

# Lecture02\_C1403 Fall 2005



Thank  
You!

**Please Turn Off Cellular Phones!**

## Tentative Course Material To Be Covered this term

***Exam 1: Wednesday, September 29*** (6 lectures covered).

Chapter 1. The Atomic Nature of Matter.

Chapter 2. Stoichiometry.

Chapter 3. Chemical Periodicity and the Formation of Simple Compounds.

***Exam 2: Wednesday, November 2*** (9 lectures covered)

Chapter 16. Quantum Mechanics and the Hydrogen Atom.

Chapter 17. Many-electron Atoms and Chemical Bonding.

Chapter 18. Molecular Orbitals, Spectroscopy, and Atmospheric Chemistry.

***Exam 3: Wednesday, November 30*** (6 lectures covered)

Chapter 19. Coordination Complexes.

Chapter 24. From Petroleum to Pharmaceuticals.

***Period before final*** (3 lectures covered)

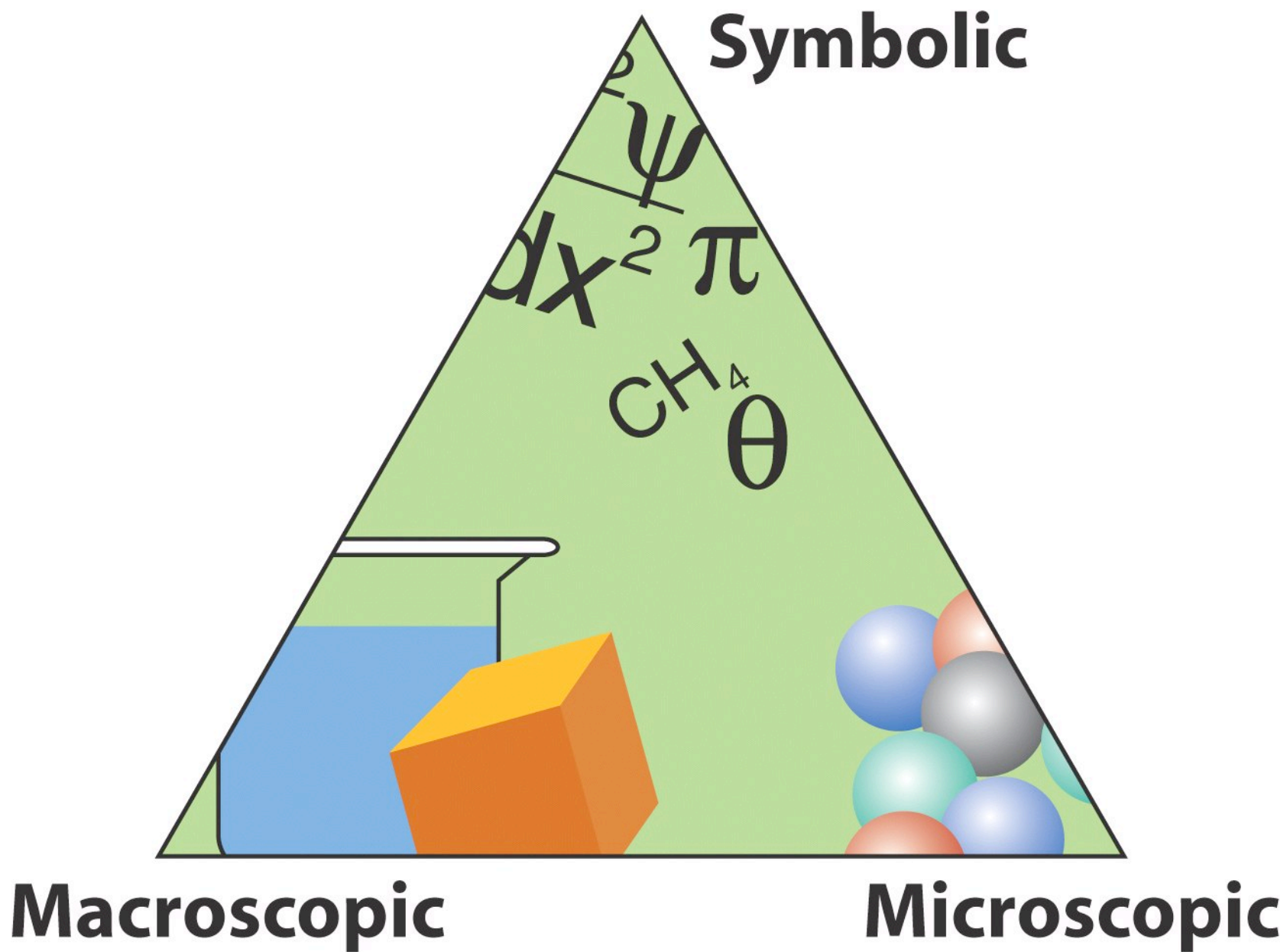
Chapter 25. Synthetic and Biological Polymers (plus spectroscopy of organic molecules)..

***Date of the final exam will be announced by the registrar.***

Science: An attitude or world view. The systematic logical and self-consistent investigation, creation and organization of knowledge through observations.

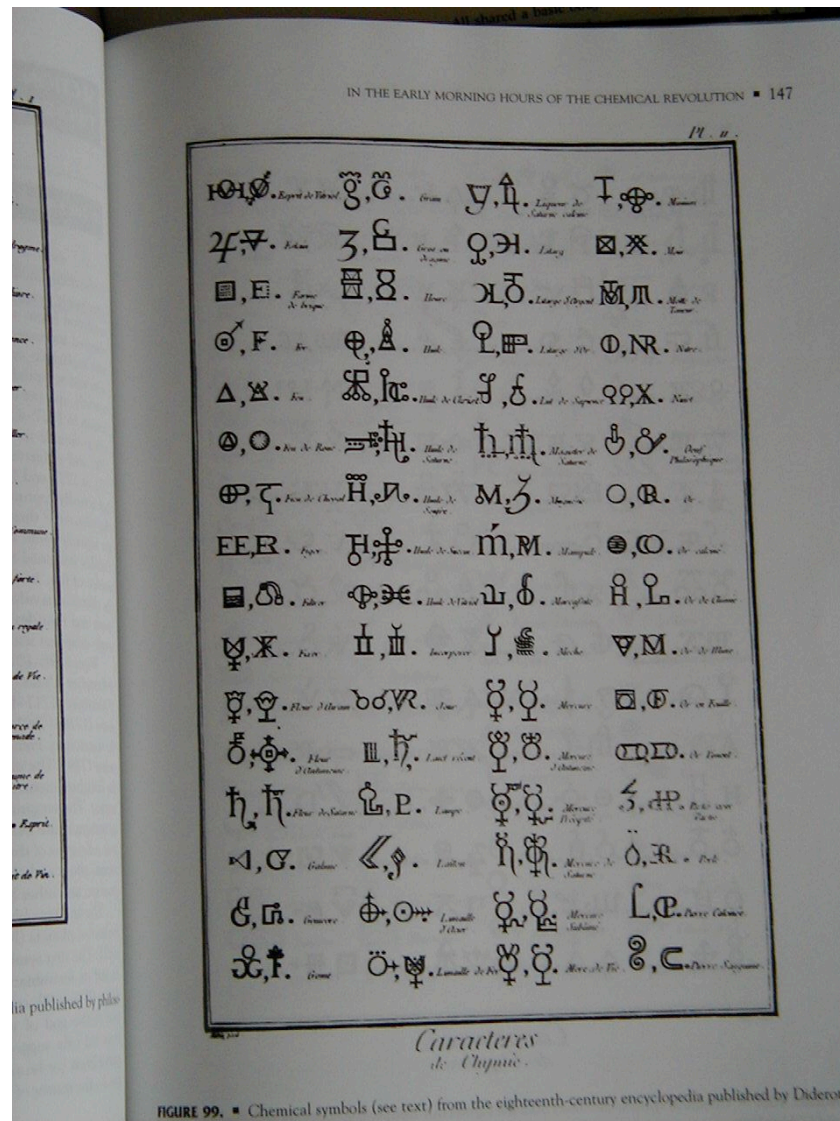
Observations in the form or experiments lead to classifications and classifications lead to rules.

Rules which are found to be universal and without exceptions lead to laws.



# “Babel” of Chemical Nomenclature 1770

- Chemistry Symbols from the 18th century encyclopedia published by philosopher Denis Diderot and mathematician Jan Le Rond D'Alembert
- These symbols describe Alloys, compounds, chemical operations, quantities, glassware, etc.



*Chemistry* employs the scientific method to investigate, create and organize knowledge that provides an understanding of the structure and transformation of matter and the interaction of light and matter.

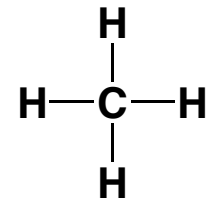
Provide a chemist with any observation and he/she interprets it in terms of the *structure and dynamics* of atoms, molecules, photons (and friends) as the key intellectual units.

***Molecular Structure: The key intellectual unit of all of chemistry. From structure to function.***

***Composition:*** Number and kinds of atoms

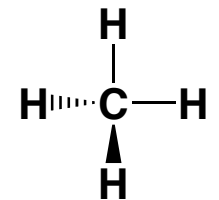
***CH<sub>4</sub>: one carbon atom, 4 hydrogen atoms***

***Constitution:*** How all the atoms are connected by bonds to one another. ***4 hydrogens connected to carbon, not to other hydrogens.***



***Configuration:*** How all the atoms are distributed in space relative to one another in three dimensions.

***The 4 hydrogen atoms point to the vertices of a tetrahedron.***



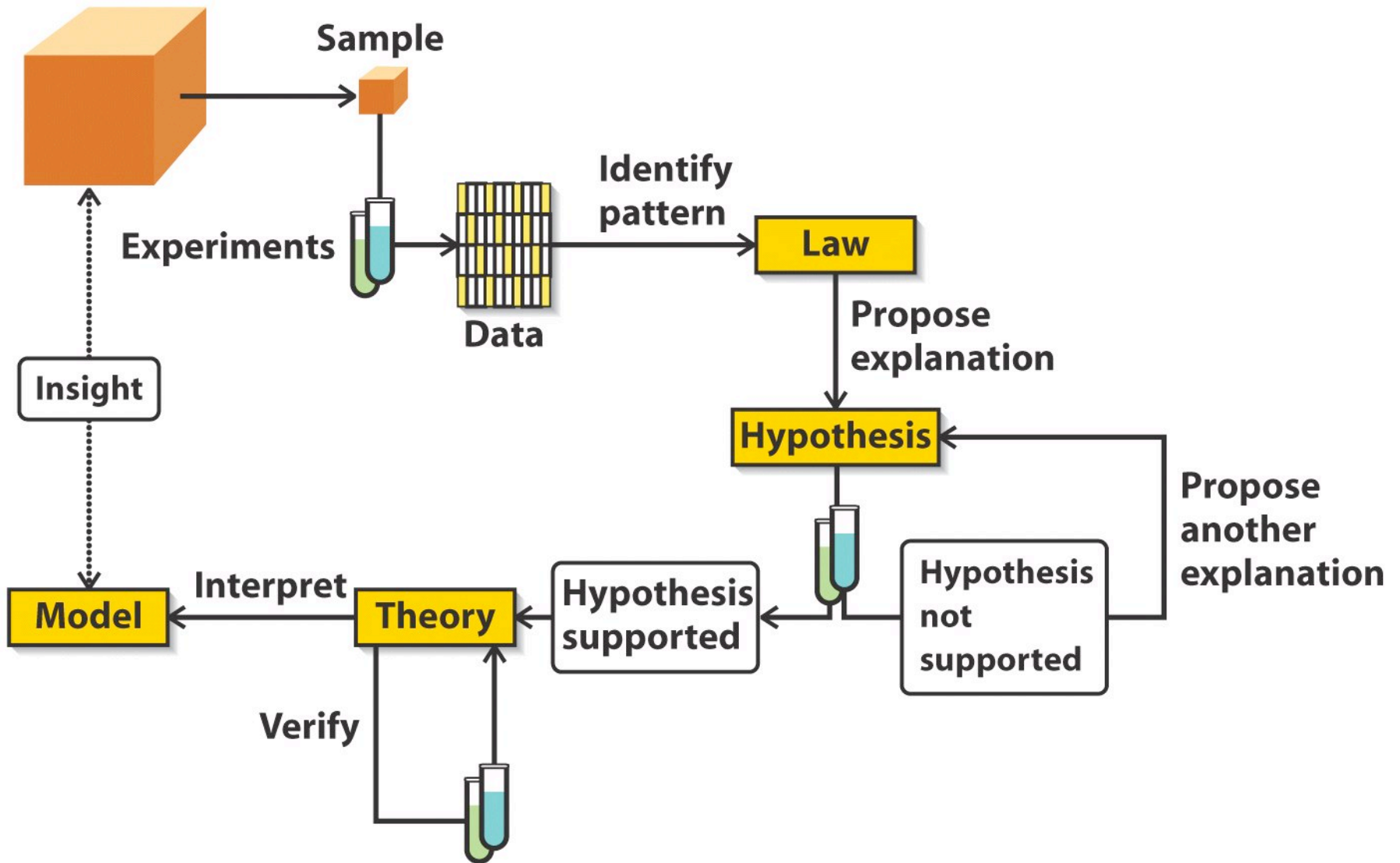
# Antoine Lavoisier: 1743-1794

He established the ***Law of Conservation of Mass*** by burning phosphorus and sulfur in air, and proving that the products weighed more than the original. The weight gained was lost from the air.

Repeating the experiments of Priestley, he demonstrated that air is composed of two parts, one of which combines with metals to form calxes. He named this portion oxygen (Greek for acid-former), and the other azote (Greek for no life). He also discovered that the inflammable air of Cavendish which he termed hydrogen (Greek for water-former), combined with oxygen to produce a dew, as Priestley had reported, which appeared to be water. ***He begins therefore a first systematic list of the elements.***




# Schematic description of the scientific process



## From atoms to the Periodic Table: Key ideas and proponents

Lucretius (400 BC)	Postulated atoms exist
1600-1800	Discovery of elements, compounds
Lavosier (1780)	Law of conservation of mass
Proust (1790)	Law of definite proportions of mass
Dalton (1800)	Atomic theory to explain laws of conservation and definite proportions
Gay-Lussac (1808)	Law of combining volumes of gases
Avogadro (1811)	Equal volumes of gases, equal particles
Cannizzaro (1860)	Scale of relative molecular weights
Mendeleev (1861)	Periodic table based on relative atomic weights

# IUPAC Periodic Table of the Elements

1													18					
1 <b>H</b> hydrogen 1.007 84(7)	2											2 <b>He</b> helium 4.002 602(2)						
Key:																		
atomic number																		
symbol																		
name																		
standard atomic weight																		
3 <b>Li</b> lithium 6.941(2)	4 <b>Be</b> beryllium 9.012 182(3)												5 <b>B</b> boron 10.811(7)	6 <b>C</b> carbon 12.0107(8)	7 <b>N</b> nitrogen 14.0067(2)	8 <b>O</b> oxygen 15.9994(3)	9 <b>F</b> fluorine 18.998 4032(5)	10 <b>Ne</b> neon 20.1797(6)
11 <b>Na</b> sodium 22.989 770(2)	12 <b>Mg</b> magnesium 24.3050(6)												13 <b>Al</b> aluminium 26.981 538(2)	14 <b>Si</b> silicon 28.0855(3)	15 <b>P</b> phosphorus 30.973 761(2)	16 <b>S</b> sulfur 32.065(5)	17 <b>Cl</b> chlorine 35.453(2)	18 <b>Ar</b> argon 39.948(1)
19 <b>K</b> potassium 39.0983(1)	20 <b>Ca</b> calcium 40.078(4)	21 <b>Sc</b> scandium 44.955 910(8)	22 <b>Ti</b> titanium 47.867(1)	23 <b>V</b> vanadium 50.9415(1)	24 <b>Cr</b> chromium 51.9961(6)	25 <b>Mn</b> manganese 54.938 045(6)	26 <b>Fe</b> iron 55.845(2)	27 <b>Co</b> cobalt 58.933 200(9)	28 <b>Ni</b> nickel 58.6934(2)	29 <b>Cu</b> copper 63.546(3)	30 <b>Zn</b> zinc 65.409(4)	31 <b>Ga</b> gallium 69.723(1)	32 <b>Ge</b> germanium 72.64(1)	33 <b>As</b> arsenic 74.921 60(2)	34 <b>Se</b> selenium 78.96(3)	35 <b>Br</b> bromine 79.904(1)	36 <b>Kr</b> krypton 83.798(2)	
37 <b>Rb</b> rubidium 85.4678(3)	38 <b>Sr</b> strontium 87.62(1)	39 <b>Y</b> yttrium 88.905 85(2)	40 <b>Zr</b> zirconium 91.224(2)	41 <b>Nb</b> niobium 92.906 38(2)	42 <b>Mo</b> molybdenum 95.94(2)	43 <b>Tc</b> technetium [97.9072]	44 <b>Ru</b> ruthenium 101.07(2)	45 <b>Rh</b> rhodium 102.905 50(2)	46 <b>Pd</b> palladium 106.42(1)	47 <b>Ag</b> silver 107.8682(2)	48 <b>Cd</b> cadmium 112.411(8)	49 <b>In</b> indium 114.818(3)	50 <b>Sn</b> tin 118.710(7)	51 <b>Sb</b> antimony 121.760(1)	52 <b>Te</b> tellurium 127.60(3)	53 <b>I</b> iodine 126.904 47(3)	54 <b>Xe</b> xenon 131.29(8)	
55 <b>Cs</b> caesium 132.905 45(2)	56 <b>Ba</b> barium 137.327(7)	57-71 <b>lanthanoids</b>	72 <b>Hf</b> hafnium 178.49(2)	73 <b>Ta</b> tantalum 180.9479(1)	74 <b>W</b> tungsten 183.84(1)	75 <b>Re</b> rhenium 186.207(1)	76 <b>Os</b> osmium 190.23(3)	77 <b>Ir</b> iridium 192.227(3)	78 <b>Pt</b> platinum 195.078(2)	79 <b>Au</b> gold 196.966 55(2)	80 <b>Hg</b> mercury 200.59(2)	81 <b>Tl</b> thallium 204.3833(2)	82 <b>Pb</b> lead 207.2(1)	83 <b>Bi</b> bismuth 208.980 38(2)	84 <b>Po</b> polonium [209.9824]	85 <b>At</b> astatine [209.9871]	86 <b>Rn</b> radon [222.0176]	
87 <b>Fr</b> francium [223.0197]	88 <b>Ra</b> radium [226.0254]	89-103 <b>actinoids</b>	104 <b>Rf</b> rutherfordium [261.1088]	105 <b>Db</b> dubnium [262.1141]	106 <b>Sg</b> seaborgium [266.1219]	107 <b>Bh</b> bohrium [264.12]	108 <b>Hs</b> hassium [277]	109 <b>Mt</b> meitnerium [268.1388]	110 <b>Ds</b> darmstadtium [271]	111 <b>Uuu</b> ununium [272]								
																		
57 <b>La</b> lanthanum 138.905(2)	58 <b>Ce</b> cerium 140.116(1)	59 <b>Pr</b> praseodymium 140.907 65(2)	60 <b>Nd</b> neodymium 144.24(3)	61 <b>Pm</b> promethium [144.9127]	62 <b>Sm</b> samarium 150.36(3)	63 <b>Eu</b> europium 151.964(1)	64 <b>Gd</b> gadolinium 157.25(3)	65 <b>Tb</b> terbium 158.925 34(2)	66 <b>Dy</b> dysprosium 162.500(1)	67 <b>Ho</b> holmium 164.930 32(2)	68 <b>Er</b> erbium 167.259(3)	69 <b>Tm</b> thulium 168.934 21(2)	70 <b>Yb</b> ytterbium 173.04(3)	71 <b>Lu</b> lutetium 174.967(1)				
89 <b>Ac</b> actinium [227.0277]	90 <b>Th</b> thorium 232.0381(1)	91 <b>Pa</b> protactinium 231.036 88(2)	92 <b>U</b> uranium 238.028 91(3)	93 <b>Np</b> neptunium [237.0482]	94 <b>Pu</b> plutonium [244.0642]	95 <b>Am</b> americium [243.0614]	96 <b>Cm</b> curium [247.0794]	97 <b>Bk</b> berkelium [247.0793]	98 <b>Cf</b> californium [251.0796]	99 <b>Es</b> einsteinium [252.0830]	100 <b>Fm</b> fermium [257.0951]	101 <b>Md</b> mendelevium [259.0984]	102 <b>No</b> nobelium [259.1018]	103 <b>Lr</b> lawrencium [262.1037]				

## Notes

- Aluminium and caesium are commonly used English-language spellings for aluminium and caesium.
- IUPAC 2001 standard atomic weights (mean relative atomic masses) are listed with uncertainties in the last figure in parentheses [R. D. Loss, *Pure Appl. Chem.* **75**, 1107-1122 (2003)]. These values correspond to current best knowledge of the elements in natural terrestrial sources. For elements with no IUPAC assigned standard value, the atomic mass (in unified atomic mass units) or the mass number of the nuclide with the longest known half-life is listed between square brackets.
- Element with atomic number 111 has not yet been named. The IUPAC provisional name is shown.
- Elements with atomic numbers 112, 114, and 116 have been reported but not fully authenticated.

## **Chapter 1: Learning goals concerning the atomic nature of matter**

- (1) Distinguish between elements, compounds and mixtures.**
- (2) Understand the atomic and molecular interpretation of elements, compounds and mixtures.**
- (3) Understand the Laws leading to the Dalton's atomic theory of matter (Conservation of mass and definite proportions).**
- (4) Understand the principles of Dalton's atomic theory.**
- (5) Understand the Law of combining volumes of gases.**
- (6) Understand Avogadro's hypothesis and Cannizzaro's proposal.**
- (7) Understand the mole concept.**

**Chapter 1: Some learning goals dealing with molecular structure and the relationship between weights of elements in a compound and the number of atoms in a formula.**

**(8) Distinguish between empirical formula, molecular formula, structural formula.**

**(9) Perform calculations employing the mole (the chemical amount) concept.**

## Chapter 1: Some learning skills and techniques:

- (1) Translate coefficients of a balanced chemical equation into moles. Obtain relative number of moles of reactants and products independent of the actual chemical amounts.
- (2) Translate coefficients into molecules. Obtain relative number of molecules of reactants and products independent of the actual chemical amounts.
- (3) Mass relationships in chemical reactions. Translate moles into grams (weight) or moles into liters (volume of gas).
- (4) Volume relationships in chemical reactions. Translate liters into moles.

## (1) Distinguish between elements, compounds and mixtures.

**Pure substance (an idealization):** A pure substance does not change its chemical characteristics upon exhaustive attempts of purification.

**Atomic interpretation:** A pure substance possesses a structure that is composed of a definite number and kinds of *atoms* that are connected in a specific manner.

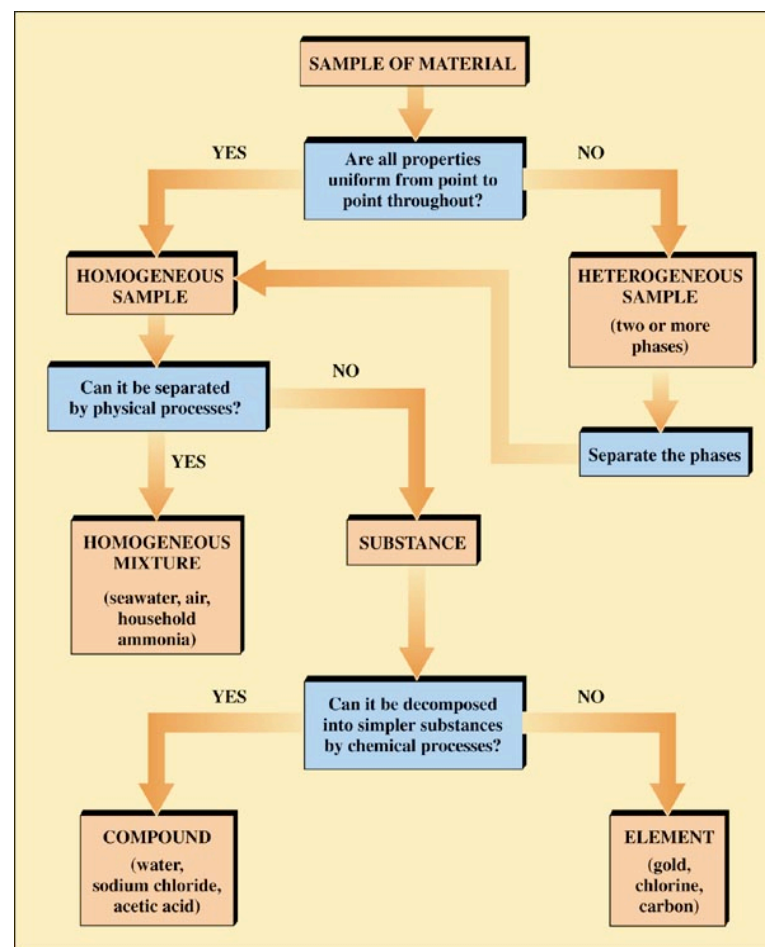
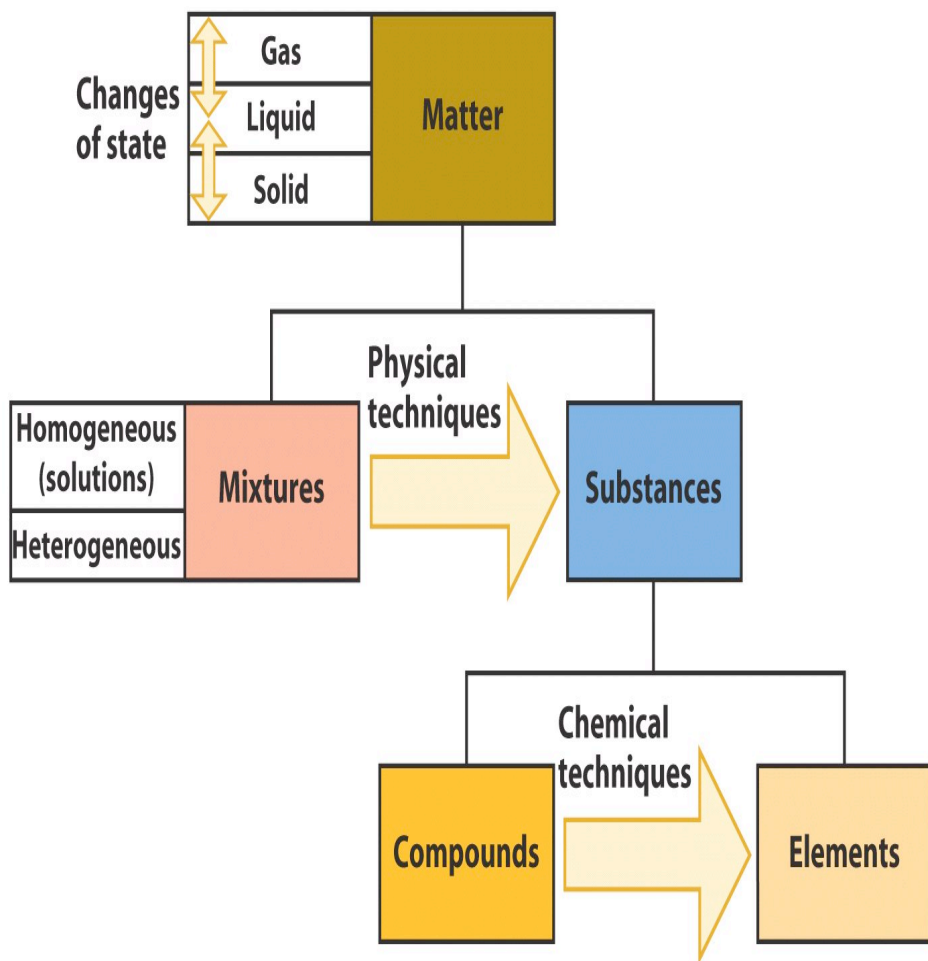
**Element:** An element is a substance which *cannot* be decomposed into simpler substances by chemical processes. Exemplars: hydrogen, carbon, oxygen.

**Atomic interpretation:** An element is a substance that contains only one kind of *atom*. Exemplars: Hydrogen (H) *atoms*, carbon *atoms* (C), oxygen *atoms* (O).

**Compound:** A compound is a substance that *can* be decomposed into simpler substances by chemical processes. Exemplars: water, carbon dioxide, carbon monoxide.

**Atomic interpretation:** A compound is a substance that contains *atoms* of two or more chemical elements. Exemplars: H, C, O.

# (Goal 1) Distinguish between elements, compounds and mixtures.



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## *The intellectual history of atomic theory.*

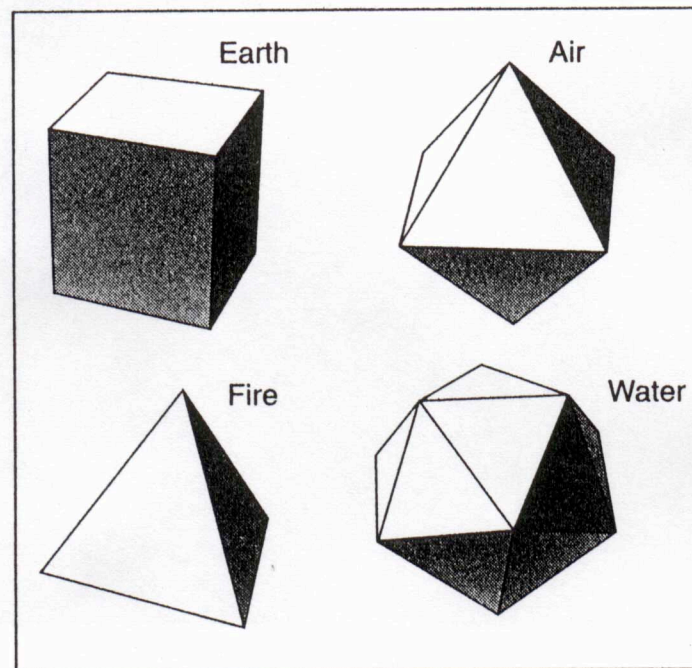
The ancient Greek philosophers attempted to reconcile the observation that natural objects are in a constant state of *change*, yet intuitively there is a *permanence* underlying the change.

Conjecture: The permanence reflects the existence of indestructible atoms, the change reflects the ever changing positions and motions of the atoms.

The atoms are constant, but their positions and motions change.

However, the Greek philosophers did not believe in measurements. They felt that the intellect trumped laboratory work!

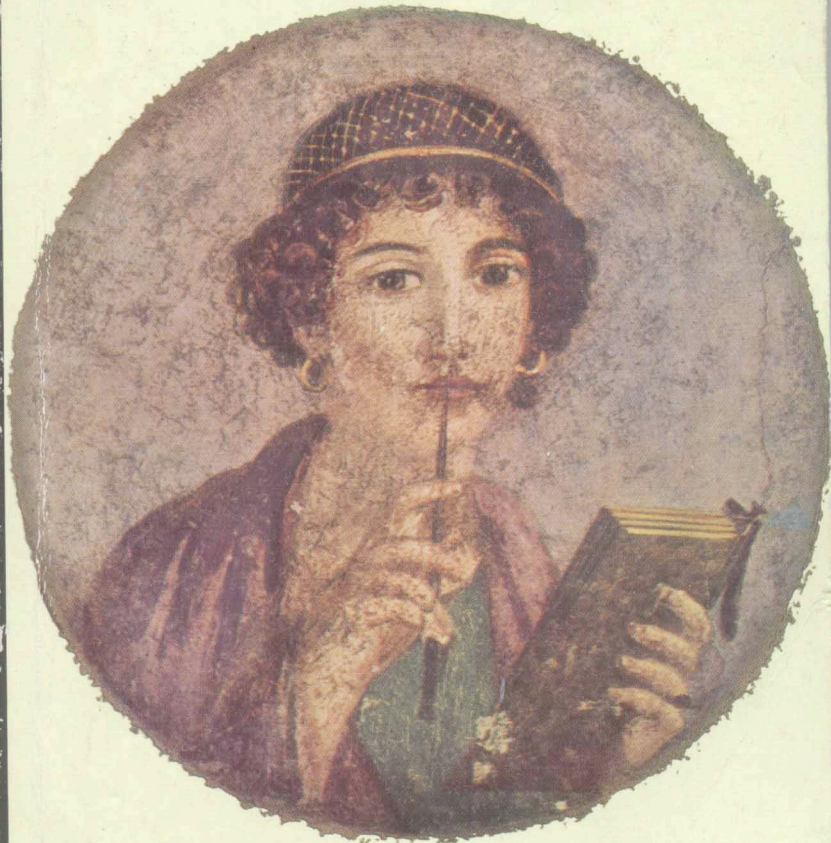
# The four elements of ancient times.



PENGUIN CLASSICS

LUCRETIUS

ON THE NATURE  
OF THE UNIVERSE



The existence of atoms is postulated by Lucretius in his poem: *De Rerum Natura* (100 BC).

"Pay attention, therefore, while I demonstrate that there exist certain bodies that are absolutely solid and indestructible, namely those *atoms* which according to our teaching are the seeds or prime units of things from which the whole universe is constructed."

## *(2) Understand the atomic and molecular interpretation of elements, compounds and mixtures*

**Element:** a molecule that contains only one type of atom.

**Examples:** Hydrogen molecules ( $H_2$ ), Oxygen molecules ( $O_2$ ), Ozone ( $O_3$ ), buckyballs ( $C_{60}$ ), Diamond ( $C_n$ ), Graphite ( $C_n$ ).

**Compound:** a molecule that contains two or more atoms.

**Examples:** Water ( $H_2O$ ), Hydrogen peroxide ( $H_2O_2$ ), Carbon monoxide ( $CO$ ), Carbon dioxide ( $CO_2$ ), glucose ( $C_6H_{12}O_6$ ).

**Mixture:** a combination of two or more elements or compounds.

**Examples:** Brass ( $Cu + Zn$ ), Salt water ( $NaCl + H_2O$ )

**Remember:** A pure substance can only be an element or a compound. The word material is a term to refer to a sample of unknown composition and may be a pure substance or mixture.

### (3) Understand the Laws leading to the Dalton's atomic theory of matter: from Laws (observations) to structures

**Law:** A scientific law is a summary of a large number of scientific facts in a compact yet broad and sweeping statement.

**Law of conservation of mass:** Mass is neither created nor destroyed during a chemical reaction.

**Exemplar:** 4.0 g of hydrogen + 32.0 g of oxygen = 36.0 g of water

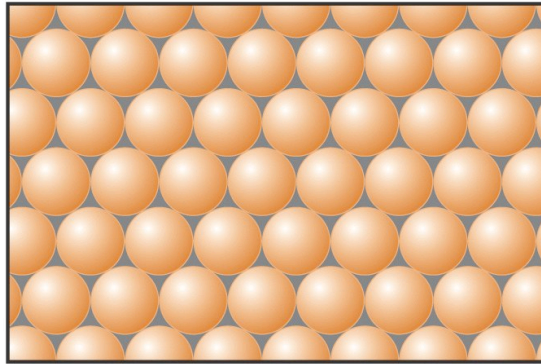
**Law of definite proportions:** In a pure compound, the constituent elements are always present in a definite proportion or % by weight. The relative weights are fixed.

**Exemplar:** Pure water is always in the ratio of 11.1 % H and 88.9 % O, no matter what the source or method of preparation.

# All States of Matter Are Made of Atoms and Molecules

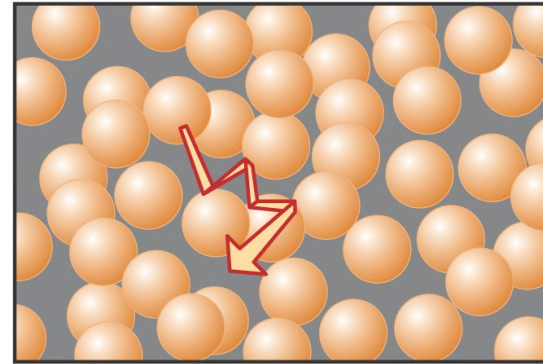
## Densities of Molecules:

(a) *Dense, Well-Packed and Mostly Stationary. **Solid***

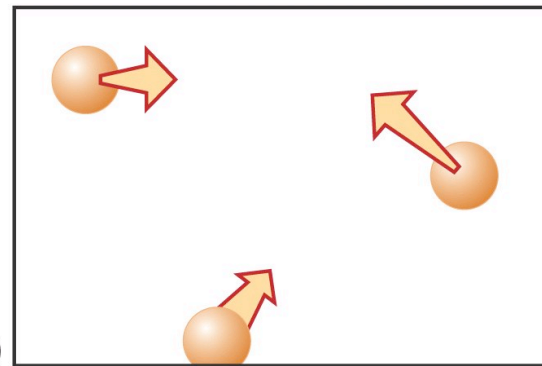


(a)

*Dense but Fluid: **Liquid***



(b)



(c)

(c) *Rare, or Low: **Gas***  
Gas: mainly empty space

## (4) Understand the principles of Dalton's atomic theory.

Dalton developed an atomic theory to explain two Laws:

- (1) The Law of conservation of mass during a chemical reaction: Mass is neither created nor destroyed in a chemical reaction.
- (2) The Law of definite proportions of weights of elements in a compound: the ratio of weights of elements are the same in all pure compounds.

## *Dalton's Atomic Theory of Matter.*

- (1) All matter consists of indestructible *atoms* possess mass.
- (2) All *atoms* of a given element are identical in mass and other properties.
- (3) Different **elements** have different kinds of *atoms*. The mass of different atoms are different.
- (4) The properties of *atoms* are unchanged when they are involved in chemical transformations (*Law of conservation of mass = conservation of atoms*).
- (5) **Compounds** are formed from **elements** when *atoms* of unlike elements combine (*Law of definite proportions = when a fixed number of different atoms combine their numbers and weights are in definite relative proportions*).
- (6) Deduction: More than one compound can be formed by the combination of two different *atoms*. (*Implies a Law of multiple proportions = combinations of two different atoms sometimes occur in small whole numbers, e.g., NO, N<sub>2</sub>O, NO<sub>2</sub>*).

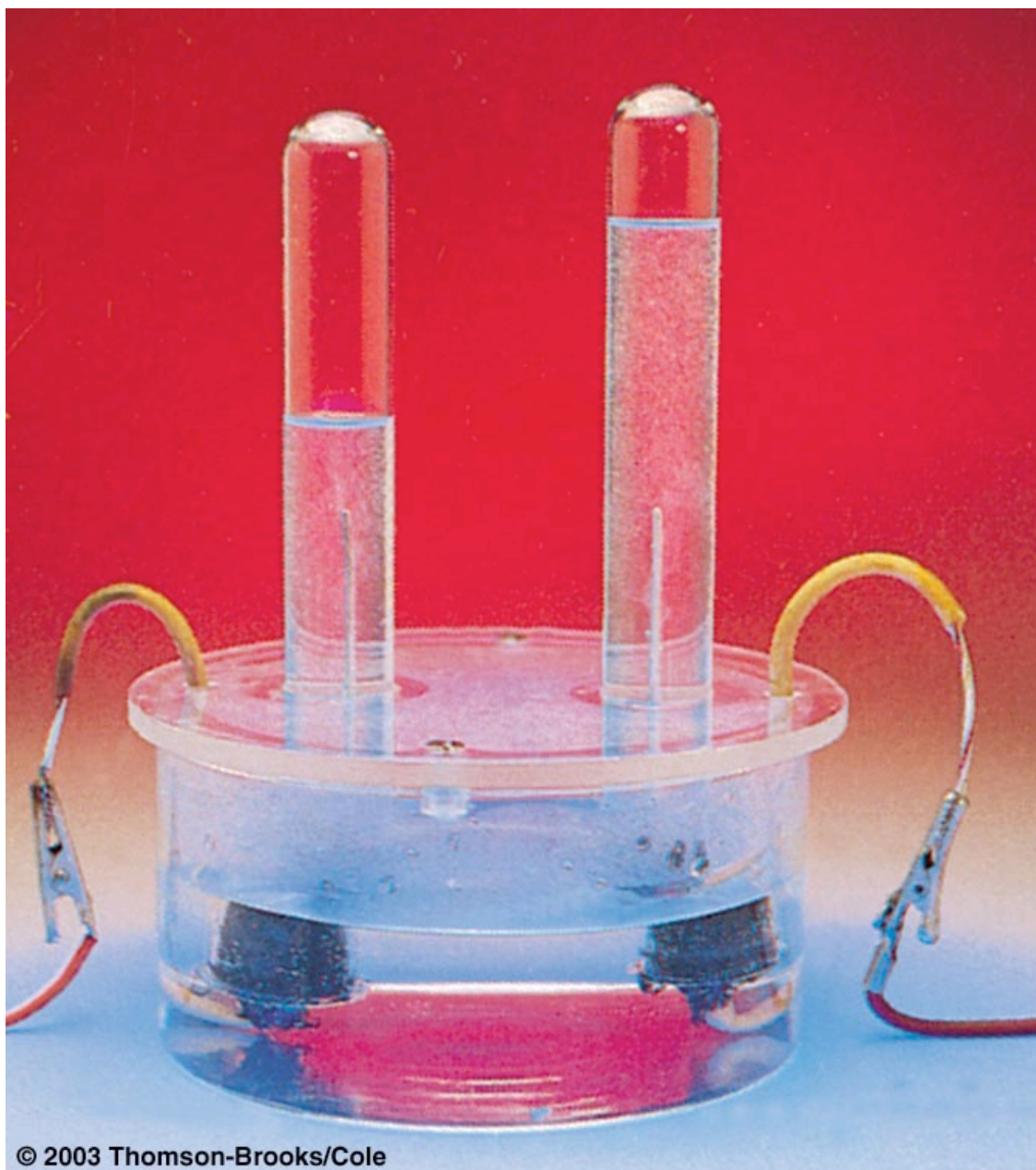
## Example of the Law of multiple proportions

Three binary compounds of H and O:  $\text{H}_2\text{O}$ ,  $\text{H}_2\text{O}_2$ ,  $\text{H}_2\text{O}_3$

Common Name	%H	%O	Moles H in 100 g of substance	Moles O in 100g	Molar Ratio H/O	Empirical Formula	Molecular Formula
Water	11%	89%	11 mol (11g/1 gmol <sup>-1</sup> )	5.6 mol (89g/16 gmol <sup>-1</sup> )	1.95 ~ 2/1	H <sub>2</sub> O	H <sub>2</sub> O
Hydrogen Peroxide	6.0%	94%	6.0 mol (6g/1 gmol <sup>-1</sup> )	5.9 mol (94g/16 gmol <sup>-1</sup> )	1.01 ~ 1/1	HO	H <sub>2</sub> O <sub>2</sub>
Hydrogen Trioxide	4.0%	96%	4.0 mol (4g/1 gmol <sup>-1</sup> )	6.0 mol (96g/16 gmol <sup>-1</sup> )	.0.67 ~ 2/3	H <sub>2</sub> O <sub>3</sub>	H <sub>2</sub> O <sub>3</sub>

Four binary compounds of N and O:  $\text{NO}$ ,  $\text{N}_2\text{O}$ ,  $\text{NO}_2$ ,  $\text{N}_2\text{O}_2$

Common Name	%N	%O	Moles N in 100 g of substance	Moles O in 100g	Molar Ratio N/O	Empirical Formula	Molecular Formula
Nitric Oxide	47%	53%	3.4 (47g/14gmol <sup>-1</sup> )	3.3 (53g/16 gmol <sup>-1</sup> )	1.03 ~ 1/1	NO	NO
Nitrous Oxide	64%	36%	4.6 (64g/14 gmol <sup>-1</sup> )	2.3 (36g/16 gmol <sup>-1</sup> )	2.0 ~ 2/1	N <sub>2</sub> O	N <sub>2</sub> O
Nitrogen Dioxide	30%	70%	2.1 (30g/14 gmol <sup>-1</sup> )	4.4 (70g/16 gmol <sup>-1</sup> )	0.48 ~ 1/2	NO <sub>2</sub>	NO <sub>2</sub>
Dinitrogen Dioxide	47%	53%	3.4 (47g/14 gmol <sup>-1</sup> )	3.3 (53g/16 gmol <sup>-1</sup> )	1.03 ~ 1/1	NO	N <sub>2</sub> O <sub>2</sub>



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## The electrolysis of water.

The tube on the left is hydrogen gas and the tube on the right is oxygen gas. The ratio of the volume of hydrogen gas to the volume of oxygen gas is exactly 2:1.

What does this tell us about the composition of water?

## **(5) Understand the Law of combining volumes of gases.**

The volumes of gases taking part in a chemical reaction show simple whole number ratios to one another (when measurements are made at the same T and P).

**Exemplars:**

1 L of nitrogen gas + 3 L of hydrogen gas yields

2 L of ammonia gas.

Volume ratio: 1:3:2

2 L of hydrogen gas + 1 L of oxygen gas yields 2 L of water gas

Volume ratio: 2:1:2

1 L of hydrogen gas + 1 L of chlorine gas yields

2 L of hydrogen chloride gas Volume ratio: 1:1:2

6) Understand Avogadro's hypothesis or Law (interpretation of the Law of combining gases).

**Equal volumes** of any gas (measured at the same temperature and volume) contain **equal numbers of "particles"**.

The quotes are put about "particles" because Avogadro did not want to differential between atoms and molecules as particles.

The remarkable feature of this hypothesis is that it implies that the size or weight of the particle is irrelevant to the space that the particle occupies in the gas phase!

A way to understand this peculiar feature of gases is to note that the gas phase is mainly empty space and that the space taken up by a particle is due to its motion. The particle may be viewed as a three dimensional "spring" that takes up as much space as possible in the presence of other springs of exactly the same size (same motion).

## Avogadro's interpretation of the combining gas Law:

### Exemplars:

1 L of nitrogen gas + 3 L of hydrogen gas yields 2 L of ammonia gas

Mole ratio same as volume ratio: 1:3:2

**Atomic interpretation:**  $1 \text{ N}_2 + 3 \text{ H}_2 \rightarrow 2 \text{ NH}_3$

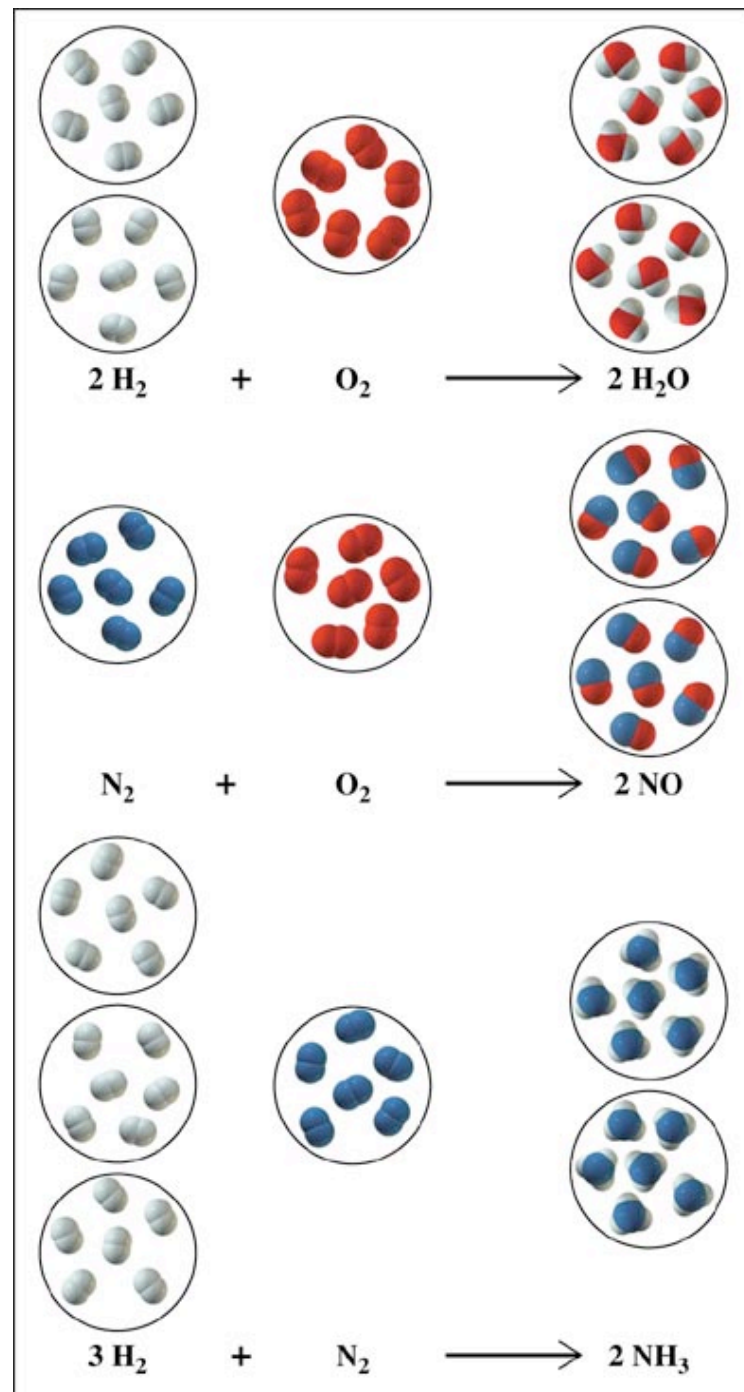
2 L of hydrogen gas + 1 L of oxygen gas yields 2 L of water gas  
Mole ratio same as volume ratio: 2:1:2

**Atomic interpretation:**  $2 \text{ H}_2 + 1 \text{ O}_2 \rightarrow 2 \text{ H}_2\text{O}$

(a) Atomic and molecular interpretation of the Law of combining volumes.

Imagine that each circle in the figure on the right represents a container of the same volume. The containers hold different gases (molecules) but *equal number of molecules*. The reactants are all gases elements which happen to be diatomic molecules.

As the result of reaction, *the number of atoms does not change, but the number molecules (the volume of the gases) may change depending on the molecular composition of the products.*

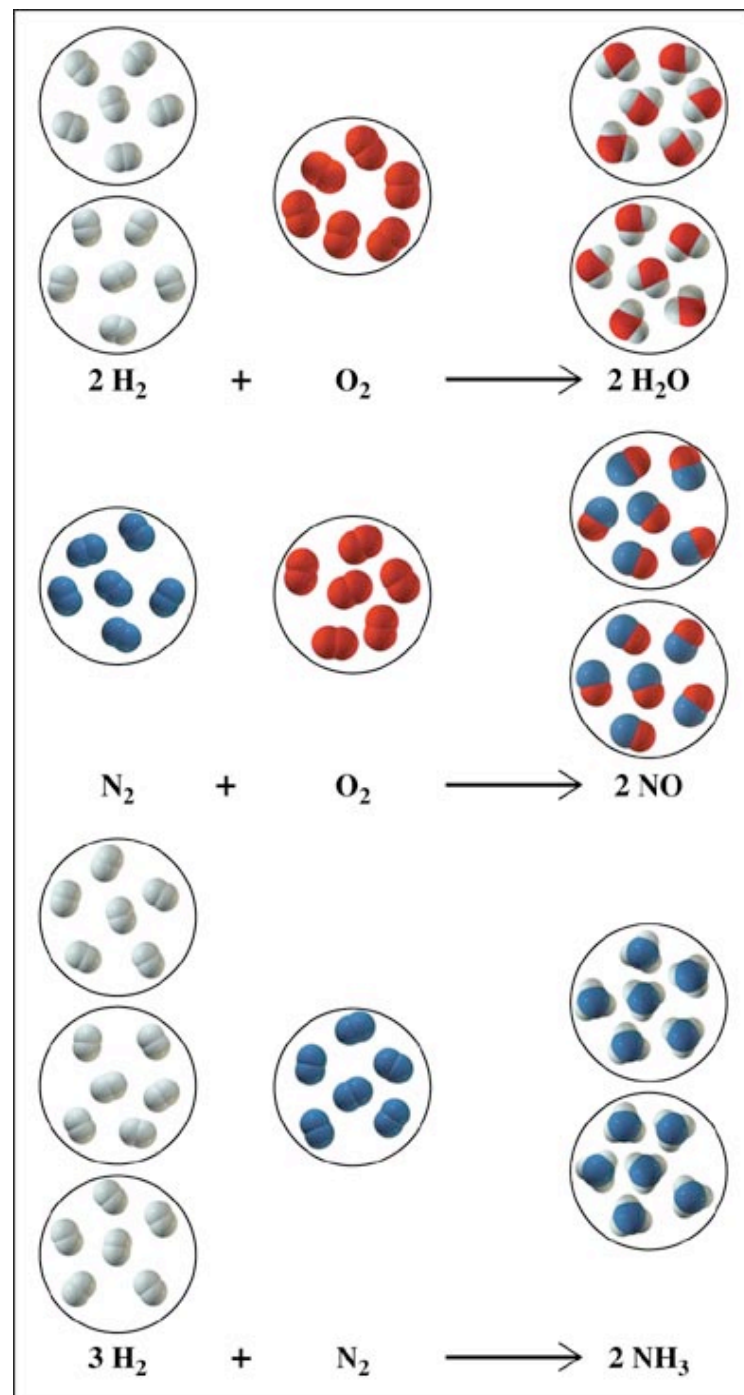


*(b) Relative molecular weights  
from the weights of equal volumes of  
gases*

Cannizzaro: The weights of equal volumes of gases are proportional to the relative particle weights (atomic or molecular weights)

Thought process: the composition of a molecule of a gas must possess a whole integral number of the atoms of the elements that make up the molecule.

Relate the weights of the gases to an equal volume of hydrogen. Relative weights of equal volumes provide relative weights of molecules!





*Amedeo Avogadro*



Stanislao Cannizzaro

From experiment it was determined that one mole of hydrogen gas weights 2 g and that 2 g of hydrogen gas occupies 22.4 L under standard conditions. Conclude: under standard conditions one mole of any gas occupies 22.4 L. The relative weights of 22.4 L of any gas reflect the relative molecular weights of the molecules that make up the gas!