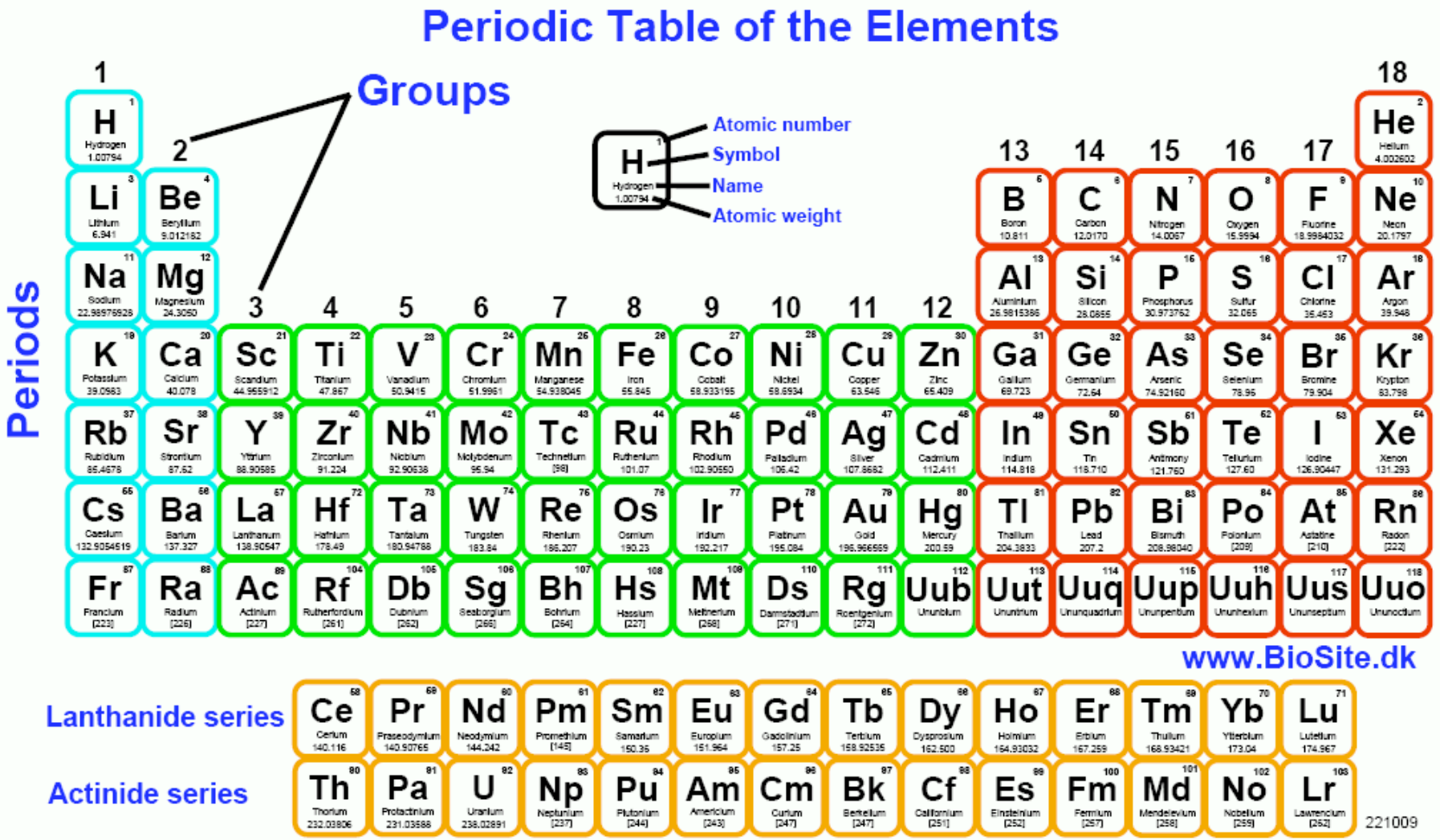
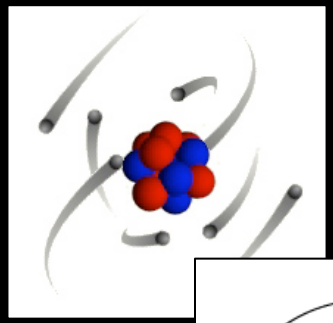
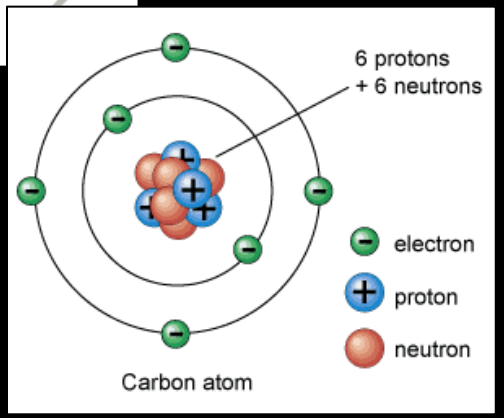
Fundamentals of Environmental Science

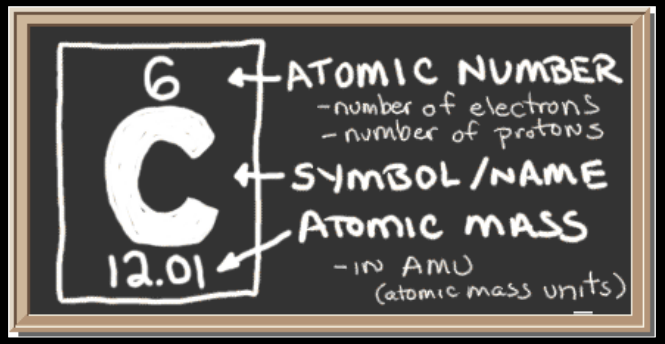


Atoms, Ions, and Molecules Are the Building Blocks of Matter

- **Matter**
  - Has mass and takes up space
- **Atomic theory**
  - All elements are made of atoms
- **Subatomic particles**
  - **Protons** with positive charge and **neutrons** with no charge in **nucleus**
  - Negatively charged **electrons** orbit the nucleus







- **Atomic number**
  = Number of protons in nucleus
- **Mass number**
  = Number of protons + neutrons in nucleus

Model of a Carbon-12 Atom

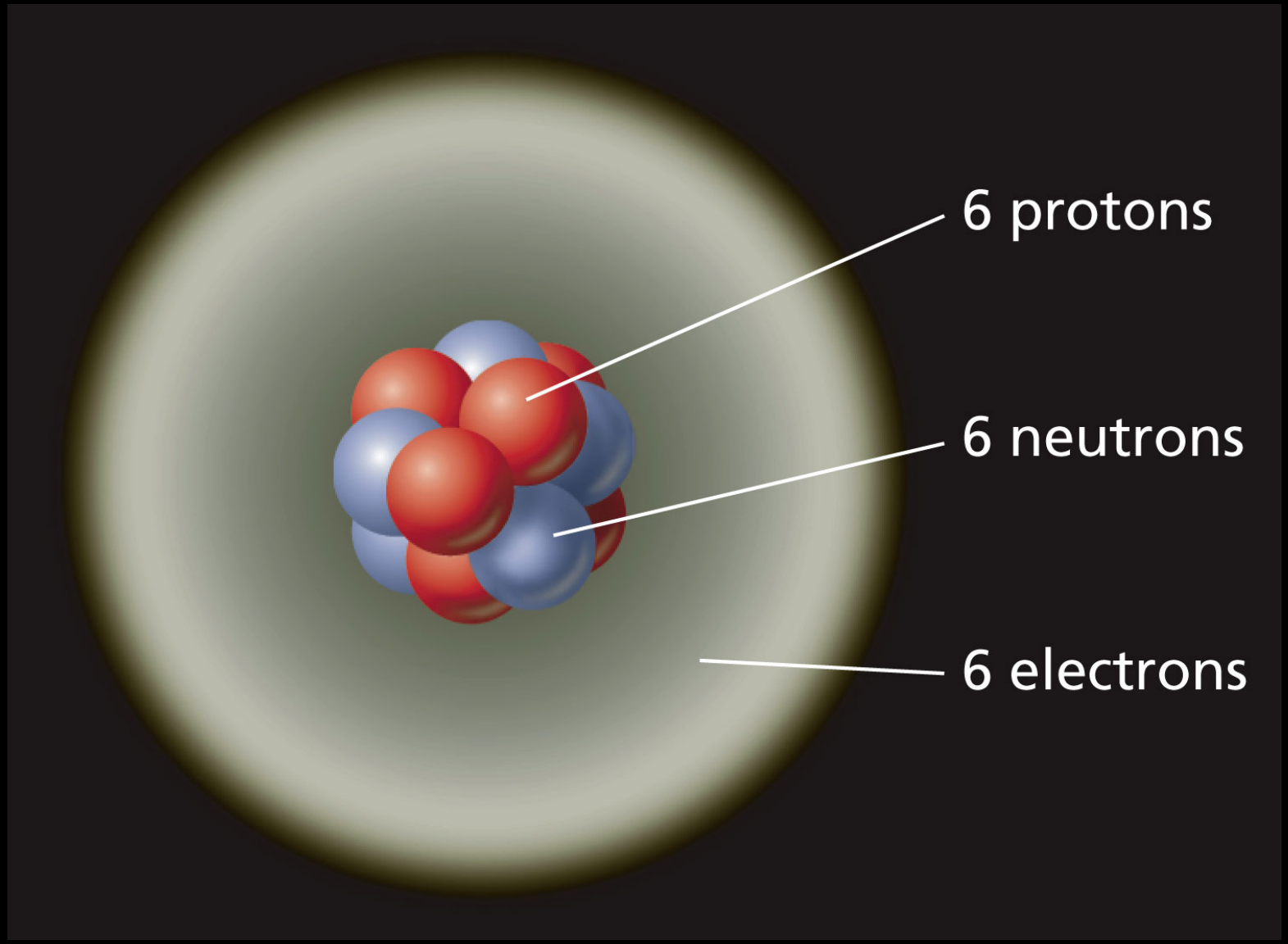


Fig. 2-5, p. 39

Fundamentals of Environmental Science

Matter Consists of Elements and Compounds

- **Elements**
  - Unique properties
  - Cannot be broken down chemically into other substances
  - Gold (Ag) and Mercury (Hg) Are Chemical Elements
- **Compounds**
  - Two or more different elements bonded together in fixed proportions
  - Sugar (sucrose) is a compound $C_{12}H_{22}O_{11}$

Common Chemical Elements & Compounds in Environmental Science

Table 2-1 Chemical Elements Used in This Book

Element	Symbol
Arsenic	As
Bromine	Br
Calcium	Ca
Carbon	C
Chlorine	Cl
Fluorine	F
Gold	Au
Lead	Pb
Lithium	Li
Mercury	Hg
Nitrogen	N
Phosphorus	P
Sodium	Na
Sulfur	S
Uranium	U

Table 2-3 Compounds Used in This Book

Compound	Formula
sodium chloride	$NaCl$
sodium hydroxide	$NaOH$
carbon monoxide	CO
oxygen	O_2
nitrogen	N_2
chlorine	Cl_2
carbon dioxide	CO_2
nitric oxide	NO
nitrogen dioxide	NO_2
nitrous oxide	N_2O
nitric acid	HNO_3
methane	CH_4
glucose	$C_6H_{12}O_6$
water	H_2O
hydrogen sulfide	H_2S
sulfur dioxide	SO_2
sulfuric acid	H_2SO_4
ammonia	NH_3
calcium carbonate	$CaCO_3$

Fundamentals of Environmental Science

- **Molecule**
  - A molecule is formed when two or more atoms join together chemically. Ex. → **oxygen** → **O_2**
- **Compounds**
  - A compound is a molecule that contains at least two different elements. Ex. → carbon dioxide → **CO_2**

  All compounds are molecules but not all molecules are compounds.
- **Chemical formula:** Ex. → **H_2O** (2 hydrogen + 1 oxygen atoms = water)

  Ex. → **$C_6H_{12}O_6$** (6 carbon + 12 hydrogen + 6 oxygen = glucose)
- **Chemical Reaction:** atoms separate from molecules they are a part of and recombine to form other molecules (shown in chemical equations).

Photosynthesis can be represented using a chemical equation.

$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{Sunlight energy}} C_6H_{12}O_6 + 6\ O_2$$

Ions

- Gain or lose electrons
- Form ionic compounds

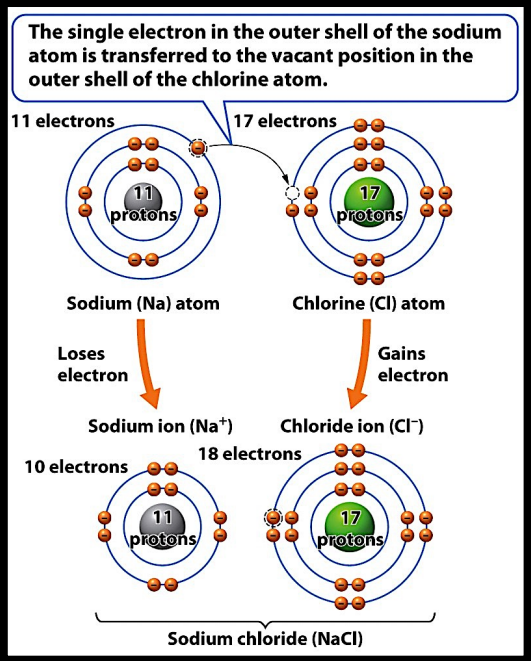
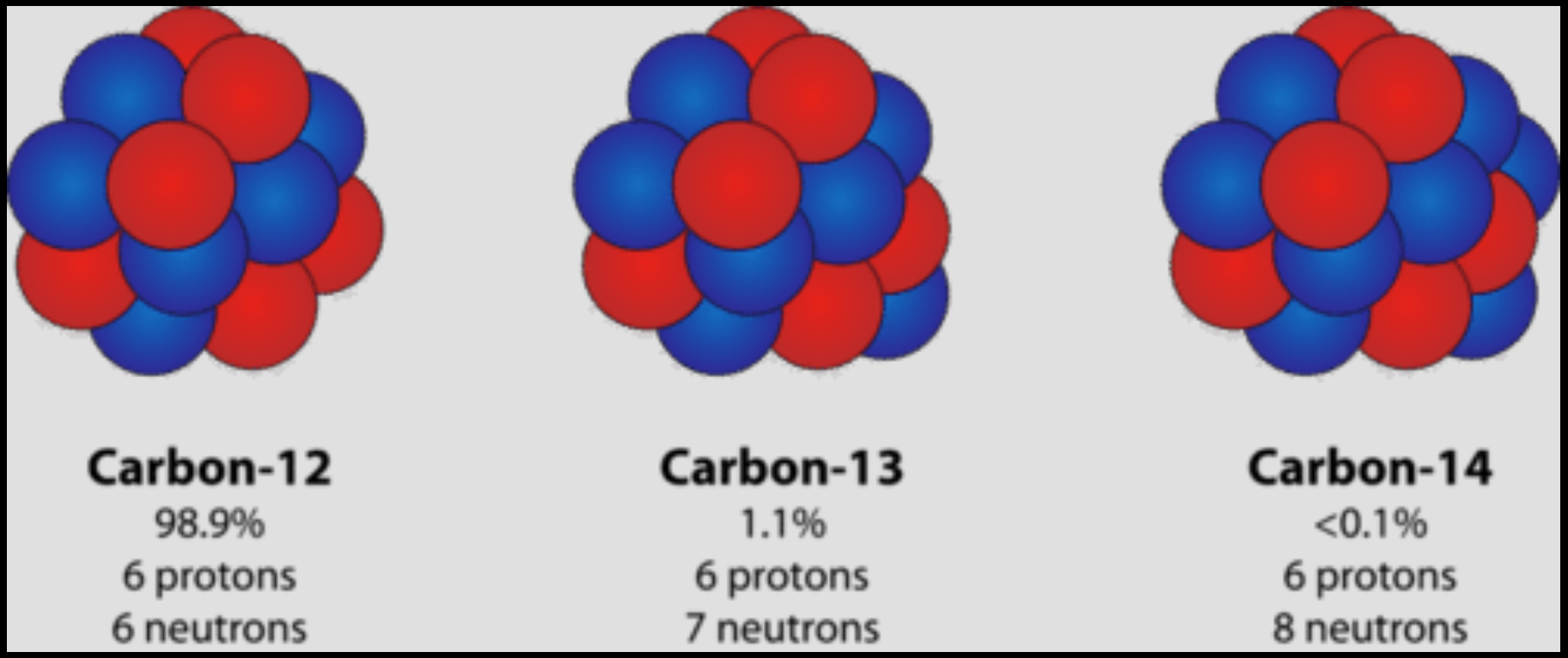


Table 2-2 Chemical Ions Used in This Book

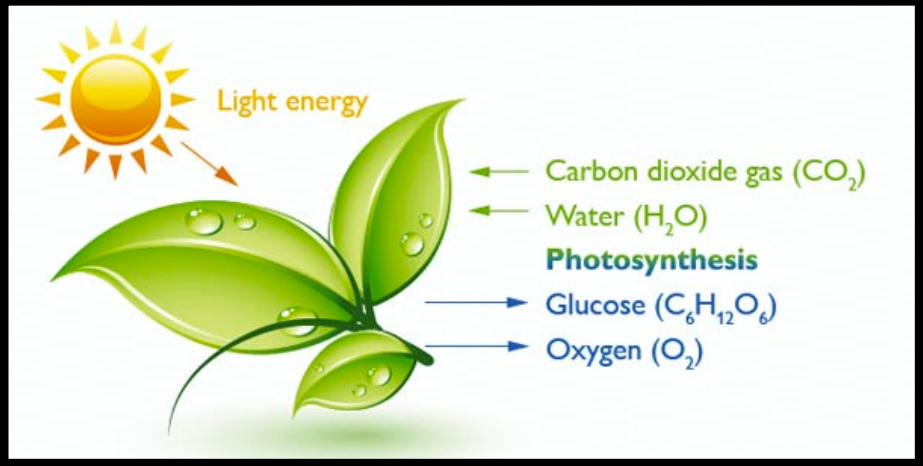
Positive Ion	Symbol	Components
hydrogen ion	H^+	One H atom, one positive charge
sodium ion	Na^+	One Na atom, one positive charge
calcium ion	Ca^{2+}	One Ca atom, two positive charges
aluminum ion	Al^{3+}	One Al atom, three positive charges
ammonium ion	NH_4^+	One N atom, four H atoms, one positive charge
Negative Ion	**Symbol**	**Components**
chloride ion	Cl^-	One chlorine atom, one negative charge
hydroxide ion	OH^-	One oxygen atom, one hydrogen atom, one negative charge
nitrate ion	NO_3^-	One nitrogen atom, three oxygen atoms, one negative charge
carbonate ion	CO_3^{2-}	One carbon atom, three oxygen atoms, two negative charges
sulfate ion	SO_4^{2-}	One sulfur atom, four oxygen atoms, two negative charges
phosphate ion	PO_4^{3-}	One phosphorus atom, four oxygen atoms, three negative charges



Isotope: forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei, and hence differ in relative atomic mass

Matter Undergoes Physical & Chemical Change

- **Physical Change**
  - No change in chemical composition; Ex. phase change, dissolving
- **Chemical change, chemical reaction**
  - Change in chemical composition; chemical reaction
  - Reactants and products; new substances formed



Law of Conservation of Matter

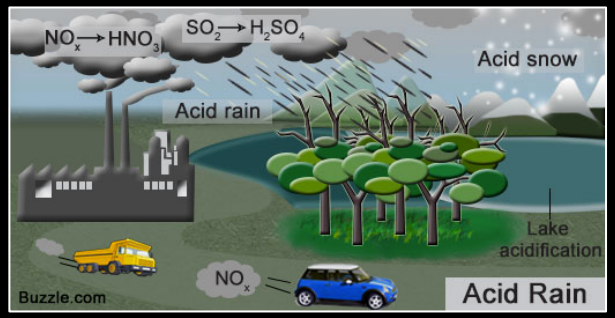
We Cannot Create or Destroy Matter!

- Whenever matter undergoes a physical or chemical change, no atoms are created or destroyed

Balancing Chemical Equations

Compounds and Formulas

Hydrogen (H), sulfur (S), and oxygen (O) combine to form the compound sulfuric acid, a pollutant when present in the environment.



Subscript means "written below". A subscript number written after a symbol tells how many atoms of that element are in the compound. Sulfuric acid is composed of two hydrogen atoms, one sulfur atom, and four oxygen atoms.

Chemical Symbol for hydrogen → H_2SO_4

Subscript- 2 atoms of hydrogen

Chemical Symbol for sulfur

Chemical Symbol for oxygen

Subscript- 3 atoms of oxygen

Balancing Chemical Equations

Chemical Reactions

A chemical reaction is a well-defined example of a chemical change.

In a chemical reaction one or more substances are changed to new substances.

The substances that are about to react are called reactants.

The new substances produced are called products.

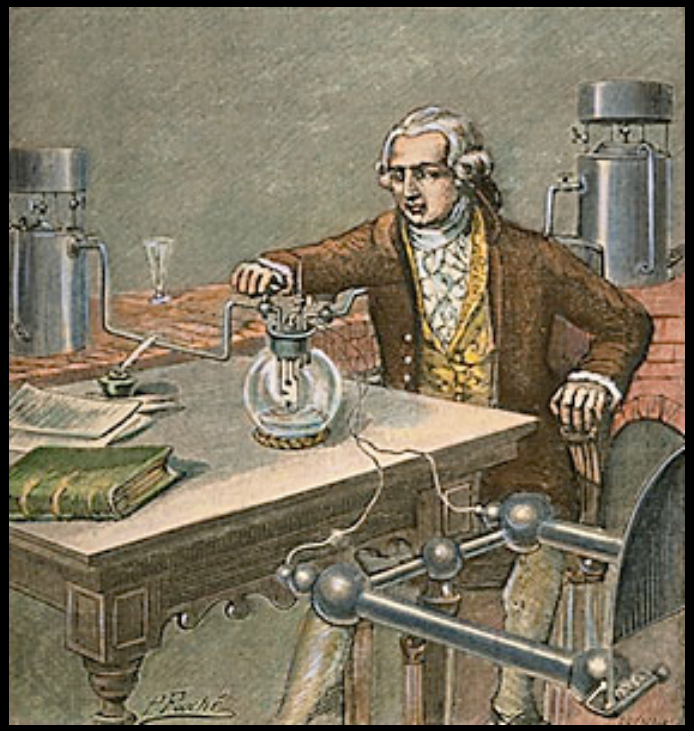
Yields, Produces, or Forms

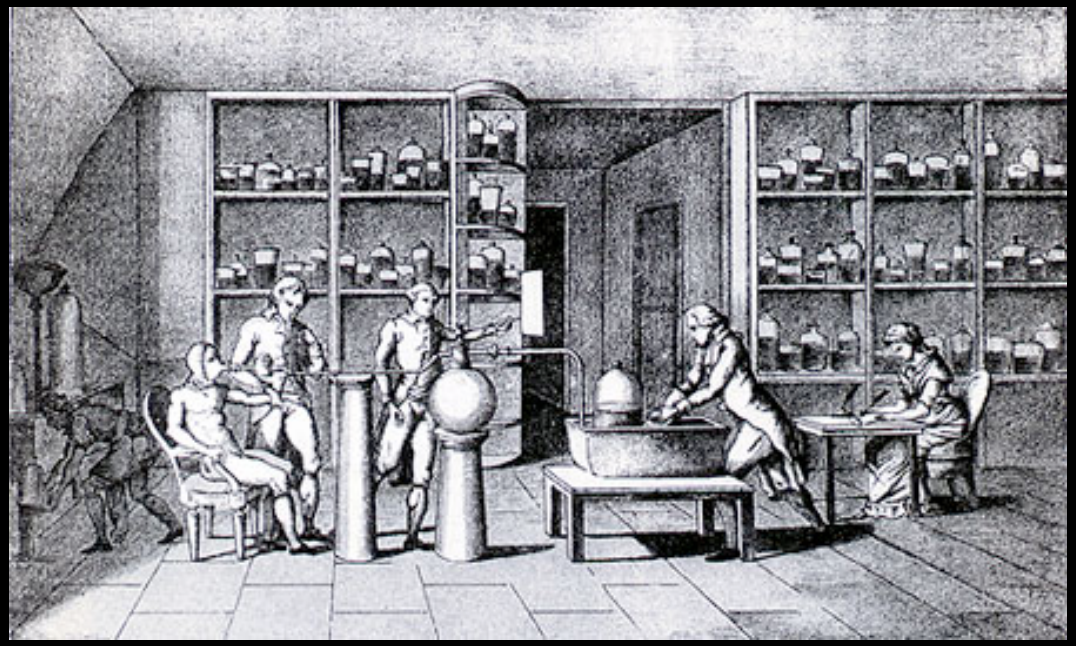
Reactants ⟶ Products

Conservation of Mass

In the early 1700's Antoine Lavoisier performed many experiments to determine the answer to this question:

What happens to the masses of the reactants and the products in chemical reactions?





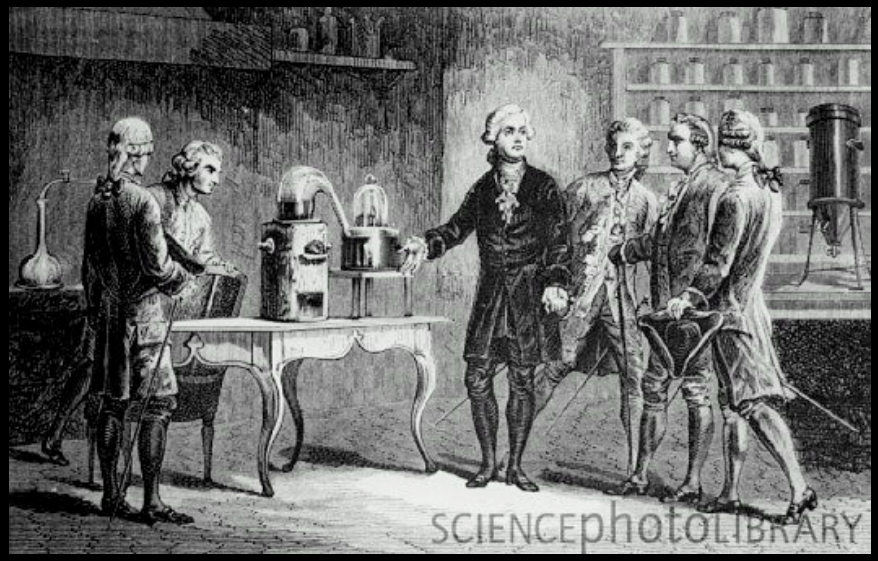
Conservation of Mass

In one experiment Lavoisier placed a carefully measured amount of mercury (II) oxide into a sealed flask. When he heated this flask, oxygen gas and liquid mercury were produced.

Lavoisier found that the mass of the oxygen and the mercury produced was equal to the mass of the mercury (II) oxide that he started with.

Mercury (II) oxide produces oxygen plus mercury

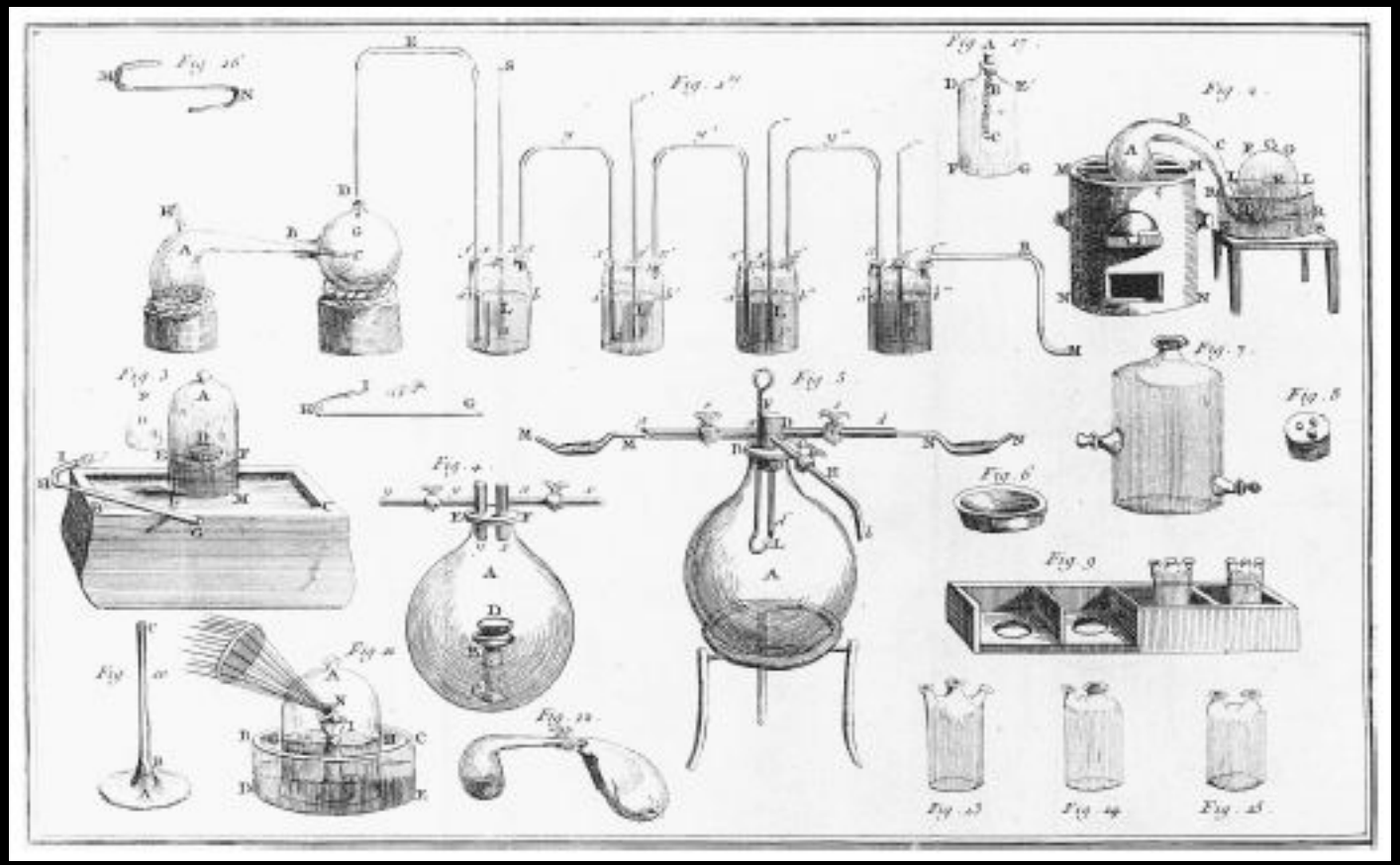
10.0 g = 0.7g + 9.3 g



Balancing Chemical Equations

Conservation of Mass

One Lavoisier's great achievements was to separate water into it's elemental components, hydrogen gas and oxygen gas and the recombine hydrogen gas and oxygen gas into liquid water H_2O.

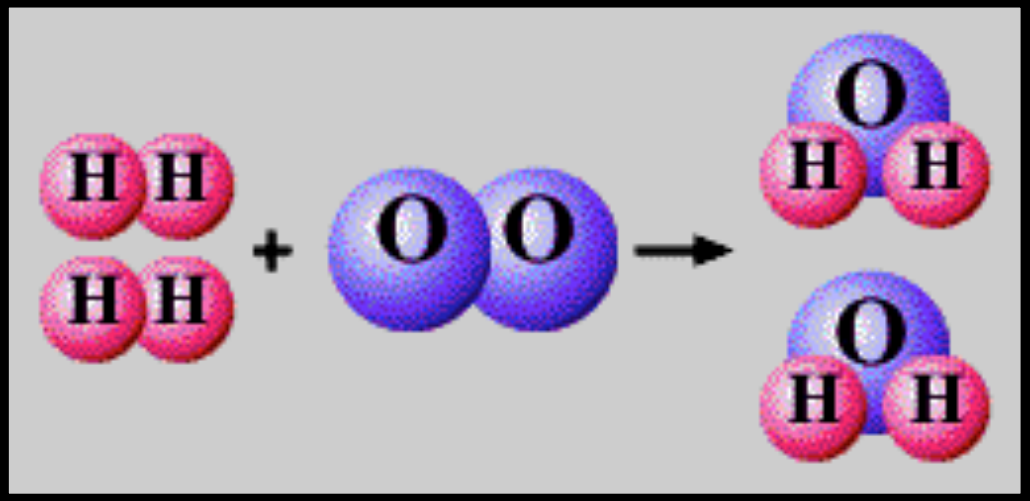


Balancing Chemical Equations

Conservation of Mass

Before: 4 atoms of hydrogen & 2 atoms of oxygen

Reactants

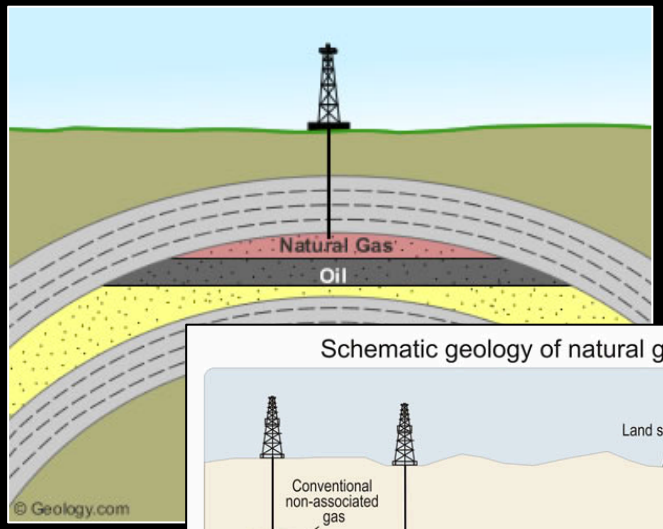


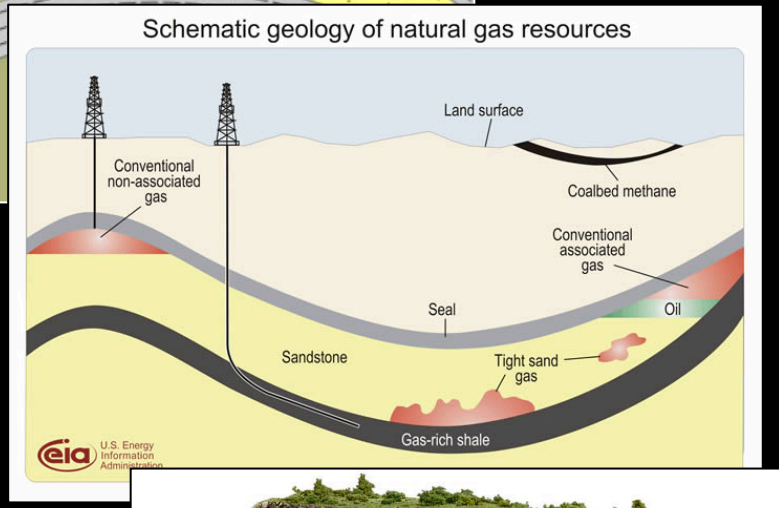
Products

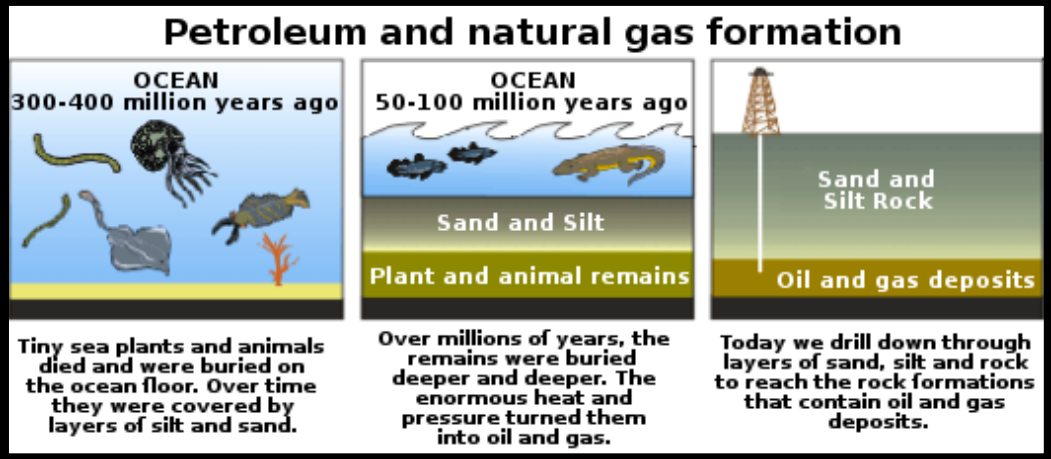
After: 4 atoms of hydrogen & 2 atoms of oxygen

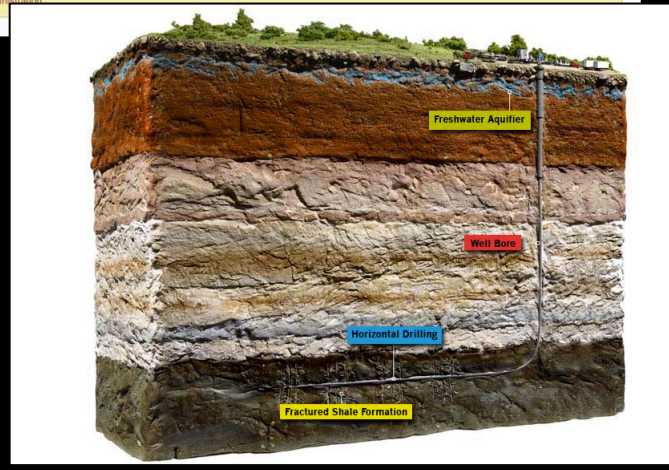
The Law of Conservation of Mass
In a chemical reaction, matter is not created or destroyed but is conserved.
Atoms can only rearrange.

Balancing Chemical Equations









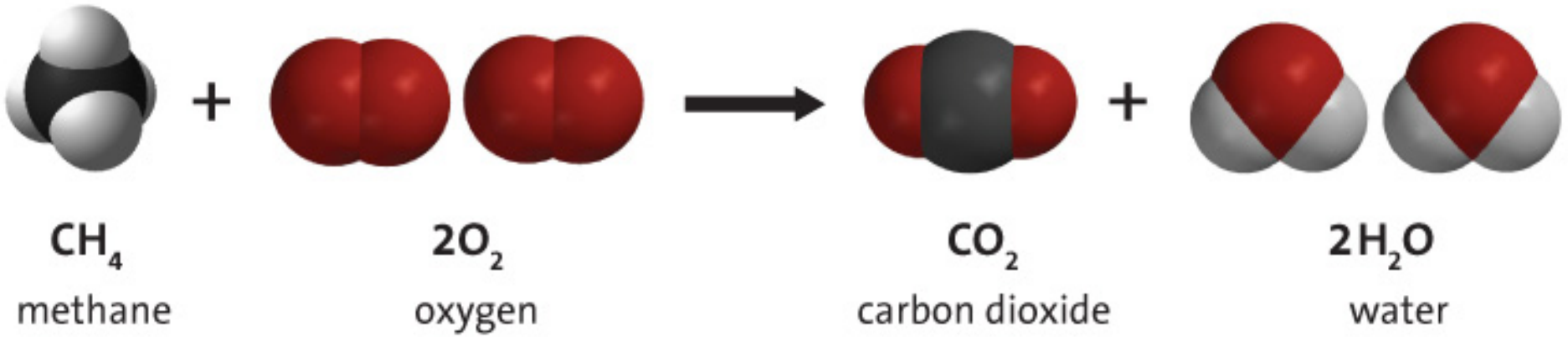
Balancing Chemical Equations

Chemical Reactions

For a chemical reaction in which all of the reactants change to products, the law of conservation of mass means that the starting mass of the reactants equals the final mass of the products.

The law of conservation of mass must be satisfied when describing a chemical reaction.

Balancing Chemical Equations



A chemical equation:

-is a shorthand method to describing a chemical reaction.

-is an expression that describes a chemical reaction using chemical formulas and other symbols.

-uses coefficients to show that atoms a are rearranged but never lost or destroyed; mass is conserved.

Balancing Chemical Equations

SYMBOL	MEANING
	produces, forms
+	plus, and
(s)	solid
(l)	liquid
(g)	gas
(aq)	aqueous (solid dissolved in water)
	the reactants are heated

CH_4 methane + $2O_2$ oxygen → CO_2 carbon dioxide + $2H_2O$ water

$$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (l)$$

The symbols to the right of the formulas are (*s*) for solid, (*aq*) for aqueous, which means "dissolved in water", (*g*) for gas, and (*l*) for liquid.

Coefficients

The numbers to the left of the formulas are called coefficients.

Coefficients represent the number of units of each substance taking part in the reaction.

CH_4 methane + $2O_2$ oxygen → CO_2 carbon dioxide + $2H_2O$ water

$$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (l)$$

Remember that the law of conservation of mass states that matter is neither created nor destroyed during chemical reactions. Atoms are rearranged but never lost or destroyed.

By conducting an element inventory it is easy to see that this equation is not balanced.

CH_4
methane

$2O_2$
oxygen

CO_2
carbon dioxide

$2H_2O$
water

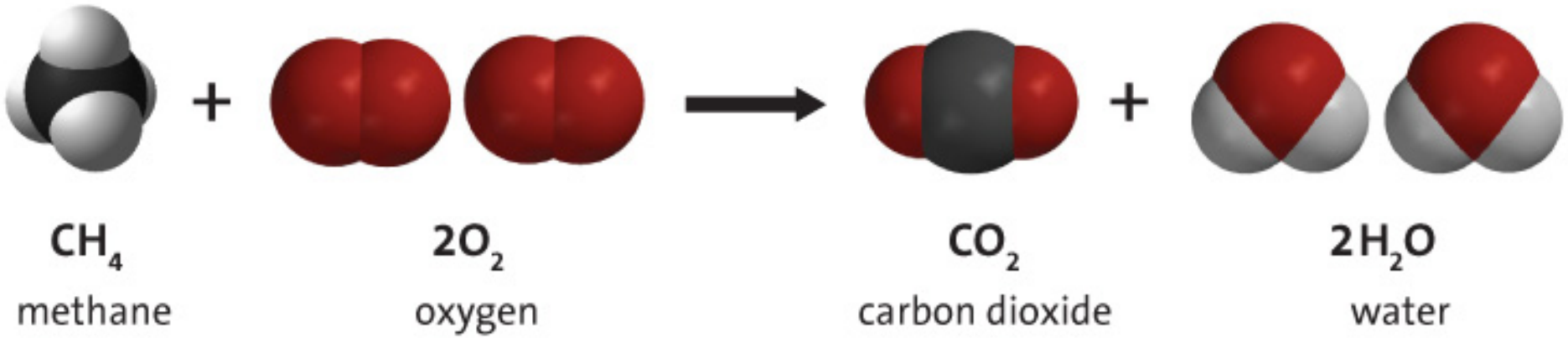
Element Inventory		
$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$		
C	1	1
H	4	4
O	4	4

This chemical equation is balanced!

The Law of Conservation of Mass

In a chemical reaction, matter is not created or destroyed but is conserved.

Atoms can only rearrange.



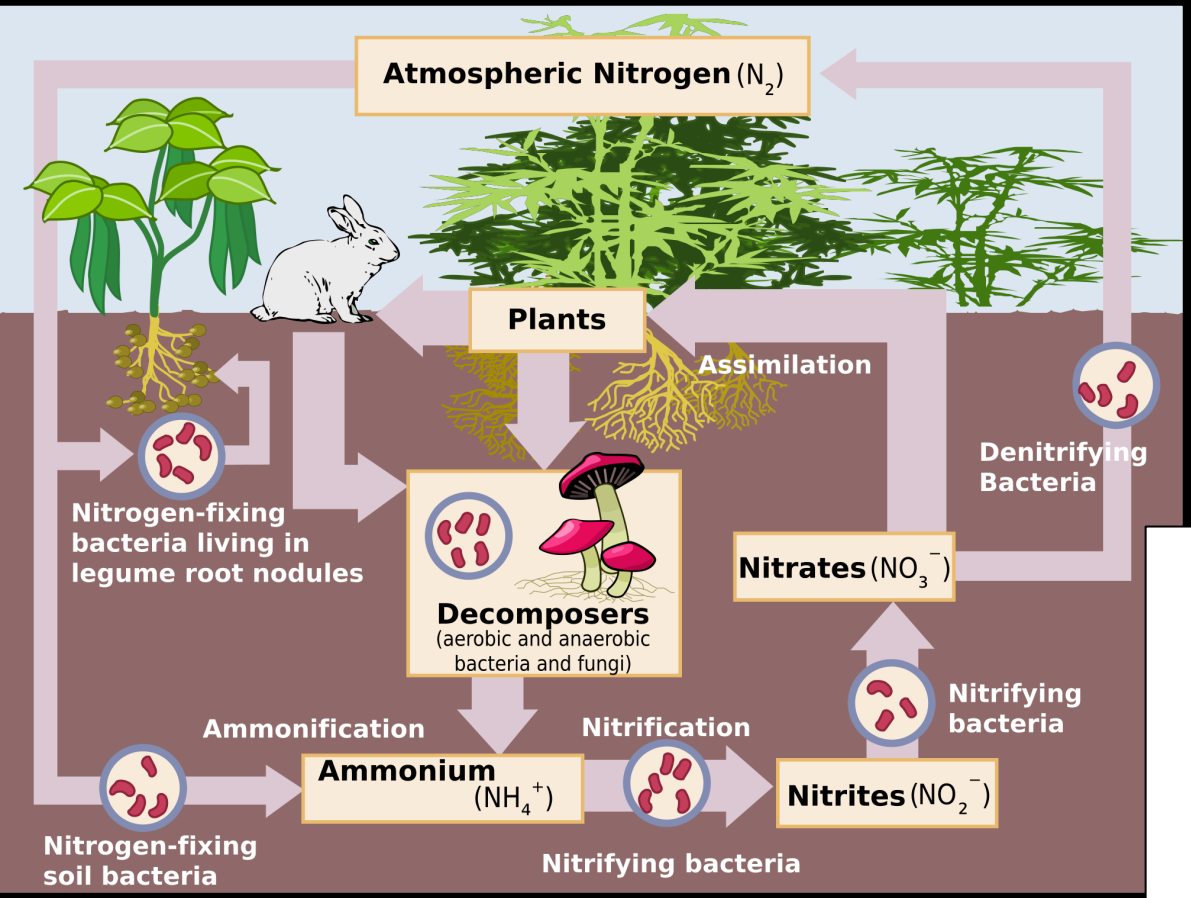
$$CH_4\,(g) + 2O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(l)$$

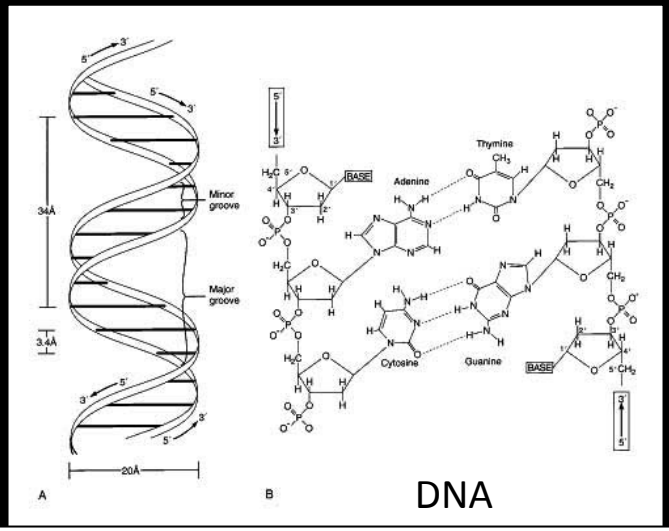
Diatomic molecules

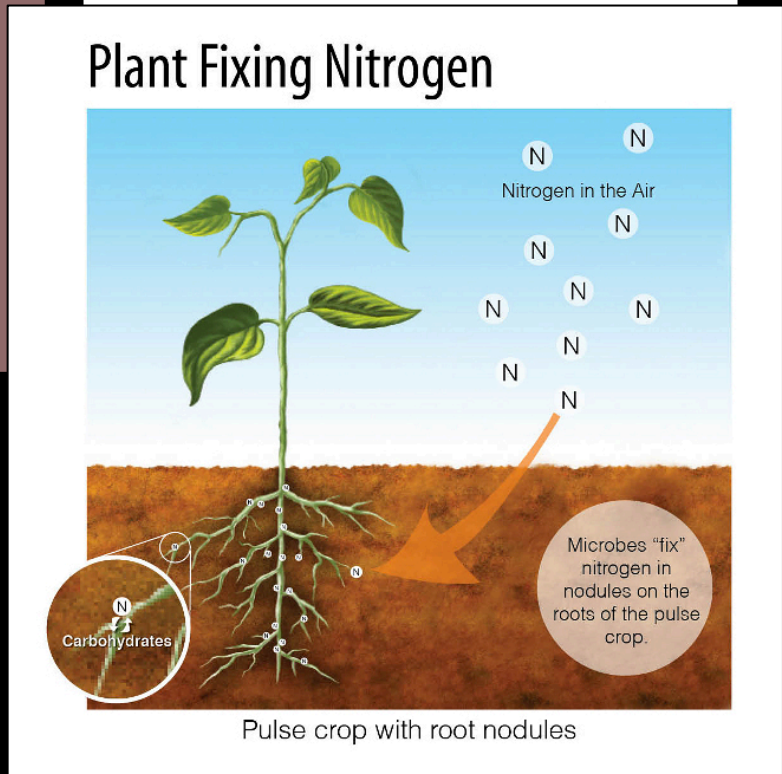
- Diatomic molecules are molecules composed only of two atoms, of either the same or different chemical elements
- There are seven elements that exist as diatomic molecules in their natural state.

H_2, Cl_2, N_2, O_2, F_2, Br_2, & I_2

The nitrogen cycle: nitrogen fixation







Balancing Chemical Equations

Element Inventory- Unbalanced		
$N_2\ (g) + H_2\ (g) \rightarrow NH_3\ (l)$		
N	2	1
H	2	3

Choosing Coefficients

To balance an equation, **never change the subscripts** of a correct formula. Instead, place a whole number to the left of the formulas of the reactants and products so that equal numbers of nitrogen and hydrogen atoms are on both sides of the equation.

If no number is written the coefficient is understood to be 1.

Balancing Chemical Equations

Element Inventory- Unbalanced		
$N_2\ (g) + H_2\ (g) \rightarrow NH_3\ (l)$		
N	2	1
H	2	3

Choosing Coefficients

Choosing the correct coefficient, to balance a chemical equation, is a trial and error process and requires patience.

Look at the formulas containing nitrogen and hydrogen molecules.

2 atoms of nitrogen are on the left and only 1 is on the right.

2 atoms of hydrogen are on the left and there are 3 is on the right.

Balancing Chemical Equations

Element Inventory- Balanced		
	$N_2\ (g) +$ 3 $H_2\ (g) \rightarrow$ 2 $NH_3\ (l)$	
N	2	2
H	6	6

Choosing Coefficients

There are 2 hydrogen atoms on the reactants side and 3 hydrogen atoms on the products side. The least common multiple of 2 & 3 is 6. Let's see if this will help us balance this chemical equation. If we put a coefficient of 3 before H_2 on the reactants side, and a coefficient of 2 before NH_3 on the products side, **the equation is balanced** because there are 2 nitrogen atoms on each side and 6 hydrogen atoms on each side.

Balancing Chemical Equations

Writing Balanced Chemical Equations

To write a balanced chemical equation for most reactions follow these five steps.

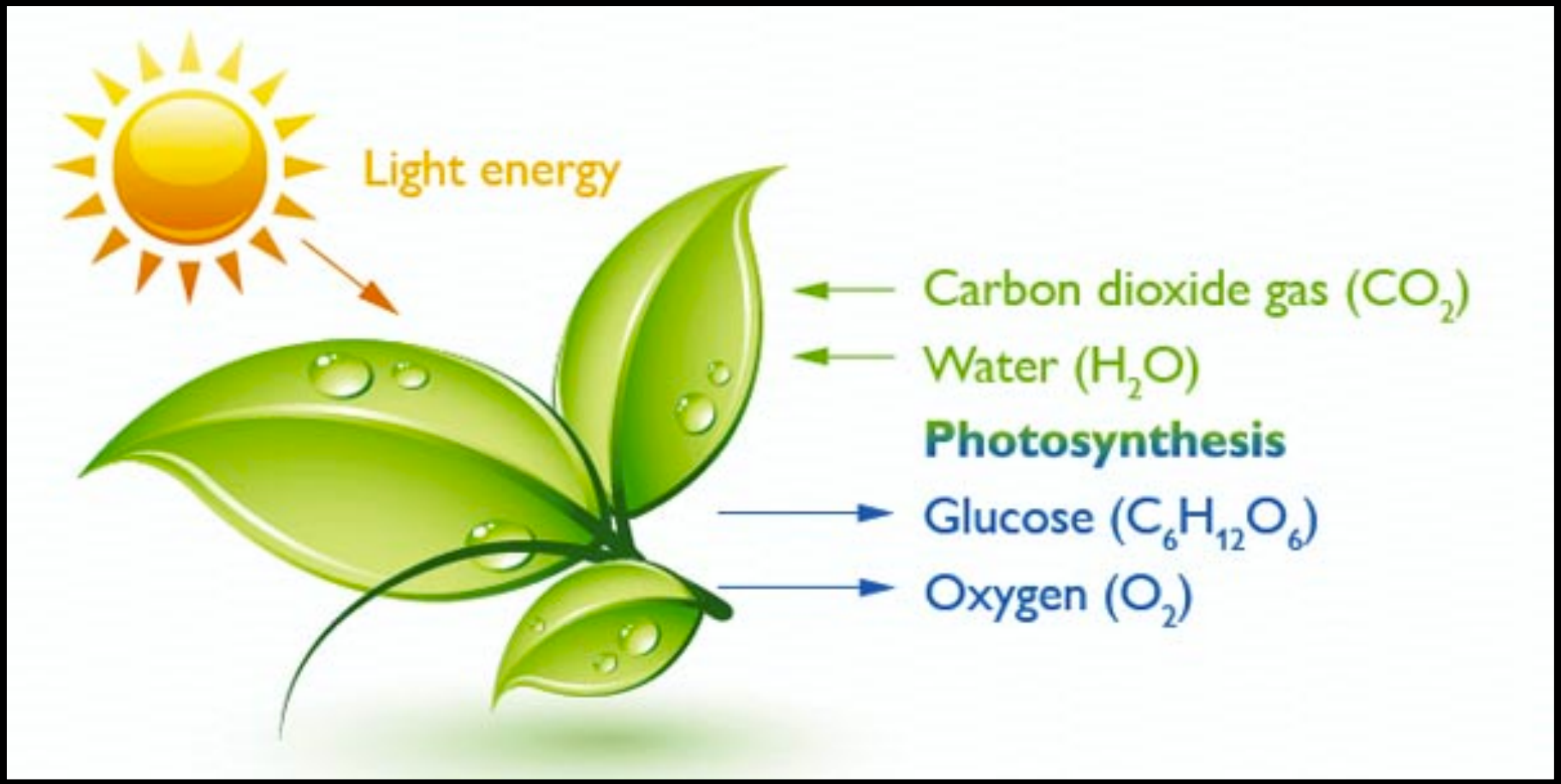
1. Write the unbalanced equation.
2. Count atoms on each side.

   Use an element inventory table.
3. Add coefficients to make #s equal.

   Coefficient × subscript = # atoms

   Use an element inventory table.
4. Reduce coefficients to lowest possible ratio.

   (If necessary)
5. Double check atom balance!!!


Light energy
Carbon dioxide gas (CO_2)
Water (H_2O)
Photosynthesis
Glucose ($C_6H_{12}O_6$)
Oxygen (O_2)

Writing Balanced Chemical Equations- Photosynthesis

Step 1- Write the unbalanced equation:

$$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$$

(Oxygen is a diatomic molecule, so there must be 2)

Step 2- Count atoms on each side: (Use an element inventory table.)

None of the carbon, oxygen, and hydrogen atoms are balanced.

The equation is not balanced.

Element Inventory- Unbalanced		
$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$		
C	1	6
O	3	8
H	2	12

Step 3- Add coefficients to make #s equal.

Coefficient × subscript = # atoms

$$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

Element Inventory- Balanced		
$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$		
C	6	6
O	18	18
H	12	12

Step 4- Reduce coefficients to lowest possible ratio. (not necessary)

Step 5- Double check atom balance!!!

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

CH_4 methane

$2O_2$ oxygen

CO_2 carbon dioxide

$2H_2O$ water

$$6\,CO_2 + 6\,H_2O \rightarrow C_6H_{12}O_6 + 6\,O_2$$