Chemical Reactions - Distance Learning Unit 5 Packet

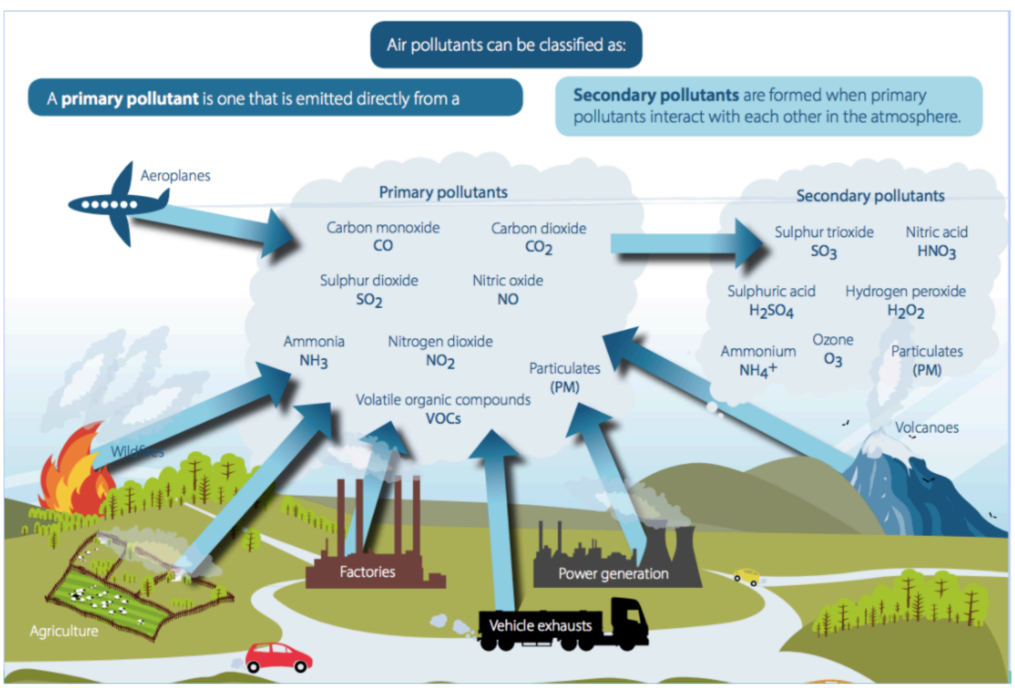
Standard Performance Expectation: Predict the products of simple chemical reactions, balance equations, construct explanations for observed reaction outcomes, and provide evidence for the conservation of mass.
Anchoring Phenomenon: There is a large variety of natural and manmade sources of pollution, these pollutants have far reaching impacts on our health, the quality of our air and water, as well as the stability of our climate. **Unit Essential Questions:** How are pollutants produced and what are their chemical consequences for our air, water, and climate?
Vocabulary: primary pollutants, secondary pollutants, particulate matter, synthesis, decomposition, single replacement, double replacement, combustion, reactants, products, conservation of mass, precipitate

Part 1: Pollution & Types of Reactions

Essential Questions: How are pollutants produced and how do they affect the environment?

This year we have been talking about climate change and both what causes it and the impacts from it. In this unit we'll take a closer look at the chemical reactions that impact climate change.
The chemical reactions that we'll study deal with environmental pollutants. There are primary pollutants and secondary pollutants.

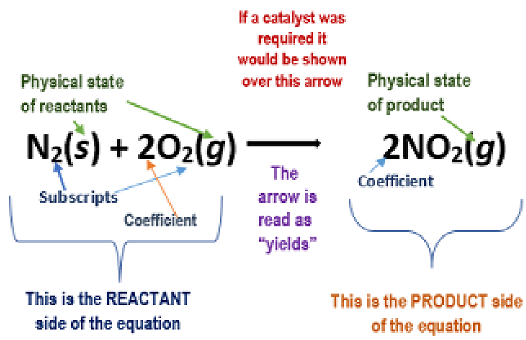
- A **primary pollutant** is emitted directly from a source.
- A **secondary pollutant** is produced from a primary pollutant that has chemically reacted in the atmosphere.



This picture shows that primary pollutants are emitted directly from vehicle exhaust, factories, power generating plants, agriculture, wildfires, and transportation sources like airplanes. The secondary pollutants are formed when these primary pollutants participate in chemical reactions in the atmosphere.

Next, we'll look at what these chemical reactions are and identify the types of reactions.

First, some reaction basics. Chemical reactions are composed of reactants, which appear on the left side of the arrow, and products which appear on the right side. A chemical reaction is when the reactants chemically recombine to form products. Chemical bonds are broken and new ones are formed to make new substances. In the picture below, the letters in parenthesis refer to the substance's physical state: solid, liquid, gas, or aqueous (aq, dissolved in water). Recall from an earlier unit that the subscripts refer to how many of that element there is in the molecule. We will explore more with coefficients later in this packet.



There are many types of chemical reactions, but we'll be focusing on five types.

Activity 1: Discovering Reaction Types

Sort the list of "equations" into five (5) different categories.

Rules:

- There must be at LEAST 3 equations in each group
- Equal sign location matters. 1 + 2 = 3 cannot be in the same group as 3 = 1 + 2

Report:

On a separate piece of paper, record your classification scheme. It should include the following:

- a general description of each category
- A list of the equations you've sorted
- After you've sorted the equations, check the answer key at the back of this packet

Label	Reaction	Label	Reaction
A	1 + 2 = 3	I	👗🙍 + 👠 = 👗👠 + 🙍
B	22 + 55 = 25 + 52	J	😀 + 💛 = 😍
C	6 = 4 + 2	K	⛄🎿 + 🏂🏔️ = ⛄🏔️ + 🏂🎿
D	A + B = C	L	TE + A = TA + EA
E	C = A + B	M	21 + 5 = 25 + 1
F	AB + CD = AD + BC	N	CH + O = CO + HO
G	AB + C = AC + B	O	10 + 1 = 11 + 01
H	🌲🔥+ 🌬️= 🌲🌬️ + 🔥🌬️	P	💕 = 💔+ 💗

On a separate piece of paper write down the 5 categories, describe them and write down example equations

Example table:

Category	Description (words)	Equations (list letters: A, C, etc)
1		
2		
3		
4		
5		

Next, try the activity again, but this time with actual unbalanced chemical equations. Sort your chemical equations into five (5) different categories.

Rules:

- There must be at LEAST 3 equations in each group
- Arrow location matters. 1 + 2 → 3 cannot be in the same group as 3 → 1 + 2

Report:

On a separate piece of paper record your classification. It should contain the following:

- a general description of each category
- A list of equations you've sorted
- After you've sorted the equations, check the answer key at the back of this packet

Hints

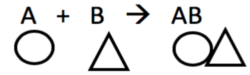
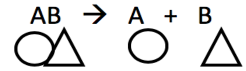
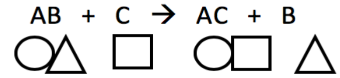
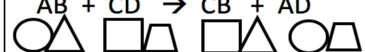
- An element has one capital letter (and sometimes a small letter)
- Compounds have multiple elements so multiple capital letters
- Try thinking about whether elements move around or pieces of compounds move.
- If it helps, use highlighters to highlight were specific elements are on the left and right of the arrow

Label	Reaction	Label	Reaction
A	$Ag_2S + Al \rightarrow Al_2S_3 + Ag$	I	$CH_4 + O_2 \rightarrow H_2O + CO_2$
B	$SO_2 + O_2 \rightarrow SO_3$	J	$Na_3PO_4 + Al_2(SO_4)_3 \rightarrow Na_2SO_4 + AlPO_4$
C	$C_3H_8 + O_2 \rightarrow H_2O + CO_2$	K	$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$
D	$H_2CO_3 \rightarrow CO_2 + H_2O$	L	$H_2SO_4 \rightarrow SO_3 + H_2O$
E	$CaCO_3 + H_2SO_4 \rightarrow H_2CO_3 + CaSO_4$	M	$BaCl_2 + MgSO_4 \rightarrow BaSO_4 + MgCl_2$
F	$ZnS + O_2 \rightarrow ZnO + SO_2$	N	$CO + O_2 \rightarrow CO_2$
G	$NO_2 + H_2O + O_2 \rightarrow HNO_3$	O	$C_8H_{18} + O_2 \rightarrow H_2O + CO_2$
H	$Cu + H_2SO_4 \rightarrow CuSO_4 + H_2$	P	$H_2O_2 \rightarrow H_2O + O_2$

Example table for classification scheme:

Category	Description (words)	Equations (list letters: A, C, etc)
1		
2		
3		
4		
5		

In this activity you determined five types of reactions. Our next task is to understand how to name and identify the type of reaction. What are the clues to look for? Using the table below as a note taking space, record the clues and the names of each type of reaction as you read through the next lesson.

Type	How to Identify	Example Equation	Generic Equation/Picture
			A + B → AB 
			AB → A + B 
			AB + C → AC + B  (or AB + C → CB + A)
			AB + CD → CB + AD 
			CxHy + O_2 → CO_2 + H_2O

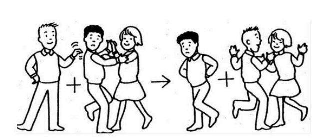
In a **Synthesis** reaction, reactants are combined together to make one product. An example of this reaction is when Magnesium metal is burned in the presence of Oxygen gas to produce magnesium oxide. (In this lesson all reactions shown will be unbalanced. We will learn about balancing reactions later in this packet)

$$Mg + O_2 \rightarrow MgO$$

A **decomposition** reaction is the opposite of a synthesis. When something decomposes, it breaks down. A decomposition reaction is identified by the presence of one reactant. When hydrogen peroxide decomposes when exposed to light, it breaks down into two gases, hydrogen and oxygen.

$$H_2O_2 \rightarrow H_2 + O_2$$

In a **single replacement** reaction, one of the reactants is a "single", or alone, and the other reactant is a compound. An analogy is if you went to a school dance alone because the person you really wanted to go with went with someone else. At the dance, you swoop in and take away your desired date. An example of this is when zinc metal reacts with copper nitrate.



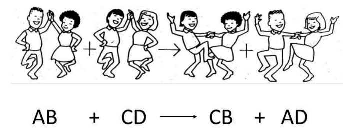
A + BC —— B + AC

Single Replacement Reaction

$$Zn\ (s) + Cu(NO_3)_2 \rightarrow Zn(NO_3)_2 + Cu\ (s)$$

In a **double replacement**, everyone gets a new partner at the dance! An example of this is when sodium hydroxide reacts with barium nitrate.

$NaOH + Ba(NO_3)_2 \rightarrow NaNO_3 + Ba(OH)_2$ (s)



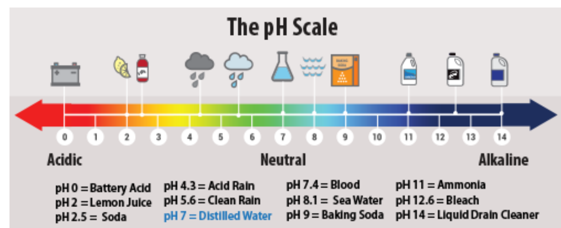
Double Replacement Reaction

Finally, in a **combustion** reaction, a compound that contains hydrogen and carbon is reacted with oxygen to produce water and carbon dioxide. The number of carbons and hydrogens can vary, but the products are always carbon dioxide and water. An example is when methane from the gas jets at our lab benches reacts with oxygen.

$CH_4 + O_2 \rightarrow CO_2 + H_2O$

Now, let's connect the types of reactions with the formation of pollution.

Chemical Reactions Related to Environmental Pollution



Acid rain: Acid precipitation is rain, snow, fog, or dew that has a pH less than 5.6. When something is more acidic, it contains more H^{+1} ions. On the pH scale, this would be below 7.The two main causes of acid rain are sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). Coal and oil contain sulfur and when burned in factories and powerpants, the sulfur combines with oxygen in the air and is emitted into the atmosphere. The gas then undergoes chemical reactions in the atmosphere that result in the formation of acids, which eventually fall as acid precipitation. Sulphur dioxide is converted to sulphuric acid by two chemical reactions.

$$\mathbf{2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)}$$
$$\mathbf{SO_3\ (g) + H_2O(l) \rightarrow H_2SO_4(aq)}$$

1. What type of chemical reactions are these? ______________________ How do you know?
2. Sulfuric acid can dissociate (break into) into 2 kinds of ions. What kind of reaction starts with one compound breaking into 2 or more pieces? ___________________ .
3. When we call something an acid, it usually means it will lose H^+ when it is in water. If we remove the H^+ from H_2SO_4, What is left over? ___________
4. Recall from the bonding unit, the charge on the ions in a compound must add up to zero. If I have 2 H^{+1} ions, what has to be the charge on the SO_4 ion? ___________
5. When H_2SO_4 breaks up, how many H^{+1} ions does it make?_______ How many SO_4^{-2} ions ____?
6. Use the information in questions 5, 6, and 7 to **Finish the reaction: $H_2SO_4 \Rightarrow$** _____________

Automobiles and electricity (which largely relies on combustion) are the leading sources of nitrogen dioxide in the atmosphere. A small amount of NO_2 is produced naturally by lightning. Nitrogen dioxide gas dissolves in water droplets in the atmosphere to form nitric acid (**HNO_3**).

$$\mathbf{N_2 + O_2 \rightarrow NO_2}$$
$$\mathbf{NO_2 + H_2O \rightarrow HNO_3}$$

7. What type of chemical reactions are these? __________________________ How do you know?

8. Nitric acid can dissociate into 2 ions. Since it is an acid, the first ion is H^{+1}, what is the other ion? __________
9. Use this information to **Finish the reaction: HNO_3 ⇒ ________________**
10. What type of chemical reaction is this? _________________________ How do you know?

Effects on Soils - Mobilize Aluminum: Increasing amounts of acids can "mobilize" aluminum ions which are normally present in an insoluble **non toxic form of aluminum hydroxide,** a mineral found in nature. It appears that when the soil pH dips to 5 or lower, **aluminum ions are dissolved into the water and become toxic to plants.** Aluminum ions cause a stunting of the root growth and prevent the roots from taking up calcium. The result may be the overall slowing of the growth of the entire tree. The sulfuric acid reacts with the aluminum hydroxide in a neutralization reaction. The aluminum sulfate is soluble in water and is thus released from the soil particles.

$$\mathbf{Al(OH)_3 + H_2SO_4 \text{-->} Al_2(SO_4)_3 + H_2O}$$

11. What type of chemical reaction is this? How do you know? _________________________
12. The positive ions (cations) are usually the first elements that are in each compound. For example, in H_2SO_4 we said the positive ion was just the first element H^{+1}. Identify the positive ions in each of the reactants: ______ ________
13. The negative ions (anions) are usually what is left over when we remove the positive ions. What is left over when we remove the cations? ________ and _________
14. In the equation above, we have written the positive ions in the same locations on the left and right of the equation. What happens to the negative ions?____________________
15. In the bonding unit we learned that the charge on an ion relates to the number of valence electrons. This number also relates to the column in the periodic table. What column are H and Al in? H is in column _____. Al is in column ______.
16. Once you know what goes together, you need to determine the correct ratio of positive and negative ions. What is the ratio of Al^{+3} to OH^{-1} ? (remember that the charges are in the upper right corner of the ion so Al^{+3} has a charge of +3 and the charges have to add up to zero)
17. What is the ratio of Al^{+3} to SO_4^{-2} ? _________________________

When acid precipitation falls on cities and towns, what is its effect? Acids have a corrosive effect on limestone or marble buildings or sculptures. It is well established that either wet or dry deposition of sulfur dioxide significantly increases the rate of corrosion on limestone, sandstone, and marble. The sulfuric acid then further reacts with the limestone ($CaCO_3$) in a reaction. This leaves a fine white powder known as gypsum ($CaSO_4$) on buildings and sculptures.

$$\mathbf{CaCO_3\,(s) + H_2SO_4\,(aq) \rightarrow CaSO_4\,(aq) + H_2CO_3\,(aq)}$$

18. What type of chemical reaction is this? _________________________ How do you know?

The gypsum or calcium sulfate ($CaSO_4$) breaks apart in water. The limestone dissolves and crumbles. $CaSO_4$, an ionic compound, breaks into two ions. Finish this reaction: What is the reaction for the calcium sulfate breaking apart?

19. **$CaSO_4$ (s)** → _________
20. What type of chemical reaction is this? _________________________ How do you know?

Neutralization of Acidic Lakes: Acid rain and the presence of limestone can be considered in another context. In some Canadian provinces, such as Alberta and Saskatchewan, most lakes are naturally protected from the effects of acid precipitation because limestone rock surrounds them. This type of rock reacts with excess acid and neutralizes it, which restores the pH of the lake water. However, this is not true of lakes in Ontario. The surroundings of Ontario lakes do not contain much of this rock, and a significant amount of acid precipitation enters the lakes in Ontario. This means that those lakes are at greater risk of acidification. Carbonic acid, H_2CO_3, will be broken down into the bicarbonate ion (HCO_3^-). Because surface waters are in equilibrium with atmospheric carbon dioxide there is a constant concentration of carbonic acid, H_2CO_3, in the water.

$$\mathbf{CO_2 + H_2O \rightarrow H_2CO_3}$$
$$\mathbf{H_2CO_3 \rightarrow HCO_3^- + H^+}$$

21. What type of chemical reactions are these? ___________ & ______________ How do you know?

The presence of limestone and other calcium carbonate rock in lakes and streams helps to maintain a constant pH because the minerals react with the excess acid. However, acid rain eventually can overcome the capacity of the lake to buffer (maintain constant pH) against this acidification. One way to raise the pH of heavily acidified lakes is by adding lime (CaO). However, this process is very expensive and, therefore, only practical in protecting lake ecosystems in the short term.

$$\mathbf{CaO + H_2O \rightarrow Ca(OH)_2}$$

22. In $\mathbf{Ca(OH)_2}$ what is the positive ion? ______ what is the negative ion? ________

What type of reaction occurs when nitric acid (acid rain) and this substance combine?

$$\mathbf{2\ HNO_3(aq) + Ca(OH)_2(s) \rightarrow Ca(NO_3)_2(aq) + 2\ H_2O\ (l)}$$

23. What type of chemical reaction is this? _________________________ How do you know?

Acid Rain Solutions: Internal combustion engines found in cars emit a number of harmful gases, including nitrogen oxides. The **catalytic converter**, which is located in the exhaust system of a vehicle converts nitrogen oxides in a chemical reaction that creates nitrogen gas and oxygen gas.

$$\mathbf{2\ N_2O_3(g) \rightarrow 2\ N_2(g) + 3\ O_2\ (g)}$$

24. What type of chemical reaction is this? _________________________ How do you know?

Hydrocarbons as Fuel Sources

$$2C_8H_{18}(g) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g) \quad (C_8H_{18} = \text{octane—gasoline component})$$
$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g) \quad (C_4H_{10} = \text{butane—lighter fuel})$$
$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g) \quad (CH_4 = \text{methane—natural gas})$$

25. What type of chemical reactions are these? ________________________ How do you know?

26. What reactant is common in all of the ________________ reactions above?

Part 2: Predicting products - How to know the outcome of a chemical reaction
Essential Question: Can we predict the outcomes of reactions using patterns of valence electron configurations and electronegativity?

Tips:
1. Using the type of reaction, determine which elements end up together
2. Using the valence electrons (charge on the ions) determine the right ratio of ions
3. Hints: Most charges on ions are related to its column. For transition metals finding the charge is a bit trickier. In this case, Cu forms Cu^{+2} and Zn forms Zn^{+2}
4. Combustion reactions always form the same products ($CO_2 + H_2O$)
5. Decomposition reactions try to make CO_2 or H_2O. If they can't the reactant falls apart into its elements.

	Reaction Type	Reactants	Products Which elements go together?	Products Compounds written with correct ratio of ions or elements
1.	**Example:** Synthesis	$Na + Cl_2 \rightarrow$	Na and Cl	Since Na is +1 and Cl is -1, there is a 1:1 ratio. The compound produced is NaCl.
2.	Double replacement	$CuCl_2 + H_2S \rightarrow$		
3.	Decomposition	$H_2O_2 \rightarrow$		
4.	Single replacement	$Ca + AgCl \rightarrow$		
5.	Combustion	$CH_4 + O_2 \rightarrow$		
6.	____________	$Mg(OH)_2 \rightarrow$ (hint: see Tip #5)		
7.	_____________	$Al + O_2 \rightarrow$		
8.	_____________	$Ca(OH)_2 + H_3PO_4 \rightarrow$		
9.	_____________	$ZnCl_2 + Mg \rightarrow$		
10	_____________	$C_6H_{14} + O_2 \rightarrow$		

Part 3: Balancing Equations - how matter is conserved.

Essential Question: How are atoms cycled in and between earth's systems, where does the matter go?

When you cook a meal, quite often there are leftovers because you prepared more than people would eat at one sitting. Sometimes when you repair a piece of equipment without instructions, you end up with what are called "pocket parts," small pieces you put in your pocket because you're not sure where they belong. You resolve both these problems with proper instructions. A recipe tells you how much food to expect so you can adjust to make the right amount. When you repair something with instructions, it tells you where every piece goes.

In chemistry, the instructions are like a balanced chemical equation. The balanced equation tells us how much of each reactant we need in order to make the reaction work. Because we cannot create or destroy matter (law of conservation of mass), this recipe states exactly how much we make as well. If we start out with ten carbon atoms, we need to end up with ten carbon atoms. The atoms are just in different places (according to John Dalton' atomic theory)

A balanced equation is a chemical equation in which mass is conserved.
This means that there are equal numbers of atoms of each element on both sides of the equation

We can write a chemical equation for the reaction of carbon with hydrogen gas to form methane (CH_4). In order to write a correct equation, you must first write the correct skeleton equation with the correct chemical formulas. Recall that hydrogen is a diatomic molecule and so is written as H_2.

$$C(s) \quad + \quad H_2(g) \quad \rightarrow \quad CH_4(g)$$

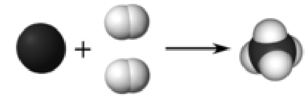
When we count the number of atoms of both elements, shown under the equation, we see that the equation is not balanced. 1 carbon, 2 H atoms → 1 carbon, 4 H atoms

$$C(s) \quad + \quad H_2(g) \quad \rightarrow \quad CH_4(g)$$

There are only 2 atoms of hydrogen on the reactant side of the equation, while there are 4 atoms of hydrogen on the product side. We can balance the above equation by adding a coefficient of 2 in front of the formula for hydrogen.

$$C(s) \quad + \quad 2\,H_2(g) \rightarrow \quad CH_4(g)$$

A **<u>coefficient</u>** is a small whole number placed in front of a formula in an equation in order to balance it. The 2 in front of the H_2 means that there are a total of 2×2=4 atoms of hydrogen as reactants. Visually, the reaction looks like the figure to the right.



In the balanced equation, there is one atom of carbon and four atoms of hydrogen on both sides of the arrow. Below are guidelines for writing and balancing chemical equations.

Sample Problem: Balancing Chemical Equations

Aqueous solutions of lead(II) nitrate and sodium chloride are mixed. The products of the reaction are an aqueous solution of sodium nitrate and a solid precipitate of lead(II) chloride.

$$Pb(NO_3)_2(aq) \quad + \quad NaCl(aq) \quad \rightarrow \quad NaNO_3(aq) \quad + \quad PbCl_2(s)$$

Count the number of each atom or polyatomic ion on both sides of the equation.

Reactants	Products
1 Pb atom 2 NO_3^{-1} ions 1 Na atom 1 Cl atom	1 Pb atom 1 NO_3^{-1} ion 1 Na atom 2 Cl atoms

The nitrate ions and the chlorine atoms are unbalanced. Start by placing a 2 in front of the NaCl. This increases the reactant counts to 2 Na atoms and 2 Cl atoms. Then place a 2 in front of the NaNO3. The result is:

$$Pb(NO_3)_2(aq) \; + \; 2\,NaCl(aq) \quad \rightarrow \quad 2\,NaNO_3(aq) \; + \; PbCl_2(s)$$

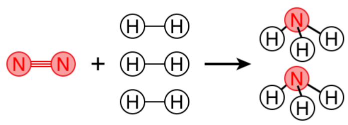
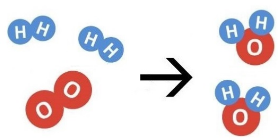
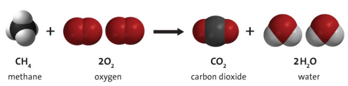
The new count for each atom and polyatomic ion becomes:

Reactants	Products
1 Pb atom 2 NO_3^{-1} ions **2 Na atoms** **2 Cl atoms**	1 Pb atom **2** NO_3^{-1} **ion** **2 Na atoms** 2 Cl atoms

- Determine the correct chemical formulas for each reactant and product.
- Write the skeleton equation.
- Count the number of atoms of each element that appears as a reactant and as a product. If a polyatomic ion is unchanged on both sides of the equation, count it as a unit.
- Balance each element on at a time by placing coefficients in front of the formulas.
- It is best to begin by balancing elements that only appear in one formula on each side of the equation.
- No coefficient is written for a 1.
- Never change the subscripts in a chemical formula – you can only balance equations by using coefficients.
- Check each atom or polyatomic ion to be sure that they are equal on both sides of the equation.
- Make sure that all coefficients are in the lowest possible ratio. If necessary, reduce to the lowest ratio.

Let's Practice!

1. For each **balanced** reaction, indicate the **total** number of molecules in the table below.

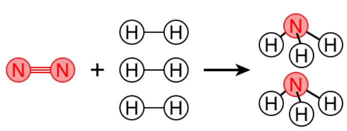
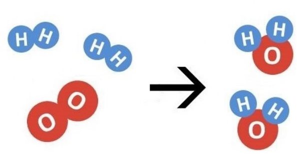
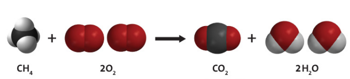
Reaction	Total Number of MOLECULES	
	Reactant Side (Left)	Product Side (Right)
Production of Ammonia (used in household cleaners) $N_2 + 3H_2 \rightarrow 2\ NH_3$ 		
Making water $2H_2 + O_2 \rightarrow 2H_2O$ 		
Combust Methane $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$ 		

2. Is the number of total molecules on the left side of a balanced equation always equal to the number of total molecules on the right side of the equation? Explain your answer.

____

____

3. For each balanced reaction, indicate the total number of **atoms** in the table below.

Reaction	Number of ATOMS	
	Reactant Side (Left)	Product Side (Right)
Production of Ammonia 	N =	N =
	H =	H =
Making water $2H_2 + O_2 \rightarrow 2H_2O$ 	H =	H =
	O =	O =
Combustion of Methane 	C =	C =
	H =	H =
	O =	O =

4. Is the number of total atoms on the left side of a balanced equation always equal to the number of total atoms on the right side of the equation? Explain your answer.

____

____

5. Both equation I and II below are balanced, but equation II is the correct way to write the balanced equation. What do you have to do to the coefficients of equation I below to get to equation II?
   i. $2\ SnO_2 + 4\ H_2 \rightarrow 2\ Sn + 4\ H_2O$
   ii. $SnO_2 + 2\ H_2 \rightarrow Sn + 2\ H_2O$

____

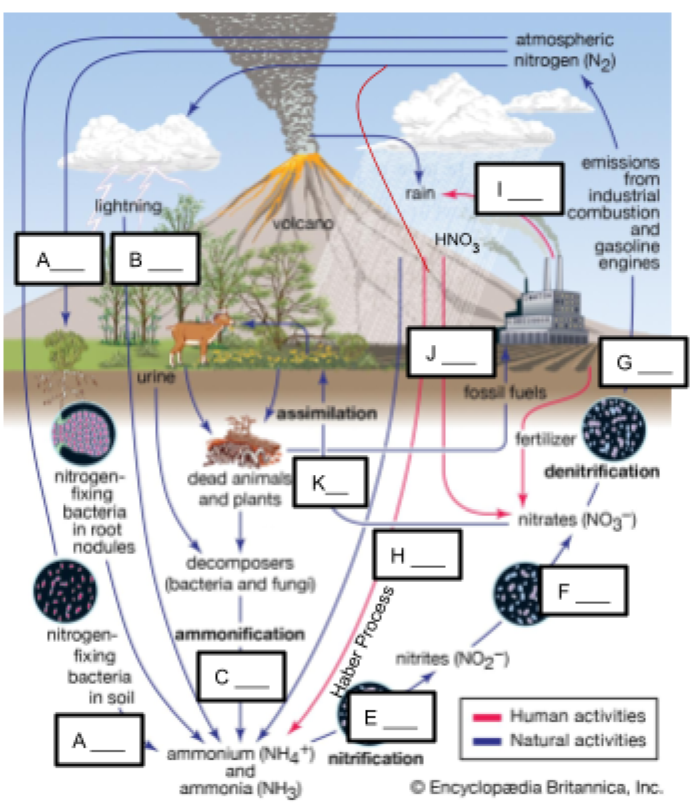
____

6. Balance the following reactions on your own:

- **____H_2 + ___O_2 → ___H_2O**
- **___C + ___S_8 → ___CS_2**
- **___Li +___ $AlCl_3$ → ___LiCl +___ Al**
- **___C_2H_6 + ___O_2 → ___CO_2 + ___H_2**
- **___Na + ___O_2 → ____Na_2O_2**
- **___N_2 + ____O_2 → ___N_2__O_5**
- **___H_2 +___ O_2 → ___H_2O_2**

Balanced or Imbalanced?- the Nitrogen Cycle

The nitrogen cycle has evolved over billions of years, in balance between living systems, the atmosphere, and the geosphere. As industrial farming has grown over the last century, the balance of the nitrogen cycle has been shifted, with vast consequences for aquatic ecosystems. Nitrogen is fixed when it is changed into a form that **organisms** can use. Dead zones come about when excess nitrogen in the water causes algae to grow out of control. Decomposers use oxygen to decompose the algae when they die. The lack of oxygen makes it impossible for other **organisms** to live in that zone, thus it is called a dead zone. Where did all this nitrogen come from, and where does it go?



78% of Earth's atmosphere is nitrogen gas (N_2), but in this form nitrogen is unreactive, with only a few natural processes that convert it into different forms. Humans rely on large amounts of nitrogen containing compounds, such as ammonium and nitrates to grow food. Below is an image of the nitrogen cycle on earth, with blue arrows showing natural reactions and the red arrows showing human driven processes. Nitrogen atoms can take many forms throughout this cycle. Use the model below and the information in the questions to track nitrogen atoms through this cycle by **balancing the reactions**.

Step 1 - Balance the Nitrogen Cycle Chemical Equations

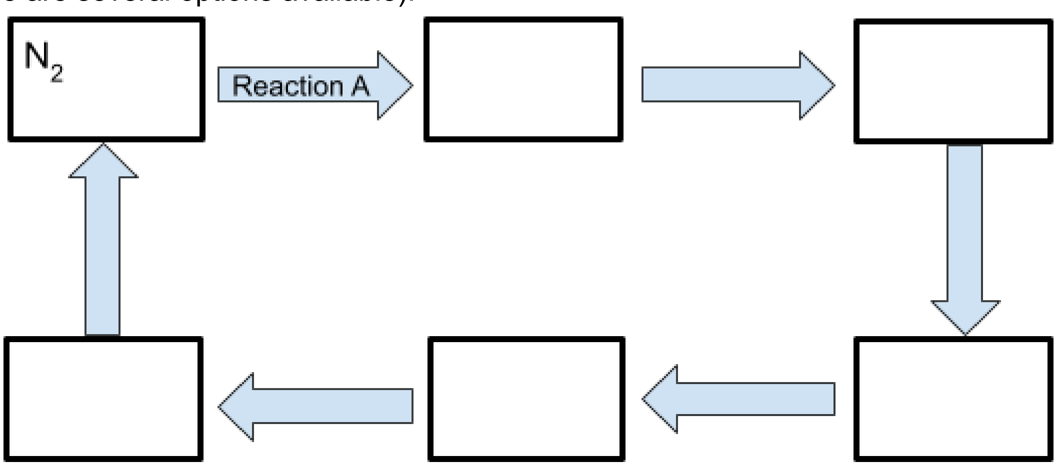
Instructions: Balance the following equations and read about how that equation plays a role in the nitrogen cycle above.

1	**Nitrogen Fixation** Plants require nitrogen to make their DNA and protein, but cannot use the nitrogen gas (N_2) in the atmosphere. Plants rely on bacteria in the soil and bacteria in root nodules to "fix" that nitrogen.	**___N_2 + ___H^+ → ___NH_4^+** ***The H+ is in the soil from other chemical reactions.** (this reaction is present in two boxes on the model above)
2	**Animals Excreting Nitrogen** Animals obtain nitrogen by eating plant material or other animals. They dispose of excess nitrogen from their body when they break down proteins. Nitrogen is excreted in the urine as urea $(NH_2)_2CO$. Bacteria break down urea into ammonia using the enzyme urease.	**___$(NH_2)_2CO$ + ___H_2O → ___CO_2 + ___NH_3**
3	**Lightning Strikes** During lightning strikes, enough energy is supplied to break the bonds of the nitrogen molecule and form nitrous oxide according to the equation.	**___N_2 +___ O_2 → ___NO**
4	**Dissolving Nitrogen Molecules** Nitrogen dioxide readily dissolves in water to produce nitric and nitrous acids which provides a source of nitrates available to plants so they can assimilate the nitrogen and use it to produce DNA and protein.	**___NO_2 + ___H_2O → ___HNO_3 + ___HNO_2**
5	**Haber Process** The Haber process, also called the Haber–Bosch process, is an artificial nitrogen fixation process and is the main industrial procedure for the production of ammonia today. This is when nitrogen from the air combines with hydrogen derived mainly from natural gas (methane) into ammonia.	**___N_2 + ___H_2 → ___NH_3**
6	**Production of Acid Rain** Nitrogen dioxide is released when we burn fossil fuels. When this nitrogen dioxide reacts with water in the air, it makes nitric acid and nitrous acid, or acid rain.	**___NO_2 + ___H_2O → ___HNO_2 + ___HNO_3**
7	**Denitrification** Denitrification is the loss or removal of nitrogen or nitrogen compounds in the soil, specifically by the reduction of nitrates or nitrites by bacteria in the soil. This nitrogen gas usually escapes back into the air.	**___NO_3^- + ___H^+ → ___ N_2 +___ H_2O** ***This represents a multistep reaction**

8	**Nitrification by Bacteria: Part 1** Nitrification is the biological oxidation (loss of electrons) of ammonia to nitrite followed by the oxidation of the nitrite to nitrate. A bacteria called Nitrosomonas specifically converts ammonium (NH_4^+) to nitrite (NO_2^-).	**___NH_4^+ + ___O_2 → ___NO_2^- + ___H^+ + ___H_2O**
9	**Nitrification by Bacteria: Part 2** Nitrification is the biological oxidation of ammonia to nitrite followed by the oxidation of the nitrite to nitrate. A bacteria called Nitrobacter specifically converts nitrite (NO_2^-) to nitrate (NO_3^-)	**___NO_2^- + ___O_2 → ___NO_3^-**
10	**Acid Rain in the Environment** Acid rain reacts with organic substances on earth to produce nitrates.	**___HNO_3 → ___H^++ ___NO_3^-**

Step 2 - Matching Equations to the Model
Now that you have balanced the equations involved in the nitrogen cycle in the table above, figure out which steps (labelled A-J) in the model (on the first nitrogen cycle page) correspond to which numbered equations (1-10). **Label the graphic with the numbers from the equations**.

Step 3 - Creating a Path Through the Nitrogen Cycle
Trace the path of nitrogen through the nitrogen cycle. Show how nitrogen begins as N_2 and through a series of reactions, ends as N_2. In each box below, write the nitrogen compound's chemical formula for that step (try for at least 3-4 reactions). Create one complete pathway that starts and ends with N_2 below (there are several options available).



Step 4 CER - For millennia, the natural cycle of nitrogen between Earth's atmosphere and soil has evolved a balance. Beginning in the early 1900s, humans started introducing additional ways to remove nitrogen from the atmosphere by "fixing" it into forms they could use to fertilize plants. Using the principle of "conservation of mass" and balanced systems, write a claim-evidence-reasoning paragraph that explains why these human-driven processes are both critical for the world's populations and problematic for ecosystems:

Possible sentence frames:

Claim	Evidence	Reasoning
• It can be inferred from ___ that … • The relationship between ___ and ___ is ___.	• ___ shows that ___. • As shown on the graph/data table ...	• In ___, it can be seen that ___, whereas in ___, ___. • This evidence makes sense because ___.

Part 4: Water Engineering

Introduction

The water isn't always clean. Many times in the process of producing things we want (toys, hairbrushes, cellphones, ect.) water becomes contaminated with ions.

If you were in school when there was the lead scare, you might remember that some water taps in certain schools or cities were turned off because there was lead in the water. The lead in the water was created when a small amount of metal dissolved from pipes to create lead ions in the water. When water becomes contaminated with ions like this, it cannot be purified with a filter. A chemical reaction must occur to remove the metal from the water and make it safe to drink.

Using Patterns in reactions

In reactions, what reacts is often determined by electronegativity.

1. Define electronegativity

For example, when we heat magnesium in the air, it could react with N_2 , O_2 , or CO_2, all components of air. Magnesium (Mg) is a metal and has an electronegativity of 1.2. Because it is a metal, it will lose its electrons to the element with the highest electronegativity.

2. According to the table to the right, which element has the highest electronegativity, N, C, or O?

Electronegativity values of the elements (Pauling scale)

H 2.1																	He
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne
Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 3.0
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6
Cs 0.7	Ba 0.9	La 1.1	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	Rn 2.4

Oxygen exists in 2 places: by itself in O_2 and in a covalent compound with CO_2 . In unit 7, you will see that the bonds in O_2 are weaker and easier to break than the bonds in CO_2 This causes magnesium to react with O_2 instead of CO_2.

Consider the reaction $3Ag_2S + 2Al \Rightarrow Al_2S_3 + 6Ag$.

3. According to the table on the previous sheet, what is the electronegativity of silver, Ag? ______
4. What is the electronegativity of Al? ______
5. What happens in the reaction? ____

Consider the reaction $Zn + Cu(NO_3)_2 \Rightarrow Cu + Zn(NO_3)_2$

6. What is the electronegativity of Cu ______
7. What is the electronegativity of Zn? ______
8. What happens in the reaction? ____
9. Try to put into words how electronegativity relates to how things react.
   ____
   ____
   ____
10. In single replacement reactions, which element usually ends up with more electrons, the one with higher or lower electronegativity? ________________________________

What kind of compound will it make?

Based on the reaction types listed above, when I combine two elements, they join.

$$2Mg + O_2 \Rightarrow 2MgO$$

Why does it make MgO instead of MgO_2? The ratio of elements in the final compound is determined by the number of valence electrons (electrons on the outside). In the case of the magnesium (Mg) and oxygen (O) above, we find that Mg is in column 2, that means it has 2 valence electrons. Because there is a big electronegativity difference between the two atoms, Mg and O will make an ionic bond. When Mg turns into an ion, it will lose both electrons and turn into a +2 ion, Mg^{+2}.

Oxygen is a nonmetal. It is in column 6 meaning it has 6 valence electrons. Nonmetals share or take electrons to get to the 8 valence electrons that it needs. Since we are combining with a metal, it will take two electrons to make O^{-2} . Recall that the charge on a compound has to add to zero so it only takes one Mg^{+2} and one O^{-2} to add to zero (note: look at the charges in the upper right corner +2 and -2 add to zero)

Why does this matter?

Let's say a local toy company had an accident. It released contaminated water into a nearby retention pond. Because ions are small, there are several billions of them in the water. One way of measuring the number of ions is to refer to the number of moles. A mole is just a way of referring to a specific number of particles. For example, a dozen means 12 "things" and a mole means 6.02 x 10^{23} "things". The spill contained 0.5 moles of copper (II) nitrate, $Cu(NO_3)_2$, 0.25 moles of tin (II) nitrate, $Sn(NO_3)_4$, and 0.1 moles of iron (III) nitrate, $Fe(NO_3)_3$

11. At your disposal, you have solid pieces of magnesium (Mg), zinc (Zn), iron (Fe), and tin (Sn). You are using an element to react with an ionic compound. What kind of reaction is this?

    ____

12. Write down the reactions that could occur between these metals (Mg, Zn, Fe, Sn) and the compounds listed above. Recall: metals will only replace in the compounds if the single element has a lower electronegativity. (Some compounds have multiple potential reactions).

    ____
    ____
    ____
    ____
    ____
    ____

13. You are being asked to remove one metal at a time because then you can recycle the metals. Describe how you would reclaim the metals from the water using the metals for the least amount of money.

    ____
    ____
    ____

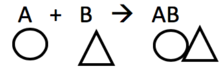
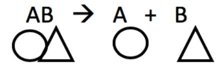
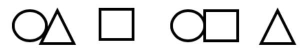
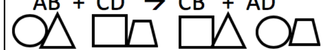
What's next?:
Balanced equations give us mole ratios, or the ratio of how much we have of one substance compared to the other. For example, the equation $Mg + 2\ HCl \Rightarrow MgCl_2 + H_2$ indicates that you need 2 moles of HCl for every mole of Mg.

Answer Key

Part 1: Pollution & Types of Reactions

Activity 1

Notes

Type	How to Identify	Example Equation	Generic Equation/Picture
Synthesis	Has only one product	$Mg + O_2 \rightarrow MgO$	$A + B \rightarrow AB$ 
Decomposition	Has only one reactant	$H_2O_2 \rightarrow H_2 + O_2$	$AB \rightarrow A + B$ 
Single Replacement	As reactants it has a single and a compound.	$Zn\ (s) + Cu(NO_3)_2 \rightarrow Zn(NO_3)_2 + Cu\ (s)$	$AB + C \rightarrow AC + B$  (or $AB + C \rightarrow CB + A$)
Double Replacement	All substances are compounds	$NaOH + Ba(NO_3)_2 \rightarrow NaNO_3 + Ba(OH)_2\ (s)$	$AB + CD \rightarrow CB + AD$ 
Combustion	A hydrogen and oxygen compound always react with oxygen gas and CO_2 and H_2O are always made.	$CH_4 + O_2 \rightarrow CO_2 + H_2O$	$CxHy + O_2 \rightarrow CO_2 + H_2O$

Activity 2

1. Synthesis 2. decomposition 3. SO_4^{-2} 4. (-2) 5. 2 H^{+1} & 1 SO_4^{-2}
6. $2H^{+1} + SO_4^{-2}$ 7. Synthesis 8. NO_3^{-1} 9. $H^{+} + NO_3^{-1}$ 10. decomposition
11.DR 12. Al^{+3} and H^{+1} 13. OH^{-1} and SO_4^{-2} 14. Negative ions swap places 15. 1, 3 16. We need 1 Al^{+3} and 3 OH^{-1}
17. 2 Al^{+3} to $3SO_4^{-2}$ makes $Al_2(SO_4)_3$ 18.DR; all compounds 19.$Ca^{+2} + SO_4^{-2}$
20.Decomp; only one reactant 21.Synthesis, Decomp 22.Ca^{+2}, OH^{-1}
23.DR 24.Decomp 25.Combustion; all have CO_2 & H_2O products
26. O_2

Part 2: Predicting products - how to know the outcome of a chemical reaction

	Reaction Type	Reactants	Products Which elements go together?	Products What is the correct ratio of ions or elements?
11	**Example:** Synthesis	$Na + Cl_2 \rightarrow$	Na and Cl	Since Na is +1 and Cl is -1, there is a 1:1 ratio. The compound produced is NaCl.
12	Double replacement	$CuCl_2 + H_2S \rightarrow$	CuS and HCl	CuS (+2/-2) and HCl (+1/-1)
13	Decomposition	$ZnCO_3 \rightarrow$	CO_2 and ZnO	CO_2 and ZnO

	Single replacement	$Ca + AgCl \rightarrow$	CaCl and Ag	$CaCl_2$ because (Ca^{+2} and Cl^{-1}) and Ag
14	Combustion	$CH_4 + O_2 \rightarrow$	CO_2 and HO	CO_2 and H_2O
15	Decomposition	$Mg(OH)_2 \rightarrow$ (see Tip #5)	MgO and H_2O	MgO and H_2O
16	Synthesis	$Al + O_2 \rightarrow$	AlO	Al_2O_3 (because $Al^{+3}$and O^{-2})
17	Double Replacement	$Ca(OH)_2 + H_3PO_4 \rightarrow$	$CaPO_4$ and HOH	$Ca_3(PO_4)_2$ and H_2O
18	Single Replacement	$ZnCl_2 + Mg \rightarrow$	MgCl and Zn	$MgCl_2$ (+2/-1) and solid Zn
19	Combustion	$C_6H_{14} + O_2 \rightarrow$	CO_2 and HO	CO_2 and H_2O

Part 3: Balancing Equations - how matter is conserved.

1. Total **molecules** on the Reactant side/Left vs Product side/Right: 4 vs 2, 3 vs 2, 3 vs 3
2. No, the number of molecules is different on each side of the equation.
3. Total number of **atoms** on the Reactant side/Left vs Product side/Right:
    a. N = 2, H = 6 vs N = 2, H = 6
    b. H = 4, O = 2 vs H = 4, O = 2
    c. C = 1, H = 4, O = 4 vs C = 1, H = 4, O = 4
4. Yes, the number of atoms is the same on both sides of the equation. This follows the law of conservation of mass.
5. Equation II is reduced down to show the ratio of molecules on each side. The ratio of 2:4 is the same as 1:2.

6.

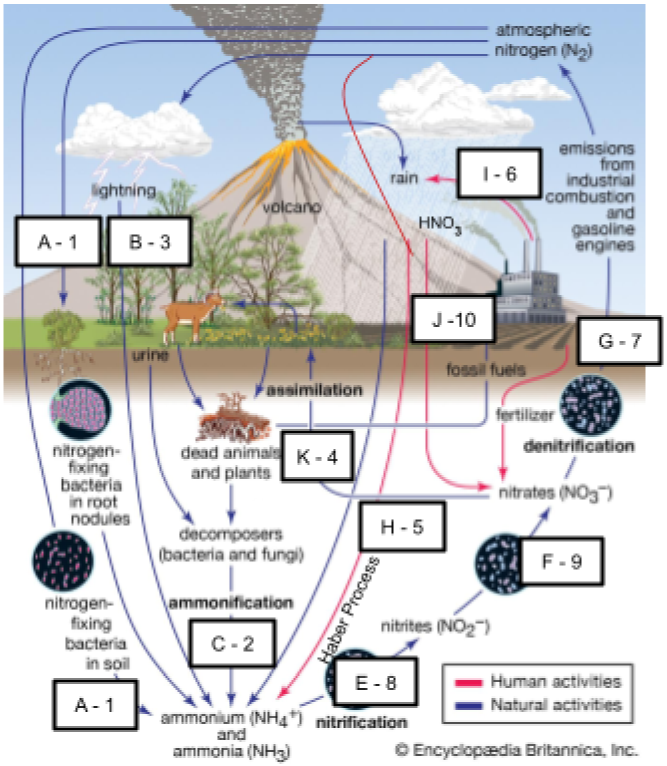
• $2 H_2 + O_2 \rightarrow 2 H_2O$ • $4 C + S_8 \rightarrow 4 CS_2$ • $3 Li + AlCl_3 \rightarrow 3 LiCl + Al$ • $2 C_2H_6 + 7 O_2 \rightarrow 4 CO_2 + 6 H_2O$	• $2 Na + O_2 \rightarrow Na_2O_2$ • $N_2 + 5 O_2 \rightarrow N_2 + 2 O_5$ • $H_2 + O_2 \rightarrow H_2O_2$

Nitrogen Cycle

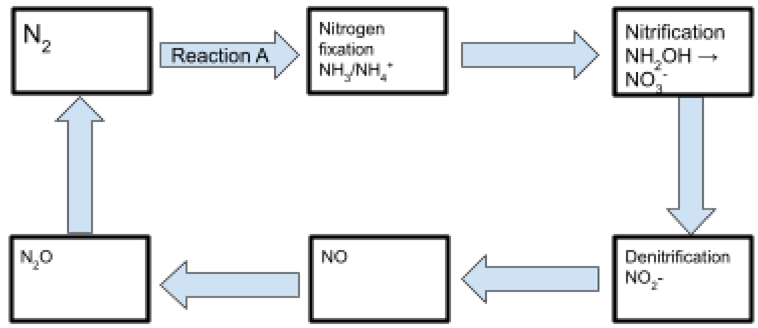
Step 1

1. **$N_2 + 8 H^+ \rightarrow 2 NH_4^+$**
2. **$(NH_2)_2CO + H_2O \rightarrow CO_2 + 2 NH_3$**
3. **$N_2 + O_2 \rightarrow 2 NO$**
4. **$2 NO_2 + H_2O \rightarrow HNO_3 + HNO_2$**
5. **$N_2 + 3 H_2 \rightarrow 2 NH_3$**
6. **$2 NO_2 + H_2O \rightarrow HNO_2 + 2 HNO_3$**
7. **$2 NO_3^- + 12 H^+ \rightarrow N_2 + 6 H_2O$**
8. **$NH_4^+ + 1.5 O_2 \rightarrow NO_2^- + 2 H^+ + H_2O$ or $2 NH_4^+ + 3 O_2 \rightarrow 2 NO_2^- + 4 H^+ + 2 H_2O$**
9. **$2 NO_2^- + O_2 \rightarrow 2 NO_3^-$**
10. **$HNO_3 \rightarrow H^+ + NO_3^-$**

Step 2



Step 3 - This is just one possible response for Step 3.



Step 4 CER - a possible response:

Humans have interrupted the nitrogen cycle to produce food to feed the growing population and this has greatly impacted ecosystems. The image above and the balanced reactions in the nitrogen cycle shows that nitrogen is present in many different forms (N_2, NH_3, N_2O, NO, etc). We never get rid of or destroy nitrogen, rather it is used to create different molecules. As humans use nitrogen fertilizers to help plants grow, this creates an over abundance of nitrogen that disrupts not only the surrounding soil, but a variety of ecosystems and can even end up in nearby streams or rivers. Additionally, the combustion of fossil fuels releases additional nitrogen into the atmosphere that contributes to the production of acid rain.

Part 4: Patterns in reactions

1. Electronegativity is the attraction felt by bonding electrons
2. Oxygen (O) has the highest electronegativity
3. Electronegativity of silver is 1.9
4. Electronegativity of aluminum is 1.5
5. Aluminum replaces silver
6. Electronegativity of copper is 1.9
7. Electronegativity of zinc is 1.6
8. Zinc replaces copper
9. Try to put into words how electronegativity relates to how things react.
10. Single replacement reactions
11. Mg would replace any metal. Zn replaces Sn or Cu, Sn replaces only Cu
12. $Mg + Cu(NO_3)_2 \Rightarrow Mg(NO_3)_2 + Cu$ $\quad$ $Mg + Zn(NO_3)_2 \Rightarrow Mg(NO_3)_2 + Zn$
    $Mg + Sn(NO_3)_4 \Rightarrow Mg(NO_3)_2 + Sn$ $\quad$ $Zn + Sn(NO_3)_4 \Rightarrow Zn(NO_3)_4 + Sn$
    $Zn + Cu(NO_3)_2 \Rightarrow Zn(NO_3)_2 + Cu$ $\quad$ $Sn + 2Cu(NO_3)_2 \Rightarrow Sn(NO_3)_4 + 2Cu$
13. Sn will only pull out Cu because Cu is the only one that has a higher electronegativity, whereas Mg will pull out all 3 metals, so adding Sn 1st to remove Cu, then add Zn 2nd to remove Sn, add Mg 3rd to remove Zn (the other remaining metal).