_3(aq) + 2\ NaOH(aq) \rightarrow Ag_2O(s) + 2\ NaNO_3(aq) + H_2O(l)$

How much Ag_2O is produced when 2.00 g of $AgNO_3$ and 0.300 g of NaOH react?

a. 0.869 g b. 1.43 g

c. 1.74 g d. 2.30 g

28. In the industrial synthesis of acetic acid, methanol is reacted with carbon monoxide. The balanced equation for this reaction is:

$CH_3OH(g) + CO(g) \rightarrow CH_3COOH(l)$

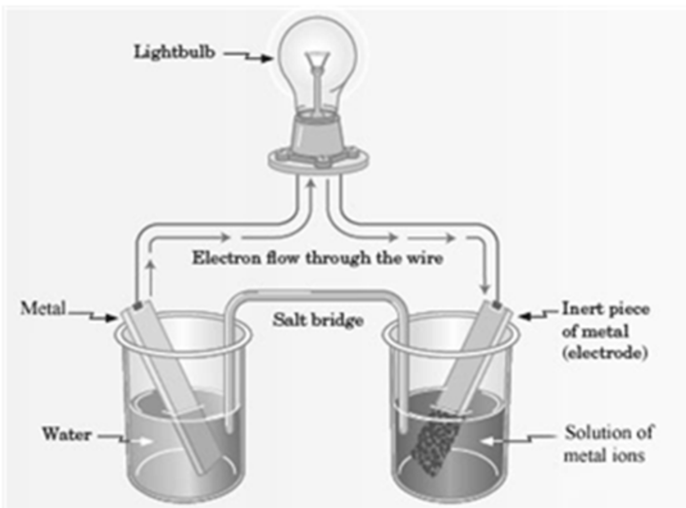
How many grams of CO(g) are required to produce 16.6 mol of acetic acid?

a. 16.6 g b. 33.2 g

c. 465 g   d. 996 g

29. Which of the following is true?
   a. An endothermic reaction is one which gives off heat.
   b. If a chemical reaction is exothermic, the reverse reaction is endothermic.
   c. Both a and b are true.
   d. Both a and b are false.

Consider the following representation of a voltaic cell.



This voltaic cell is represented by the following reaction:
$Mg(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Mg^{2+}(aq)$

30. Which of the following is true about the Mg(s) shown in the voltaic cell?
   a. It is the anode.
   b. It is the place where reduction occurs.
   c. It functions as the oxidizing agent.
   d. All of these are correct.

31. The synthesis of a certain drug requires 3 steps. The percent yield for the steps are 95.2%, 91.4% and 93.8% respectively. What is the overall percent yield?
   a. 81.6%   b. 87.0%
   c. 89.3%   d. 91.4%

32. The balanced equation for burning octane is: $2\ C_8H_{18}(g) + 25\ O_2(g) \rightarrow 18\ H_2O(g) + 16\ CO_2(g)$ What weight of H_2O is produced by completely burning 19.8 g of octane?
   a. 28.1 g   b. 34.7
   c. 69.5   d. 139 g

33. When a solution of Cu(II) chloride, $CuCl_2$, is added to a solution of potassium sulfide, K_2S, a black precipitate of copper sulfide, CuS, forms. Which of the following is the molecular equation for this reaction?

a. $CuCl_2(aq) + K_2S(aq) \rightarrow CuS(s) + 2\ KCl(aq)$

b. $Cu^{2+}(aq) + Cl_2^{2-}(aq) + K_2^{2+}(aq) + S^{2-}(aq) \rightarrow CuS(s) + K_2^{2+}(aq) + Cl_2^{2-}(aq)$

c. $Cu^{2+}(aq) + 2\ Cl^{-}(aq) + 2\ K^{+}(aq) + S^{2-}(aq) \rightarrow CuS(s) + 2\ K^{+}(aq) + 2\ Cl^{-}\ (aq)$

d. $Cu^{2+}(aq) + S^{2-}(aq) \rightarrow CuS(s)$

34. The atomic weight of copper is greater than that of chromium. If you have a 10 g sample of each of these metals, which of the following is true?

a. You have fewer of atoms of copper than of chromium.

b. You have equal numbers of atoms of copper and chromium.

c. You have more atoms of copper than of chromium.

d. There is insufficient information to determine which of the above is true.

35. If you need a sample of 2.84 mol of Na_2S, how many grams do you need?

a. 0.00451 g b. 2.84 g

c. 78.1 g d. 222 g

36. When a solution of ammonium chloride, NH_4Cl, is added to a solution of lead(II) nitrate, $Pb(NO_3)_2$, a white precipitate of lead chloride, $PbCl_2$, forms. Which of the following is the net ionic equation for this reaction?

a. $2\ NH_4Cl(aq) + Pb(NO_3)_2(aq) \rightarrow PbCl_2(s) + 2\ NH_4NO_3(aq)$

b. $2\ NH_4^{+}(aq) + 2\ Cl^{-}(aq) + Pb^{2+}(aq) + 2\ NO_3^{-}(aq)$
$\rightarrow PbCl_2(s) + 2\ NH_4^{+}(aq) + 2\ NO_3^{-}(aq)$

c. $Pb^{2+}(aq) + 2\ Cl^{-}(aq) \rightarrow PbCl_2(s)$

d. $Pb^{2+}(aq) + Cl_2^{2-}(aq) \rightarrow PbCl_2(s)$

37. Which of the following definitions of oxidation is generally most useful when dealing with ionic materials?

a. gain of oxygen b. loss of electrons

c. loss of hydrogen d. None, these are all equally useful.

38. Ethanol is produced industrially by the acid catalyzed reaction of ethylene with water. The balanced equation for this reaction is:

$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(l)$

If water is present in excess, how many moles of ethanol can be produced from 7.24 mol of ethylene?

a. 7.24 b. 14.5

c. 28.0 d. 46.0

39. Which of the following is the correct set of integer coefficients for the balanced equation, respectively:

___ $CO_2(g)$ + ___$H_2O(l)$ → ___$C_6H_{12}O_6(aq)$ + ___O_2*(g)*

a. 1, 1, 1, 1 b. 3, 3, 6, 6

c. 6, 3, 3, 6 d. 6, 6, 1, 6

40. For the reaction $N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3$*(g)* which of the following can be determined using **only** the coefficients of the balanced chemical equation?

a. the number of molecules of NH_3 obtained if 4.2 mol of N_2 react completely to form NH_3

b. the number of moles of NH_3 obtained if 4.2 mol of N_2 react completely to form NH_3

c. both a and b

d. neither a nor b

41. Of the following anions, which almost always forms soluble compounds?

a. I^- b. PO_4^{2-}

c. S^{2-} d. all of these

42. How many molecules are present in one mole of water, H_2O?

a. 1.66×10^{-24} b. 3.00×10^{-23}

c. 3.24×10^{23} d. 6.02×10^{23}

43. What is the formula weight of barium phosphate, $Ba_3(PO_4)_2$?

a. 232.3 amu b. 537.9 amu

c. 559.6 amu d. 601.9 amu

44. A bicycle manufacturer has a stock of 50 frames 70 wheels, and 120 reflectors. If each bicycle manufactured requires 4 reflectors, how many bicycles can the manufacturer make?

a. 25 b. 30

c. 35 d. 50

45. Solutions of sugars such as glucose react with $Ag^+(aq)$ to produce Ag(s). Which of the following happens to glucose in this reaction?

a. It is reduced. b. It is oxidized.

c. It is both oxidized and reduced. d. It is neither oxidized nor reduced.

46. The molar mass of gold is approximately 197 g. What is the approximate mass of one atom of gold?

a. 3.06×10^{21} g b. 197 g

c. 5.08×10^{-3} g d. 3.27×10^{-22} g

Examine the reaction taking place in the beaker in the image.

47. Which of the following might be the product forming in the beaker?
  a. $KNO_3(s)$
  b. $AgCl(s)$
  c. $Zn(s)$
  d. $Pb^{2+}(aq)$
  e. none of the above

48. Ethanol is produced industrially by the acid catalyzed reaction of ethylene with water. The balanced equation for this reaction is:
$C_2H_4(g) + H_2O(g) \rightarrow C_2H_5OH(l)$
If water is present in excess, how many grams of ethanol can be produced from 42.7 g of ethylene?
  a. 42.7 g b. 46.1 g
  c. 70.1 g d. 92.2 g

49. In a blast furnace, coke, which is solid carbon, reacts with $O_2(g)$ to form carbon monoxide. The carbon monoxide then reacts with $Fe_2O_3(s)$ to produce solid iron and carbon dioxide. Which of the following is the balanced equation for this combined process?
  a. $2\ Fe_2O_3(s) + 3\ C(s) + 3\ O_2(g) \rightarrow 2\ Fe(s) + 3\ CO_2(g)$
  b. $2\ Fe_2O_3(s) + 2\ C(s) + 3\ O_2(g) \rightarrow 4\ Fe(s) + 2\ CO_2(g)$
  c. $2\ Fe_2O_3(s) + 6\ C(s) + 3\ O_2(g) \rightarrow 4\ Fe(s) + 6\ CO_2(g)$
  d. $2\ Fe_2O_3(s) + C(s) + 3\ O_2(g) \rightarrow Fe(s) + CO_2(g)$

50. The term formula weight can be used with respect to which of the following?
  a. ionic compounds b. covalent compounds
  c. both a and b d. neither a nor b.

Answer Key

1. c

2. d

3. a

4. a

5. a

6. a

7. c

8. d

9. c

10. d

11. a

12. a

13. a

14. c

15. a

16. c

17. c

18. c

19. c

20. d

21. b

22. c

23. a

24. d

25. a

26. b

27. a

28. c

29. b

30. a

31. a

32. a

33. a

34. a

35. d

36. c

37. b

38. a

39. d

40. b

41. a

42. d

43. d

44. b

45. b

46. d

47. b

48. c

49. c

50. c