Department of Mathematics and Natural Sciences

CHE 101: Introduction to Chemistry

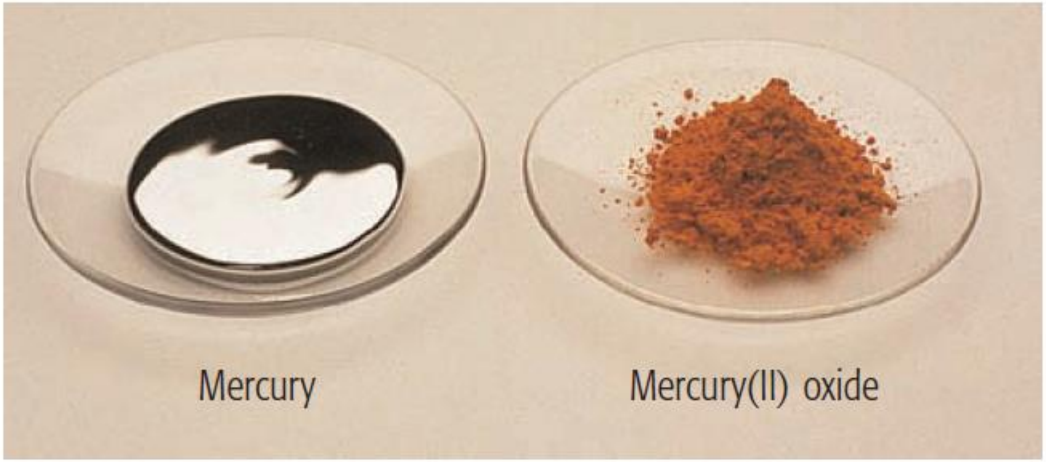
Lecture 1

Content: Structure of atom, isotopes, isobar & isotones

Modern Chemistry: Law of Conservation of Mass

- Modern chemistry emerged in the eighteenth century, when chemists began to use the balance systematically as a tool in research.
- Matter is whatever occupies space and can be perceived by our senses
- Antoine Lavoisier (1743–1794), a French chemist, was one of the first to insist on the use of the balance in chemical research.
- By weighing substances before and after chemical change, he demonstrated the law of conservation of mass
- In a series of experiments, Lavoisier applied the law of conservation of mass to clarify the phenomenon of burning, or combustion.

The law of conservation of mass says that matter is not created or destroyed in a closed system. That means if we have a chemical reaction, the amount of each element must be the same in the starting materials and the products. We use the law of conservation of mass every time we balance equations!

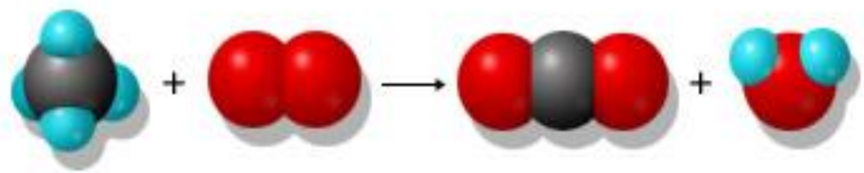


Heating mercury metal in air

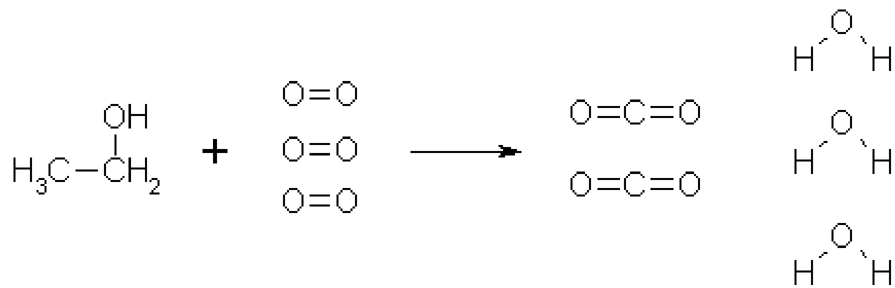
Mercury + oxygen $\longleftrightarrow$ mercury(II) oxide

Heated mercury(II) oxide

$$CH_4 + O_2 \longrightarrow CO_2 + H_2O$$



Reactants		Products
1 C atom	=	1 C atom
4 H atoms	≠	2 H atoms
2 O atoms	≠	3 O atoms



Many scientists used to believe an experiment such as this one demonstrated that mass could be destroyed, since there was less mass in the beaker after the reaction compared to the starting materials. However, they forgot one important point: the system should be closed if you want to check for conservation of mass! In this case, the products of our combustion reaction are $CO_2(g)$ & $H_2O(g)$, so we would need to be very careful to collect the gaseous products to test if mass is conserved.

Matter

- general term for the material things around us; we can define it as whatever occupies space and can be pereived by our senses

There are two principal ways of classifying matter:

- by its physical state (solid, liquid, or gas)
- by its chemical constitution (element, compound, or mixture)

Matter Classification by Physical State

Three common states of matter can be defined by two characteristics, ,:

- rigidity (or fluidity) and
- compressibility (or expansibility)

Solid:

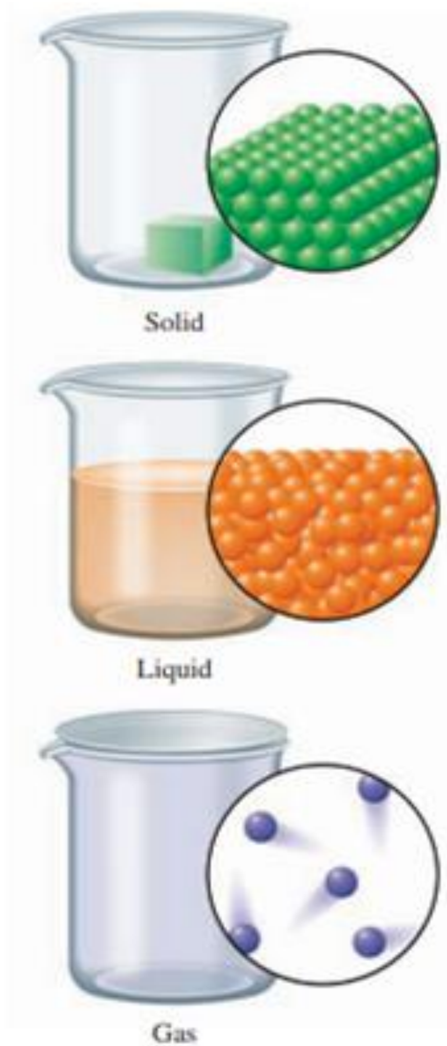
- characterized by rigidity;
- relatively incompressible with fixed shape and volume.

Liquid:

- relatively incompressible fluid;
- has a fixed volume but no fixed shape.

Gas:

- easily compressible fluid;
- a given quantity of gas will fit into a container of almost any size and shape w.



Matter Classification by Chemical Constitution

- first distinguish between physical and chemical changes and between physical and chemical properties.

- A physical change is a change in the form of matter but not in its chemical identity.

- A chemical change, or chemical reaction, is a change in which one or more kinds of matter are transformed into a new kind of matter or several new kinds of matter.

Matter

Physical property:

- is a characteristic that can be observed for a material without changing its chemical identity.

- Examples are physical state (solid, liquid, or gas), melting point, and color.

Chemical property :

- a characteristic of a material involving its chemical change.

- A chemical property of iron is its ability to react with oxygen to produce rust


Na
Cl
I am freaking
exploding after
contact with water
I've killed hundreds
of thousands people
during WWI
Our child is going to be ultimate badass
NaCl
soup is too salty

Matter Classification by Chemical Constitution

Potassium is a soft, silvery-colored metal that melts at 64 C. It reacts vigorously with water, with oxygen, and with chlorine.

- Identify all of the physical properties given in this description.
- Identify all of the chemical properties given.

Matter

Substances:

- The various materials we see around us are either substances or mixtures of substances.
- A substance is a kind of matter that cannot be separated into other kinds of matter by any physical process.
- when sodium chloride is dissolved in water, it is possible to separate the sodium chloride from the water by the physical process of distillation.
- However, sodium chloride is itself a substance and cannot be separated by physical processes into new materials. Similarly, pure water is a substance.

Requires lots of heat

- No matter what its source, a substance always has the same characteristic properties. Sodium is a solid metal having a melting point of 98^0 C.

Matter

Elements

Physical + chemical -
none can break it

- Millions of substances have been characterized by chemists.
- Of these, a very small number are known as elements, from which all other substances are made.
- Lavoisier was the first to establish an experimentally useful definition of an element.
- He defined an element as "a substance that cannot be decomposed by any chemical reaction into simpler substances."
- In 1789 Lavoisier listed 33 substances as elements, of which more than 20 are still so regarded. Today 116 elements are known.

Changes by chemical reaction only

Matter

Compounds:

- Most substances are compounds.
- A compound is a substance composed of two or more elements chemically combined.
- By the end of the eighteenth century, Lavoisier and others had examined many compounds and showed that all of them were composed of the elements in definite proportions by mass.
- Joseph Louis Proust (1754–1826), by his painstaking work, convinced the majority of chemists of the general validity of the law of definite proportions (also known as the law of constant composition):
- a pure compound, whatever its source, always contains definite or constant proportions of the elements by mass.

The law of constant composition says that a pure compound will always have the same proportion of the same elements. For example, table salt, which has the molecular formula, NaCl, contains the same proportions of the elements sodium and chlorine no matter how much salt you have or where the salt came from.

Again, any water molecule is always made up of two hydrogen atoms and one oxygen atom in a 2:1 ratio. If we look at the relative masses of oxygen and hydrogen in a water molecule, we see that 88.81% of the mass of a water molecule is accounted for by oxygen and the remaining 11.19% is the mass of hydrogen. This mass proportion will be the same for any water molecule.

This does not mean that hydrogen and oxygen always combine in a 2:1 ratio to form H_2O. Multiple proportions are possible. For example, hydrogen and oxygen may combine in different proportions to form H_2O_2 rather than H_2O. In H_2O_2, the H:O ratio is 1:1 and the mass ratio of hydrogen to oxygen is 1:16. This will be the same for any molecule of hydrogen peroxide.

Matter

Mixtures

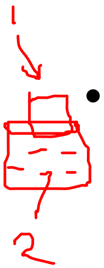
- Most of the materials around us are mixtures.
- A mixture is a material that can be separated by physical means into two or more substances.
- Unlike a pure compound, a mixture has variable composition.
- Mixtures are classified into two types.
- A heterogeneous mixture is a mixture that consists of physically distinct parts, each with different properties

Salt+ sand

- A homogeneous mixture (also known as a solution) is a mixture that is uniform in its properties throughout given samples. When sodium chloride is dissolved in water, you obtain a homogeneous mixture, or solution.

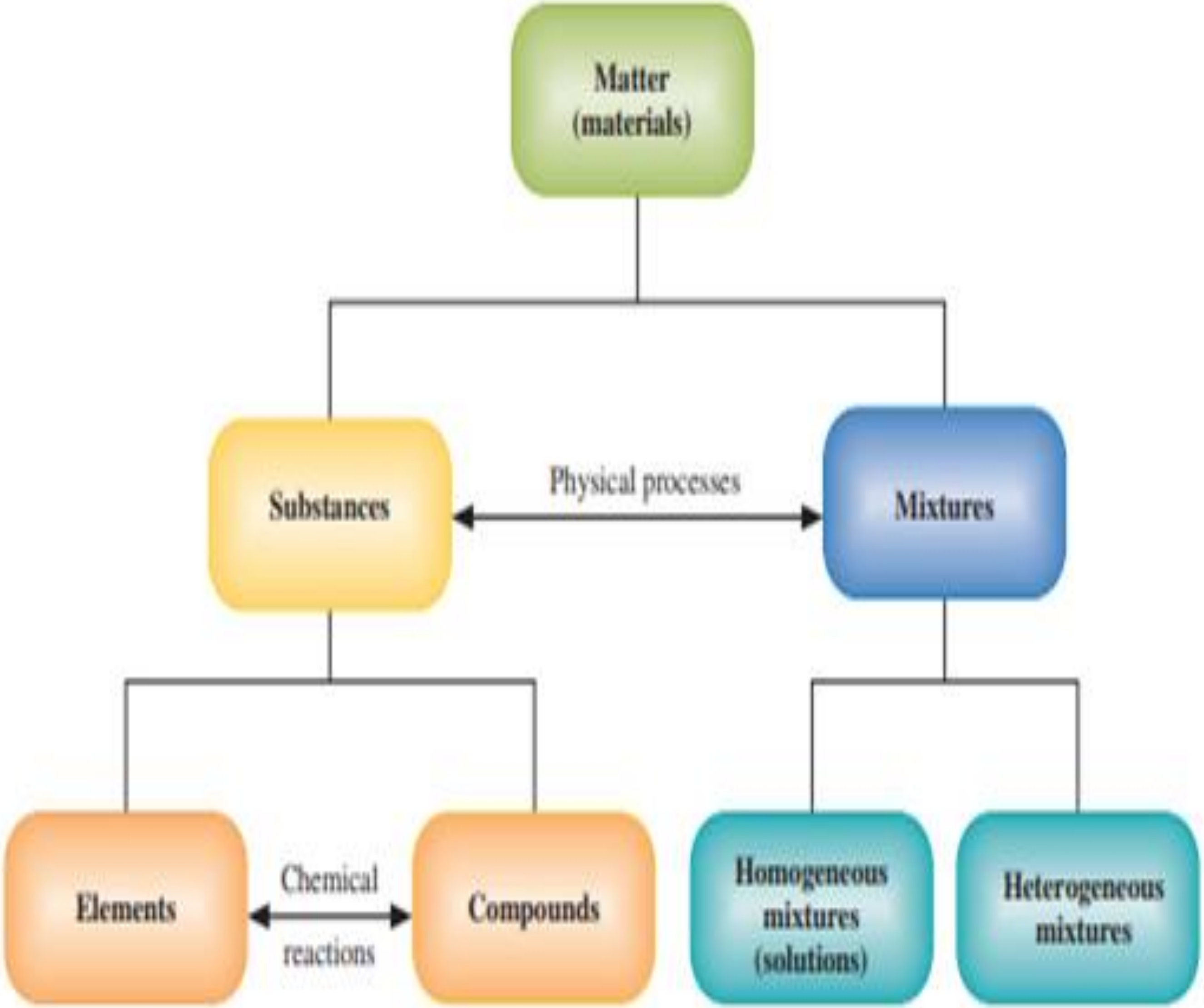
Matter: Phase

- A phase is one of several different homogeneous materials present in the portion of matter under study.
- A heterogeneous mixture of salt and sugar is said to be composed of two different phases: one of the phases is salt; the other is sugar.

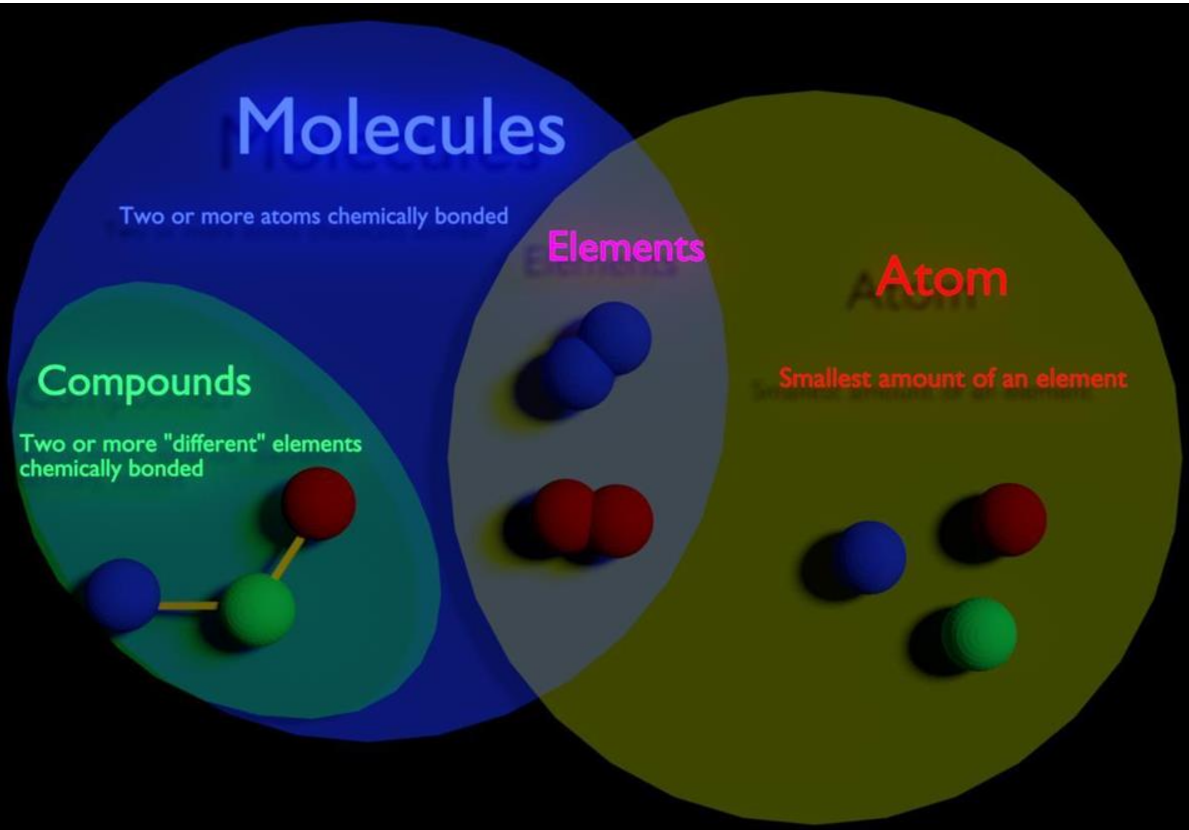


- Similarly, ice cubes in water are said to be composed of two phases: one phase is ice; the other is liquid water.
- Ice floating in a solution of sodium chloride in water also consists of two phases, ice and the liquid solution.
- A phase may be either a pure substance in a particular state or a solution in a particular state (solid, liquid, or gaseous).
- Also, the portion of matter under consideration may consist of several phases of the same substance or several phases of different substances

Matter



Matter
(materials)
Substances
Physical processes
Mixtures
Elements
Chemical
reactions
Compounds
Homogeneous
mixtures
(solutions)
Heterogeneous
mixtures



Elements : a substance consisting of atoms which all have the same number of protons.

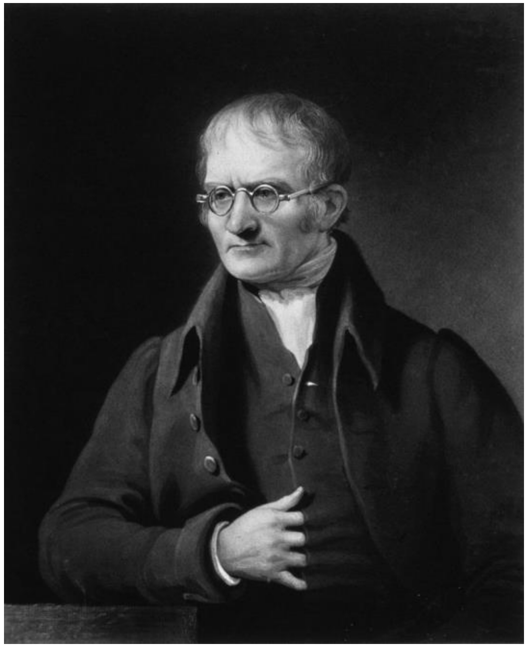
Substance : is matter which has a specific composition and specific properties.

Atomic theory of Matter

- Lavoisier laid the experimental foundation of modern chemistry.
- But the British chemist John Dalton (1766–1844) provided the basic theory:

"all matter—whether element, compound, or mixture—is composed of small particles called atoms"

John Dalton 1766-1844

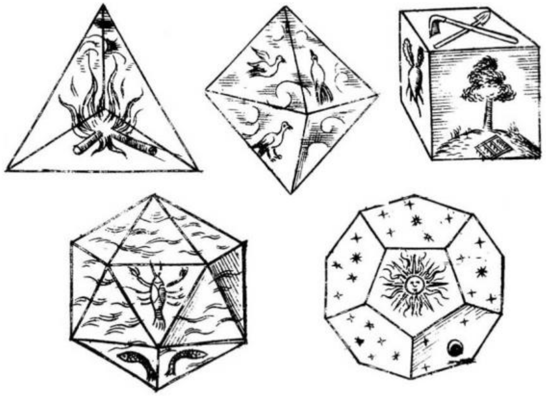


Royal Medal in Physics
1826

"For his development of the Atomic Theory and his other important labours and discoveries in Physical Science."

Dalton's Atomic Theory

- Democritus first suggested the existence of the atom
- but it took almost two millennia before the atom was placed on a solid foothold as a fundamental chemical object by John Dalton (1766-1844).
- Although two centuries old, Dalton's atomic theory remains valid in modern chemical thought.
- Dalton based his theory on two laws: **the law of conservation of mass** and the **law of constant composition.**



Postulates of Dalton's Atomic Theory

1. All matter is composed of minute particles called atoms. An atom is an extremely small particles of matter that keeps retains its identity during chemical reaction. These atoms are indivisible and indestructible.

2. An element is a type of matter composed of only one kind of atom, each atom of a given kind having the same properties. Mass is one such property. Thus, the atoms of a given element have a characteristic mass.

3. The properties and masses of atoms of different substances are different.

Postulates of Dalton's Atomic Theory

constsant composition law

4. A compound is a type of matter composed of atoms of two or more elements chemically combined in fixed proportions.

Water, for example, a compound of the elements hydrogen and oxygen, consists of hydrogen and oxygen atoms in the ratio of 2 to 1.

5. A chemical reaction consists of the rearrangement of the atoms present in the reacting substance to give new chemical combinations present in the substances formed by the reaction.

So only atoms take part in chemical reaction. Atoms are not created, destroyed, or broken into smaller particles during a chemical reaction.

Deductions from Dalton's Atomic Theory

- atomic theory explains the difference between an element and a compound.
- also explains two laws we considered earlier.
- A good theory should not only explain known facts and laws but also predict new ones.

The law of multiple proportions:

- deduced by Dalton from his atomic theory, states that

"when two elements form more than one compound, the masses of one element in these compounds for a fixed mass of the other element are in ratios of small whole number"

H_2O 1 : 2

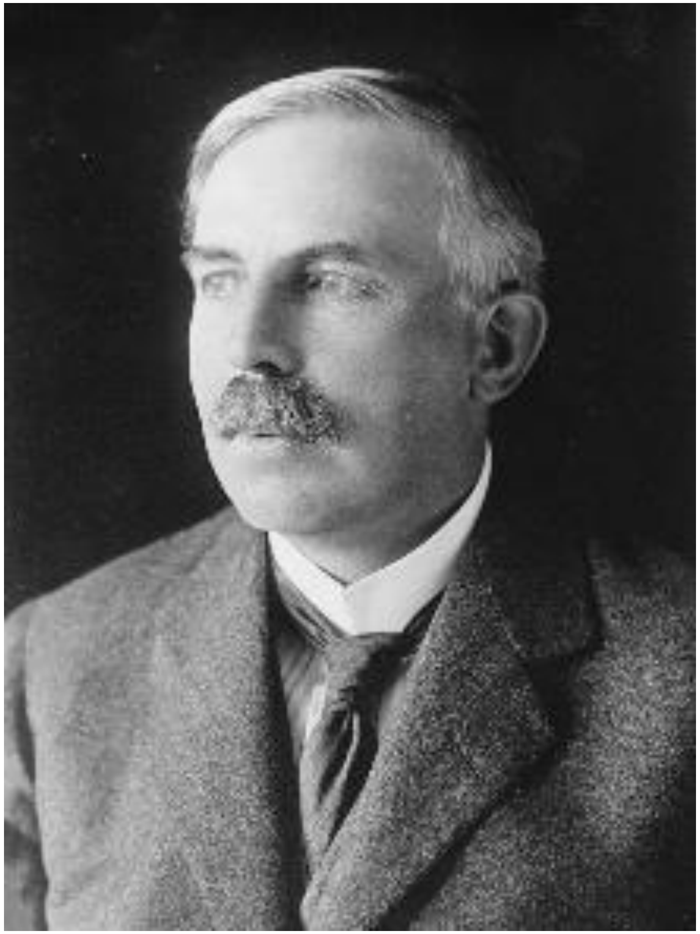
H_2O_2 1 : 1

J J Thomson 1856-1940

Nobel Prize in Physics 1906

"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases."

Earnest Rutherford
1871-1937



Nobel Prize in Chemistry 1908

"for his investigations into the disintegration of the elements, and the chemistry of radioactive substances."

James Chadwik 1891-1974

Nobel Prize in Physics 1935

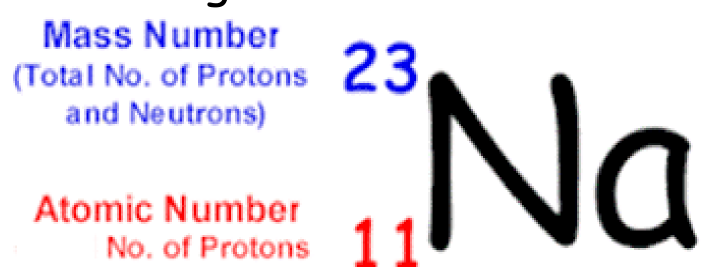
"for the discovery of the neutron."

Some related terms

Atomic number: It is the number of protons in the nucleus of an atom.
The number of protons and electrons are equal in an atom as they are electrically neutral. So it can also be defined by the total number of electrons in the atom.

Atomic mass or mass number: It is the total number of protons and neutrons in a nucleus.

Nuclide: Nuclide is an atom characterized by definite atomic number and mass number.
The symbol for naturally occurring sodium nuclide is as follows:



Here, the atomic number is written as subscript and mass number is written as superscript. Atomic number of Na is 11, that is Na has 11 proton.
As the number of proton and electron in an atom is equal, so Na has 11 electron.
The number of neutron in Na is = 23 – 11 = 12

If the following element has 20 electrons at present, the neutrons in the atom are-

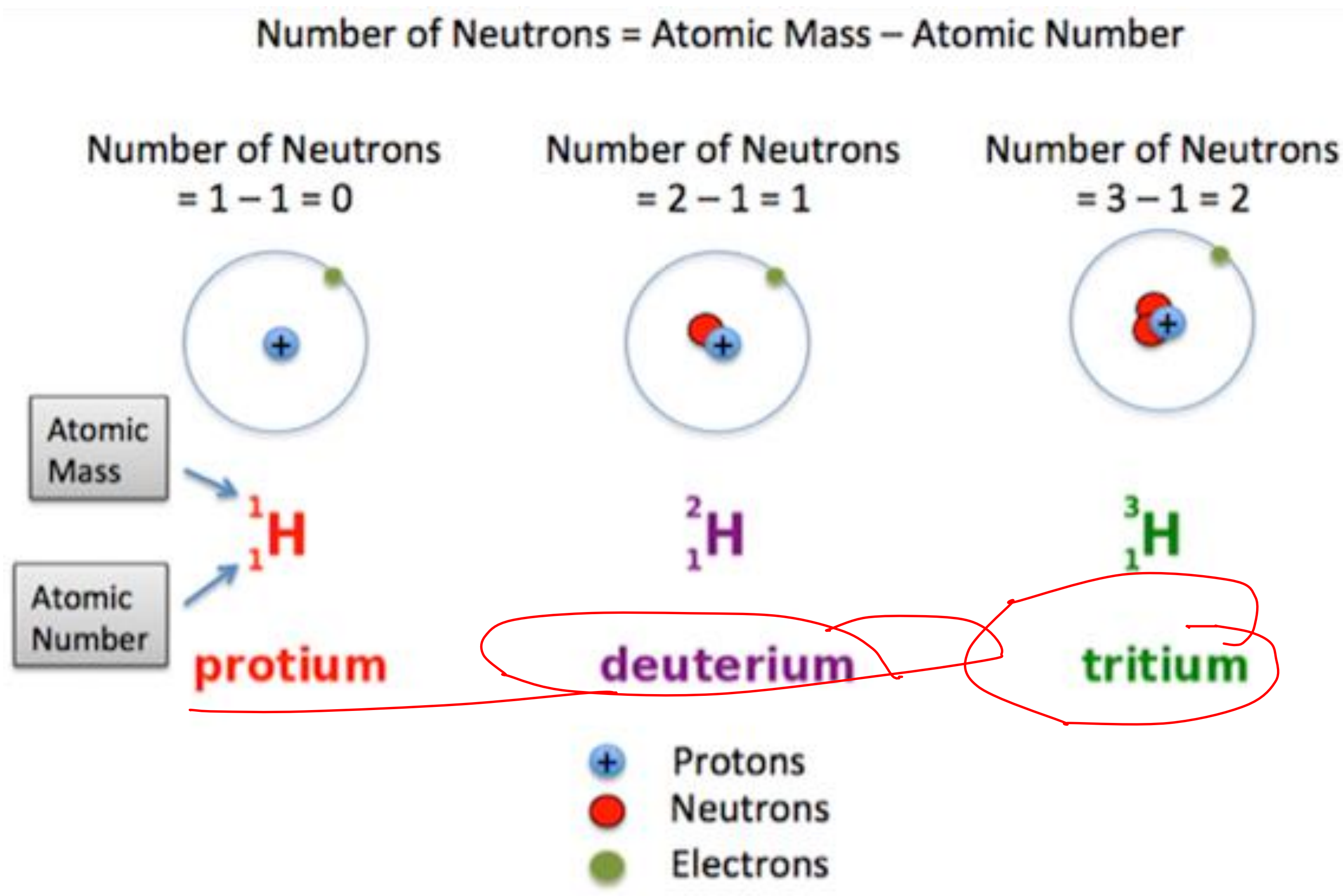
20+3

$$^{48}_{x}Q^{3+}$$

What is the nuclide symbol for a nucleus that contains 38 protons and 50 neutrons?

Isotopes

The atoms having same atomic/proton number but different atomic mass number are called **isotopes**.



Isotopes of Hydrogen

Isobars

Atoms of different elements having same mass number but different proton/atomic number are called **Isobars**.

Example:

$^{58}_{26}Fe$ $^{58}_{27}Ni$ Th^{228}_{90} Ra^{228}_{88}

$^{76}_{32}Ce$ $^{76}_{34}Se$

Isotones

Atoms of different elements having different mass number and different atomic number but same neutron number are called Isotones

Example:

Oxygen $^{16}_{8}O$ (p=8; n=8)

Nitrogen $^{15}_{7}N$ (p=7; n=8)

Carbon $^{14}_{6}C$ (p=6; n=8)

Are isotones because of having same number of neutron (8)

Limitations of Dalton's Atomic Theory

- According to Dalton theory atoms are indivisible. Now it is established that atoms are divisible into fundamental particles-proton, neutron and electron.

- Atoms of same elements have same mass according to Dalton. But isotopes show that atoms of same element can have different masses. Hydrogen has three isotopes having masses of 1, 2 and 3 units.

- Dalton said that atoms of different elements will have different masses. After the discovery of isobars, we see that atoms of different elements can have same masses. Example: Tellurium (atomic number 52) and iodine (atomic number 53) have same atomic mass 127.

- Dalton called atom to be the smallest part of both element and compound. But now it is known that atoms are smallest part of an element that can exist in free state and molecules are smallest part of compound. Dalton did not show any difference between an atom and a molecule.

- All atoms are made of three subatomic particles

- **Electrons, protons and neutrons**

Particle	Actual Charge	Actual Mass	Position	Discovered by
Electron	-1.6×10^{-19} C	9.1x10-28 g	Orbit	J.J Thomson -1897
Proton	$+1.6\times10^{-19}$ C	1.673x10-24 g	Nucleus	Ernest Rutherford -1919
Neutron	0	1.675x10-24 g	Nucleus	James Chadwick- 1932

What does an atom look like?

- Protons and neutrons are held together rather closely in the center of the atom. Together they make up the nucleus, which accounts for nearly all of the mass of the atom.
- Electrons move rapidly around the nucleus and constitute almost the entire volume
- of the atom. Atoms have sizes on the order of 10^{-10} m.

What holds an atom together?

- The negatively charged electron is attracted to the positively charged nucleus by a Coulombic attraction.
- The protons and neutrons are held together in the nucleus by the strong nuclear force (Binding energy).

"I, a universe of atoms,
But....an atom in the universe"

-Richard Feynman

Thank you