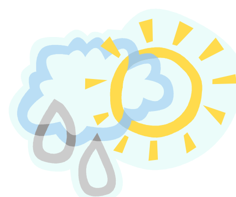
Module 1: The Material World: An Introduction to Chemistry

1. Changes and Properties Of Matter

A. ***Physical Property:*** describes a substance when observed in the absence of any change in composition. In other words it describes its appearance and not its behaviour.

Examples a) the mass of the substance was 10.0 g

B. ***Physical Change:*** a change that does not create different compounds or elements. It only changes the appearance of a substance; the physical properties change but the chemical properties stay the same.



Examples a) the sample of water evaporated

C. ***Chemical Change***: occurs when elements or compounds form pure substances that differ from the original(s).

Examples a) When magnesium is added to acid, hydrogen gas is released.

D. ***Chemical Properties***: describe how a substance behaves in the presence of other substances or whether it decomposes into different pure substances.

Examples a) Water causes sodium to undergo a violent reaction.

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E. ***Characteristic Properties***: are chemical or physical properties that help you identify a substance.

Important Physical Characteristic Properties

Density (g/ml)
Boiling point (^oC)
Melting point (^oC)
Specific heat (J/(g^oC)

Important Chemical Characteristic Properties

Substance	**Characteristic Chemical Property**
Water	
Oxygen	
Hydrogen	
Carbon dioxide	

F. ***Recognizing Chemical Changes in the Lab***

Physical Change	**Chemical Change**
Does not create a colour change. For example, water is colourless; when it freezes ice is also colourless (occasionally it turns white, but that is due to air within it). Solid iodine is purplish. When it turns to gas it is also purple.	***Often creates a colour change.*** Magnesium is shiny and grey. After it burns it becomes MgO, which is milky white.
Involves smaller amounts of energy. When water condenses it releases heat, but that heat does not set fire to things.	***Absorbs or releases larger amounts of energy.*** When nitroglycerin explodes, its gases are not only hot but they expand rapidly and damage

	anything in its path.
An element undergoing a physical change will not experience an increase in mass. A compound undergoing a physical change will not experience a decrease in mass. If 50 g of iron are heated sufficiently, 50 g of liquid iron will be produced. If 50 g of ice are melted 50 g of water will be produced.	***An element undergoing a chemical change will experience an increase in mass if compared to the compound produced.*** ***A compound undergoing a chemical change will experience an decrease in mass if compared to the element produced.*** If magnesium is burnt, the ash collected will weigh more because it contains magnesium bonded to oxygen. If 80 g CuO decompose, only 64 g of Cu will be left behind, because the oxygen breaks free from the compound.
If a gas escapes from a solution then it will have the same properties as those of the dissolved gas. Carbon dioxide that bubbles out of 7-up was still carbon dioxide when it was dissolved in the soft drink. ***If a solid precipitates from a solution, it will have the same properties as those of the dissolved solid.*** For example, excess sugar accumulating at the bottom of an oversweetened cup of coffee.	***If a gas escapes, it will have different properties from the substance that produced it.*** Magnesium + hydrochloric acid = magnesium chloride + hydrogen gas. Hydrogen is flammable; hydrochloric acid is not. ***If a solid forms in solution, it will have different properties from the substances that were dissolved.*** Sodium chloride + silver nitrate = sodium nitrate + solid silver chloride.

<u>Example</u> Was the change described a chemical change?
Was the original substance a compound? Or was it an element? Consider the experimental observations and decide.

A reddish powder was heated. A gas was released, while a silvery liquid appeared. The mass of the liquid was less than that of the powder.

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Exercises for p 1-3

1. Which of the following are observations?

a. Heat rises from the flame.
b. When I place my hand on the left hand side of the candle, my hand does not get much warmer.
c. But if I place my hand above the flame, I feel a burning sensation and I quickly remove my hand.
d. The candle is cylindrical in shape.
e. When the candle is covered with a jar the oxygen level decreases and the flame eventually dies.
f. The air temperature 2 cm above the flame was 171^{o} C.
g. The change in mass between the new and used candle was 23.43 g.

2. a. What should you first do after you've identified a problem in science (asked a question)
   b. Why should you not begin speculating immediately or go straight to the lab?

3. a. How do you test a hypothesis?
   b. What form of reference is the most reliable in science?

4. Classify as heterogeneous or homogeneous.

a. whole milk straight from a cow s udder
b. a pineapple
c. a solution of copper chloride
d. gold (Au)
e. argon gas (Ar)
f. water vapour
g. sand (assuming it is only SiO_2)
h. a cross section of a maple tree
i. methane (CH_4)
j. a sodium nitrate solution with an AgCl precipitate. (A precipitate is a solid that fall to the bottom of the container)

5. Classify as a solution , compound or element.

a. vanillin dissolved in alcohol
b. potassium (K)
c. table salt (NaCl)
d. Kool Aid
e. water
f. sodium oxide (Na_2O)
g. ozone (O_3)
h. ammonia mixed with H_2O
i. air
j. shampoo

6 Classify as a physical or chemical change.

a. wood burning
b. mercuric oxide (HgO) decomposing into mercury and oxygen
c. H_2O going from the solid to liquid form
d. $NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2\ HCl$ (the arrow indicates a change)
   (before) (after)

e. digestion
f. tearing paper
g. distilling wine
h. neutralizing acid with limewater
i. the explosion of nitroglycerin
j. igniting a mixture of air and propane
k. paint drying (which strangely *increases* in mass)

7. Classify as a physical or chemical property.

a. Lemon juice is more acidic than water.
b. The density of lemon juice is 1.1 g/mL
c. Lemon juice is a type of citrus juice
d. Lemon juice reacts with amines from decomposing fish, thus eliminating the foul smell.
e. The boiling point of lemon juice is 102^{o} C.
f. Lemon juice is a liquid at room temperature.
g. Lemon juice can slow down the browning process in an apple.
h. Frozen lemon juice melts before turning into a vapour.
i. Lemon juice can neutralize limewater.
j. Lemon juice is cloudy in appearance.
k. The specific heat of water is 4.19 J/(g ^{o}C).
l. Oxygen gas can rust metal.
m. Hydrogen pops in the presence of a flame.
n. Carbon dioxide turns into a solid at a low temperature.

8. a. In #7, which of the properties are *characteristic*? Which properties would help you figure out the identity of the substance?)

b. Read the following and pick out the characteristic properties of sulfur.

Sulfur burns in air with a highly unusual blue and stinking flame. At room temperature it is solid. If heated slowly it will melt at 119^{o} C. Sulfur, selenium and tellurium also react directly with the halogens.

9. Underline all chemical properties in the following descriptions of elements.

a. *barium* This metal melts at 725 ^{o}C and boils at 1640 ^{o} C. It oxidizes very easily and should be kept under oxygen-free liquids such as petroleum. It is decomposed by either water or alcohol.

b. *fluorine* At 0 °C and 101 kPa (pressure units) this gas has a density of 1.696 g/L. In appearance it is pale-yellow. Highly corrosive, it reacts with organic substances, including skin. Finely powdered glass will burn in a fluorine atmosphere. Even relatively inert xenon, radon and krypton form compounds with fluorine.
c. *nickel* This metal is found in most meteorites and in the meteorite dust found on your window ledge. It is silvery white and takes on a high polish. Nickel plating is often used to provide a protective coating for other metals, and finely divided nickel helps speed up reactions, which convert vegetable oil to margarine.

d. *promethium* This element does not occur naturally on earth; however, it was found in the spectrum of the star HR-465 in the Andromeda galaxy. Promethium salts glow in the dark with a pale blue or green hue.

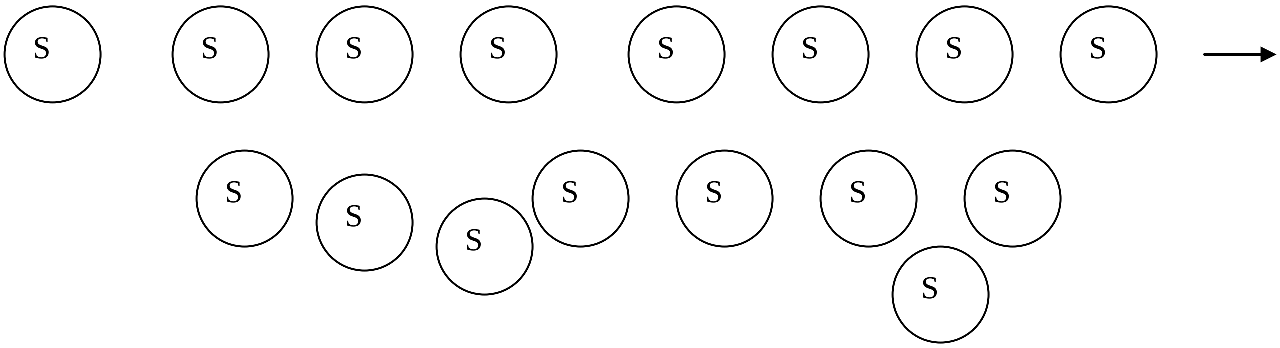
e. *sulfur* It is a brittle solid that does not dissolve in water. A finely divided form of sulfur, known as flowers of sulfur, is obtained by turning it into gas and back into solid (sublimation) . Sulfur easily forms sulfides with many elements such as sodium, calcium, iron etc. It is found in black gunpowder; it bleaches dried fruit and is a good electrical insulator. It combines with oxygen to produce a gas that leads to acid rain.

10. Find the physical properties.

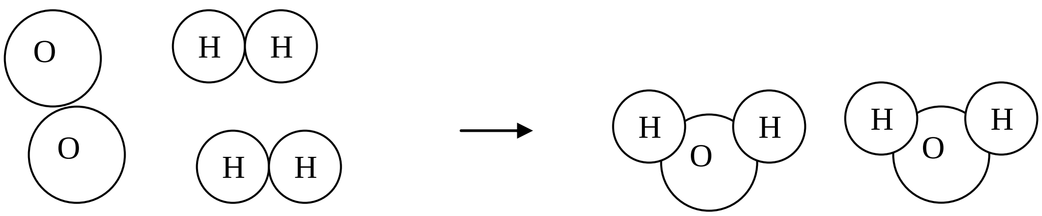
a. *zinc* Centuries before zinc was recognized as a distinct element, ores of zinc were used in the making of brass (an alloy of zinc and copper). In fact an alloy rich in zinc was found in prehistoric ruins in Transylvania.
Zinc is a bluish-white, shiny metal. It is a brittle at ordinary temperatures but malleable at 100 °C to 150 °C, and it melts at 419 °C. It is a fair conductor of electricity and burns in air at high temperatures with the release of white clouds of zinc (II) oxide. The pure metal can be obtained by roasting its ores to form the oxide and by the reduction of the oxide with charcoal. Zinc reacts with sulfur to produce zinc (II) sulfide, a compound used in making luminous watch dials.
b. *oxygen* Solid and liquid oxygen are pale blue, and O_2 turns into a liquid at -183 °C. It forms 21% (by volume) of the earth's atmosphere, and its compounds make up nearly 90% of the earth s crust. The gas is colourless, tasteless and odourless but very reactive and capable of combining with most elements. It is essential for respiration of all plants and animals and for practically all combustion. In the stratosphere it forms the important sun-screening gas, ozone, O_3.

11. Classify each of the following as a physical or chemical change.

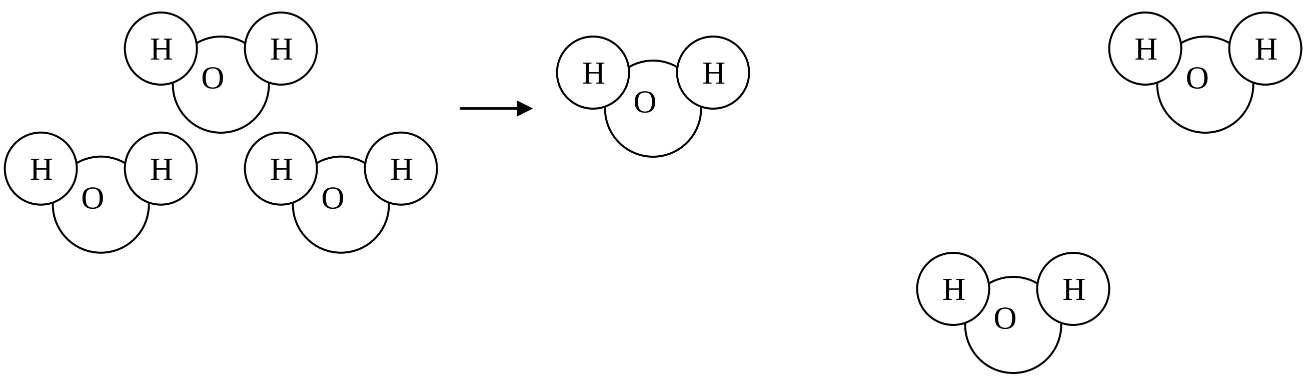
a.



b.



c.



12. You have four unlabeled gas containers. One contains pure oxygen; one has pure hydrogen; one pure carbon dioxide and the other, neon. The table below summarizes the results of various lab tests done by a group of students. Some tests were not performed because the students were instructed to perform as few experiments as possible. Identify all the unknowns based on their results.

UNKNOWN	**Glowing splint test result**	**Limewater test result**
A	Pop is heard	Clear solution
B	Bursts into flames	Clear solution
C	Not done	Solution turns milky
D	Not done	Test not done.

13. For each substance, find the property that is the *most* characteristic.

a. *ethanol*

1. clear
2. density of 0.82 g/ml
3. can kill germs
4. can be poisonous

b. *nitrous oxide*

1. makes things burn faster
2. dissolves in alcohol
3. can be used to make whipped cream
4. sweet-smelling and can make people giggle in low doses

14. You are given two liquids. One is water; the other is alcohol. Without tasting or smelling them, how can you tell them apart. You have no matches.

15. Now you found matches. How do you tell a sugar solution apart from a salt solution?

16. A purplish gas cools and turns into a shiny solid. Both the gas and the solid turn paper grey. Chemical change? Or physical? Argue your case.

17. An elemental substance was heated, and it turned from brown to black. Its mass also increased. Chemical change? Or physical? Argue your case.

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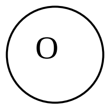
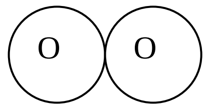
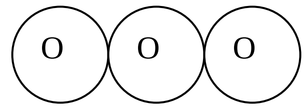
2. **Chemical Formulas** (Atoms and Molecules)

Each element from the periodic table has only one type of atom. If two or more atoms bond together to form a separate particle you’ve got yourself a molecule.

 oxygen atom	 oxygen molecule	 a different type of oxygen molecule

How do we use a formula to represent the above?

Reminder: What is an atom?

The Dalton Model of the Atom 	**Modern Model (will be studied in more detail later)**
1. Matter is made up of small, indivisible particles called ______________________	**1. In reality, atoms are made up of smaller particles called _________, _______________, and _______________**
2. All the atoms of a single element are identical. Example:	**2. Often, there are lighter and heavier versions of the same element called_______________**
3. The atoms of one element are different from the atoms of another element.	**3. Still true because of a different number of _______________**
4. Compounds can form from joining atoms of different elements in different ratios. Examples:	**4. Still true because of chemical bonding.**
5. Chemical reactions create new substances but atoms are not destroyed.	**5. Still true because chemical reactions simply move _______________around.**

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Examples

1. For each of the following, specify how many atoms of each type are found in each molecule. Also draw the molecule.

a. SO_2

b. NH_4Cl

c. P_2O_5

d. $Al_2(SO_4)_3$

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Exercises

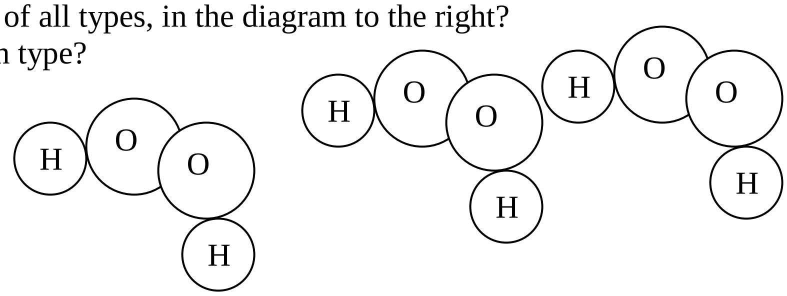
1. For each of the following, specify the number of atoms for each element in the compound.

a. H_2S_2
b. Na_2CO_3
c. $CaCl_2$
d. $C_4H_{10}O$
e. NF_3
f. $Al_2(SO_4)_3$
g. $Mg(ClO_3)_2$
h. $(NH_4)_2S$
i. C_6H_5OH

2. Draw a molecule of ozone. (It contains three atoms of oxygen.)

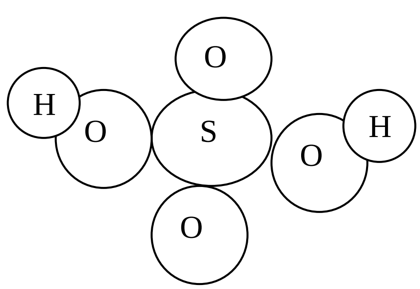
3 a. Draw an atom of boron. About a cm to the left of the first drawing, draw a second boron atom.
b. In part (a), have you drawn a molecule? Why or why not ?

4. a. How many atoms are there in all , of all types, in the diagram to the right?
b. How many atoms are there of each type?
c. How many molecules are drawn?
d. Write a formula for one molecule.

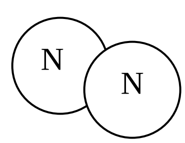


5. Write the formula for each of the molecules shown below.

a.



b.



6. Refer to the Dalton Model chart and give two other examples of points 2 and 4. You may have to use your textbook or the internet.

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2. Chemical Equations

A. Introduction to Equations

Definition A chemical equation is a symbolic representation of a chemical reaction.

<u>Example</u>: Whenever you light propane (C_3H_8) in a gas barbecue, propane reacts with oxygen gas in a ratio of 1 to 5(# of molecules) to produce carbon dioxide gas and water vapour in a ratio of 3 to 4.

Instead of saying all that, we can write the following equation:

Other symbols and definitions What do the following symbols from chemical equations mean?

a. (+) before the arrow:

b. (+) after the arrow:

c. $\longrightarrow$

d. Big numbers in front of formulas:

e. $_{(g)}$

f. $_{(aq)}$

g. $_{(s)}$

h. $_{(l)}$

i. reactants:

j. products:

k. $\downarrow$

l. $\uparrow$

B. **Characteristics of Chemical Reactions**

(1) *Mass is conserved:*

Example 1 If 44 grams of C_3H_8 completely react with 160 g of oxygen, how much CO_2 and water will be produced?

Example 2 Find x.

C	+	O_2	$\rightarrow$	CO_2
12 g react		x		44 g are produced

(2) *The number of atoms is conserved:*

Example 1 $C + O_2 \rightarrow CO_2$

Example 2 $C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$

Exercises

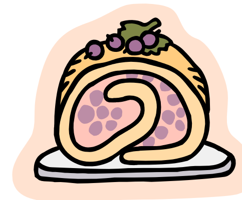
1. The synthesis of water can be represented by the following equation:

$$2\ H_{2(g)} + O_{2(g)} \rightarrow 2\ H_2O_{(l)}$$

a. What are two possible meanings for the 2 in front of H_2O?
b. What does the arrow indicate?
c. What are the reactants?
d. How many molecules of oxygen will react with every 2 molecules of hydrogen?
e. Suppose there were 6 molecules of hydrogen. How many molecules of oxygen would completely react with the hydrogen?
f. The water that is produced is in what physical state? (Solid? Liquid? etc)

2. One way to analyze the amount of salt in meat is to extract it with boiling water and to use a chemical that indicates when the following reaction is complete:

$NaCl_{(aq)}$ + $AgNO_{3(aq)}$ → $NaNO_{3(aq)}$ + AgCl↓



a. What does the arrow after silver (I) chloride indicate?
b. Is the sodium chloride dissolved in water? How do you know?
c. In all how many nitrogen atoms are on the L.H.S. of the equation?

3. Recopy the following equations and completed charts (that track the number of atoms of each type) on loose leaf:

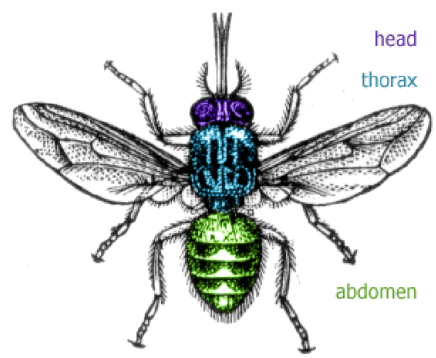
a. $2\ C_4H_{10}$ + $13\ O_2$ → $8\ CO_2$ + $10\ H_2O$
b. $2\ H_2O_2 \rightarrow O_2 + 2\ H_2O$

4. The last step in the synthesis of a poison known as nicotine is given by the following reaction:

$C_{10}H_{14}N2$ +	CH_3I +	NaOH →	H_2O +	$C_{11}H_{14}N_2$ +	NaI
162 g	142 g	40 g	18 g	__?__g	150 g

How many grams of nicotine were produced if the above amounts reacted to also produce the given amounts of sodium iodide and water?

5. Whereas human females apply *Chanel No. 5*, the product of this reaction is what female tsetse flies use to attract mates. How much of it is produced if the given amounts completely react?



$C_{37}H_{72}$	+ $2\ H_2$ →	$C_{37}H_{76}$
516 g	4g	__?__g

6. A useful insect repellent (girls are may be asking whether it works as an undesirable male-repellant) can be synthesized according to:

$C_7H_{11}ClO_3$ +	$C_4H_{11}N$ →	$C_{11}H_{21}NO_3$ +	HCl
__?__g	73 g	215 g	36.5 g

How much $C_7H_{11}ClO_3$ is needed to produce 215 g of the repellent?

7. Because of propane's simple chemical structure, it usually burns cleanly. Unlike gasoline, in a well-ventilated area, it will not produce much soot or carbon monoxide. It does however produce the greenhouse gas carbon dioxide, which has been accumulating in the atmosphere since the Industrial Revolution. Hydrogen would be a more environmentally-friendly fuel. Based on what you know about chemistry, would hydrogen burn to produce ....
a. carbon dioxide? Why? b. carbon monoxide? Why?

C. Balancing Chemical Equations

Equations have to be balanced because in reality chemical reactions cannot destroy atoms; they only ionize or rearrange them.

RULES

1. You may introduce coefficients (big #s in front of formulas or atomic symbols). Remember the coefficients can be thought of as the number of bound atoms or molecules.

2. You cannot change or add subscripts (small # s that are part of formulas)

3. For each element, the total on the L.H.S. (Left Hand Side)= total on R.H.S. of the equation.

<u>Examples</u>: 1. Balance:

a. $H_2 + Cl_2 \rightarrow HCl$

(also draw the molecules to understand what is going on)

b. $Ca(OH)_2 + HF \rightarrow CaF_2 + H_2O$

c. $C_7H_{16} + O_2 \rightarrow CO_2 + H_2O$

d. $Na_3PO_4 + CaCl_2 \rightarrow Ca_3(PO_4)_2 + NaCl$

e. $K_2SO_{4(aq)} + Mg(NO_3)_{2(aq)} \rightarrow KNO_{3(aq)} + MgSO_{4(s)}$

f. $C_6H_6 + O_2 \rightarrow CO_2 + H_2O$

g. $N_2 + F_2 \rightarrow NF_3$

<u>Example 2</u> Translate examples 1e and 1g from #1 into word equations.

Exercises

1. Balance the following. If the equation is already balanced, indicate that it is.

a. $CH_4 + O_2 \rightarrow CO_2 + H_2O$

b. $Cu + O_2 \rightarrow CuO$

c. $Be + O_2 \rightarrow BeO$

d. $Fe(NO_3)_2 + NaOH \rightarrow Fe(OH)_2 + NaNO_3$

e. $NaBr + CuCl_2 \rightarrow NaCl + CuBr_2$

f. $Al_2(SO_4)_3 + Ca(OH)_2 \rightarrow Al(OH)_3 + CaSO_4$

g. $Pb(NO_3)_2 + KI \rightarrow KNO_3 + PbI_2$

h. $CaCl_2 + BaF_2 \rightarrow CaF_2 + BaCl_2$

i. $Na + O_2 \rightarrow Na_2O$

j. $Li + H_2O \rightarrow LiOH + H_2$

k. $PbCrO_4 + HCl + FeSO_4 \rightarrow PbCl_2 + Cr_2(SO_4)_3 + FeCl_3 + H_2O + Fe_2(SO_4)_3$

l. $NO + O_2 \rightarrow NO_2$

m. $C + H_2 \rightarrow C_2H_2$

n. $AlCl_3 + NaOH \rightarrow NaAlO_2 + NaCl + H_2O$

o. $FeO + O_2 \rightarrow Fe_2O_3$

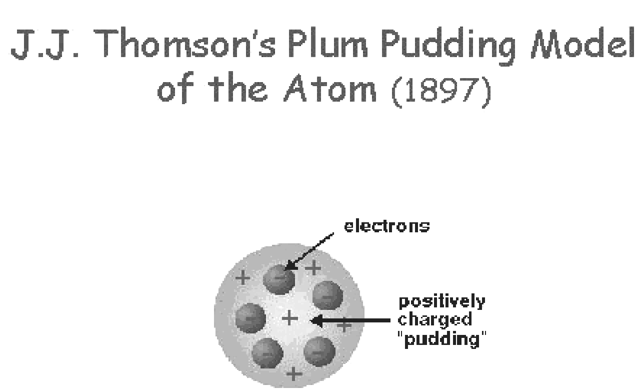
3. Models of the Atom

All life, whether in the form of trees, whales, mushrooms, bacteria or amoebas , consists of cells. Similarly, all matter, whether in the form of aspirin, gold, vitamins, air or minerals, consists of atoms, which, regardless of size, are made up of the same basic units. This took us thousands of years to realize, and the present chapter is a journey through that history, one that eventually gave us enough understanding and power to mimic, harm and repair nature in ways never before possible.

A. Dalton (b. Sept. 6, 1766, England; d. July 27, 1844) deduced the law of multiple proportions, which stated that when two elements form more than one compound by combining in more than one proportion by weight, the weight of one element in one of the compounds is in simple, integer ratios to its weights in the other compounds. For example, **Dalton** knew that oxygen and carbon could combine to form two different compounds and that carbon dioxide (CO_2) contains twice as much oxygen by weight as carbon monoxide (CO). In this case, the ratio of oxygen in one compound to the amount of oxygen in the other is the simple integer ratio 2:1. Although **Dalton** called his theory "modern" to differentiate it from Democritus' philosophy, he retained the Greek term atom to honour the ancients. Also, Dalton gave us more insight into molecules, but his idea of the atom was not that different from that of Democritus: he still imagined atoms as tiny "bowling balls."

Example Draw water molecules using the Dalton model of the atom

B.Thomson's Experiment **J.J. Thomson (b. Dec. 18, 1856, England d. Aug. 30, 1940,)** held that atoms are uniform spheres of positively charged matter in which electrons are embedded. He realized that electrons existed by improving Crooke's tube, a tube that contained a small amount of gas through which electricity was passed. Crooke had noticed that the rays inside the tube were bent by a magnet, something that ordinary light does *not* do. By developing a better vacuum, Thomson showed that these same rays also bend towards the positive plate of a battery, no matter what gas produces them.



Thomson concluded that these "cathode rays"(**electrons**) were basic particles found in all elements. By measuring a

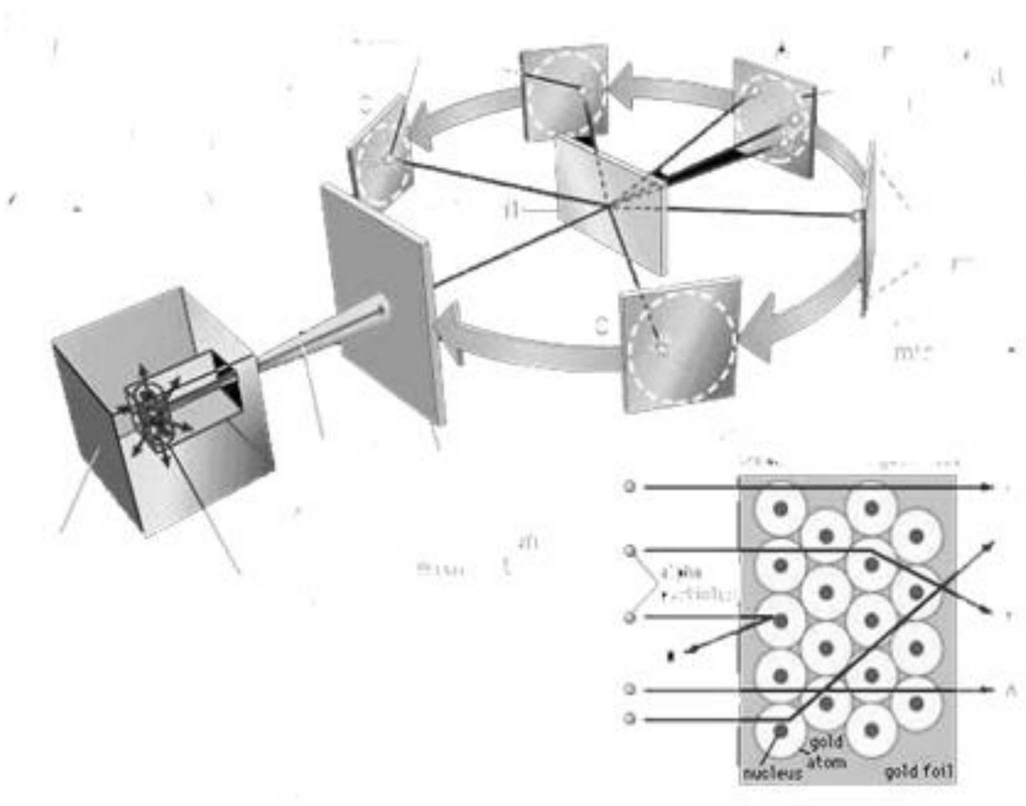
constant charge to mass ratio, he realized that these negative particles were common to all atoms, and he went on to propose what is popularly known as the plum-pudding model of the atom. In other words he thought that atoms were not indivisible spheres, but positive spheres with negative electrons embedded in them. It had to be abandoned (1911) on both theoretical and experimental grounds in favour of the

Example Draw another way of representing the plum pudding model.

C. Ernest **Rutherford**. (**b. Aug. 30, 1871, New Zealand; d. Oct. 19, 1937, England)**

The **model** described the atom as a tiny, dense, positively charged core called a nucleus, in which nearly all the mass is concentrated, around which the light, negative constituents, called electrons, circulate at some distance, much like planets revolving around the Sun. The **Rutherford** atomic **model** has been alternatively called the nuclear atom, or the planetary **model** of the atom. The young physicists beamed alpha particles through gold foil and detected them as flashes of light or scintillations on a screen. The gold foil was only 0.00004 centimeter thick. Most of the alpha particles went straight through the foil, but some were deflected by the foil and hit a spot on a screen placed off to one side. Geiger and Marsden found that about one in 20,000 alpha particles had been deflected 45^o or more. **Rutherford** asked why so many alpha particles passed through the gold foil while a few were deflected so greatly. "It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper, and it came back to hit you," **Rutherford** said later. "On consideration, I realized that this scattering backwards must be the result of a single collision, and when I made calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the greater part of the mass of the atom was concentrated in a minute nucleus. It was then that I had the idea of an atom with a minute massive center carrying a charge."

Rutherford’s Experiment (this is *not* the atomic model!!)



Example1 Draw **the model** of the atom according to Rutherford.

Example 2: Can you explain why some alpha particles were deflected at large angles?

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Exercises for p 17-19

1. Complete the following using **Dalton, Thomson, Rutherford**

a. This simplest of the models has its limitations, but it can be used to explain physical changes__________________
b. Of the three models, this is the only one that does not include electrons.__________________
c. It is the first model that proposes electrons. __________________
d. He had a chance to prove his teacher wrong by firing alpha particles at a gold foil__________________
e. He was the first to propose that most of the atom's mass was concentrated in the positively charged nucleus__________________
f. His model can be described as the "plum-pudding" or "chocolate chip" model because he evenly distributed the (+) and (-) charges__________________
g. This is the planetary model of the atom__________________
h. He imagined that atoms consisted of solid spheres, just like miniature bowling balls. __________________
i. He discovered " cathode rays" or electrons which can be deflected by a strong magnet or by another electric field__________________
j. In this model electrons are scattered outside the nucleus in what is mostly empty space__________________

2. The Rutherford Model In Detail

TRUE? *or* FALSE?

a. Alpha particles are positively charged and unlike gamma radiation, they are an example of matter, not energy__________________
b. Rutherford obtained similar results, regardless of whether he used thin gold, silver or platinum foil__________________
c. Most alpha particles bounced back after hitting the foil__________________
d. The percent of particles which came back gives us a rough estimate of how big the nucleus is relative to the rest of the atom__________________

4. Complete the following table.

	Dalton	**Thomson**	**Rutherford**
Drawing			
Does the model have positives and negatives?			
Where is the mass of the atom concentrated?			
How did it improve the previous model?			

5. a. In what way is Rutherford's model of the atom similar to Thomson's?
   b. Explain how they differ.

6. a. In the gold foil experiment, what observation surprised Rutherford?
   b. What had he expected to happen when he fired alpha particles at gold foil?