Chemistry 3A

Introductory General Chemistry

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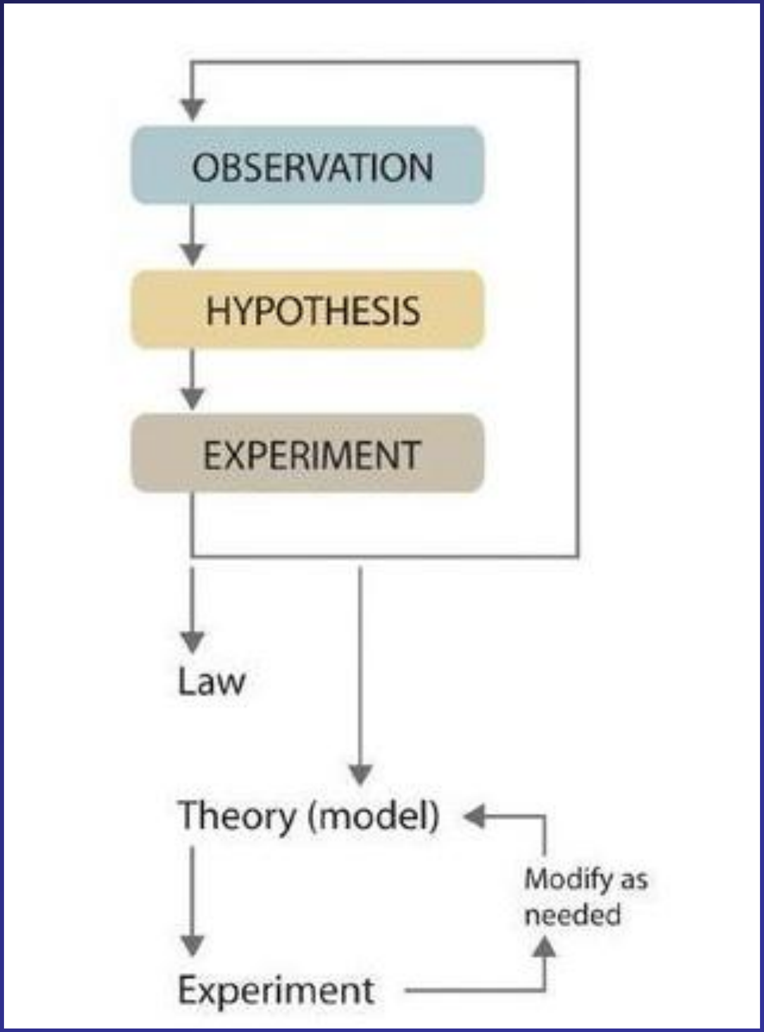
Concepts

- Scientific Method
- Atomic Theory
- Subatomic Structure: protons, electrons, neutrons
- Atomic Properties
- Patterns of matter: Periodic Table
- Electric properties of atoms: ions
- Neutrons and isotopes
- Atomic mass: weight average of atoms

Scientific Method

Terms You Should Know

- *Observation*
- *Hypothesis*
- *Experiment*
- *Theory* (or model)
- *Law*



Scientific Method

Observations

- Qualitative

  properties or occurrences in ways that do not rely on numbers

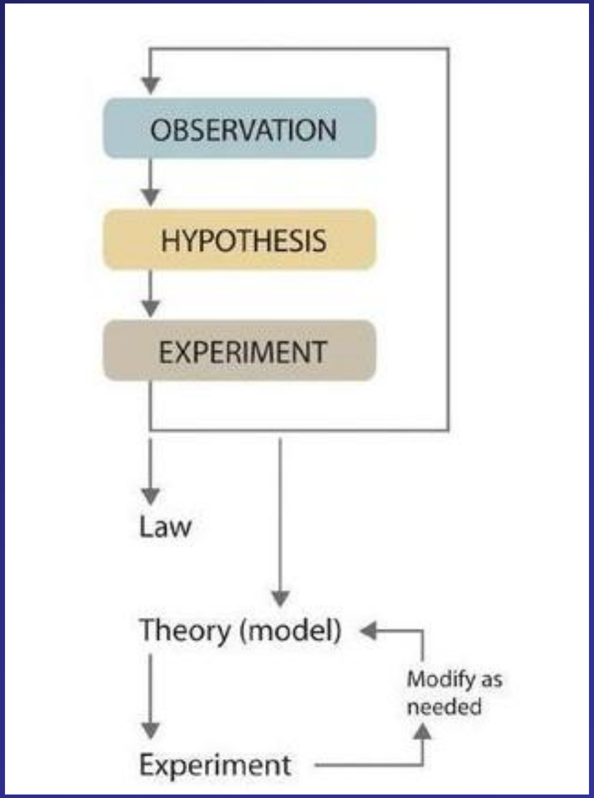
  - table salt is crystalline solid
  - dilute nitric acid used to dissolve penny forms blue solution and brown gas
  - air temperature is cooler in winter season

- Quantitative

  numerical measurements

  data has number with units!

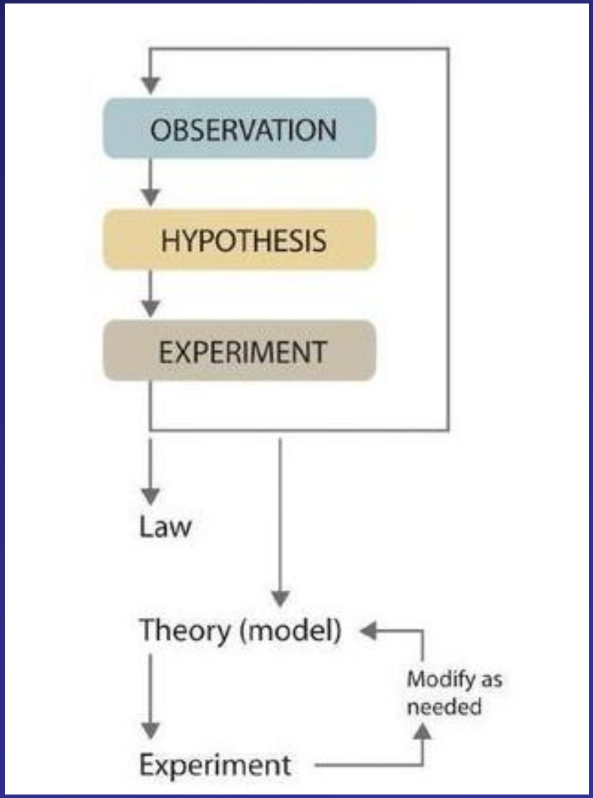
  - melting point of crystalline sulfur → 115.21°C
  - 35.9 g sodium chloride ($NaCl$) will dissolve in 100 g water at 20 °C
  - Iridium in sediments from 66 million years ago were 20-160 times higher than normal



Scientific Method

Hypothesis

- A tentative explanation to account for (set of related) observations
- Two hypotheses to account why sun rises in east and sets in the west
    1. Sun revolves around the Earth
       geocentric hypothesis for observation
    2. Earth rotates on an axis, exposing only one side to sun
       heliocentric hypothesis for observation

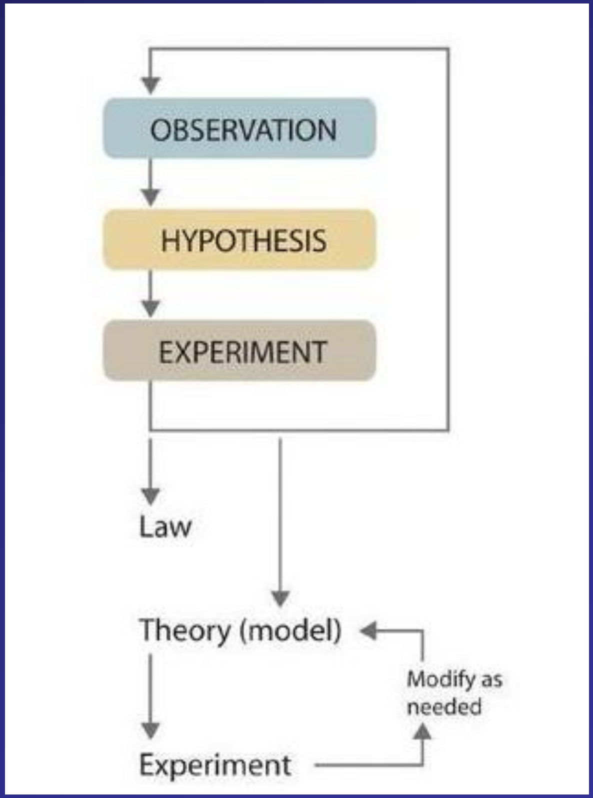


Iridium levels observation brought hypothesis that dinosaur extinction event by large extraterrestrial object hitting Earth

Scientific Method

Experiment

- Systematic observations or measurements, preferably made under controlled conditions—that is, under conditions in which a single variable changes
- These are designed to test validity of a hypothesis (more experiments test additional hypotheses)
- Experimental results should show if hypothesis is correct or sound or needing to be modified or revised

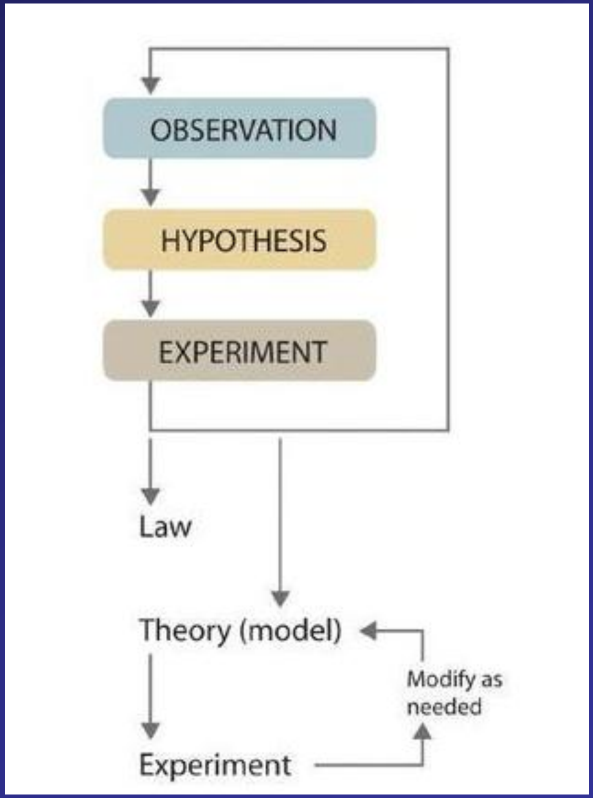


A wrong hypothesis does not mean there are problems with scientific method or with "doing science". It means an educated guess was made, was not true in whole or in part, and a new guess is needed

Scientific Method

***n* = 3, not *n* = 1**

Experimental results should be reproducible, that is repeated experiments



n refers to the number of times an experiment under identical conditions is to be done to get results which should be reproduced to prove the reliability, dependability, precision, accuracy of observations

It is generally accepted an experiment should be done 3 times (n = 3) to show results are reproducible. It is never acceptable to do an experiment only once (n = 1)

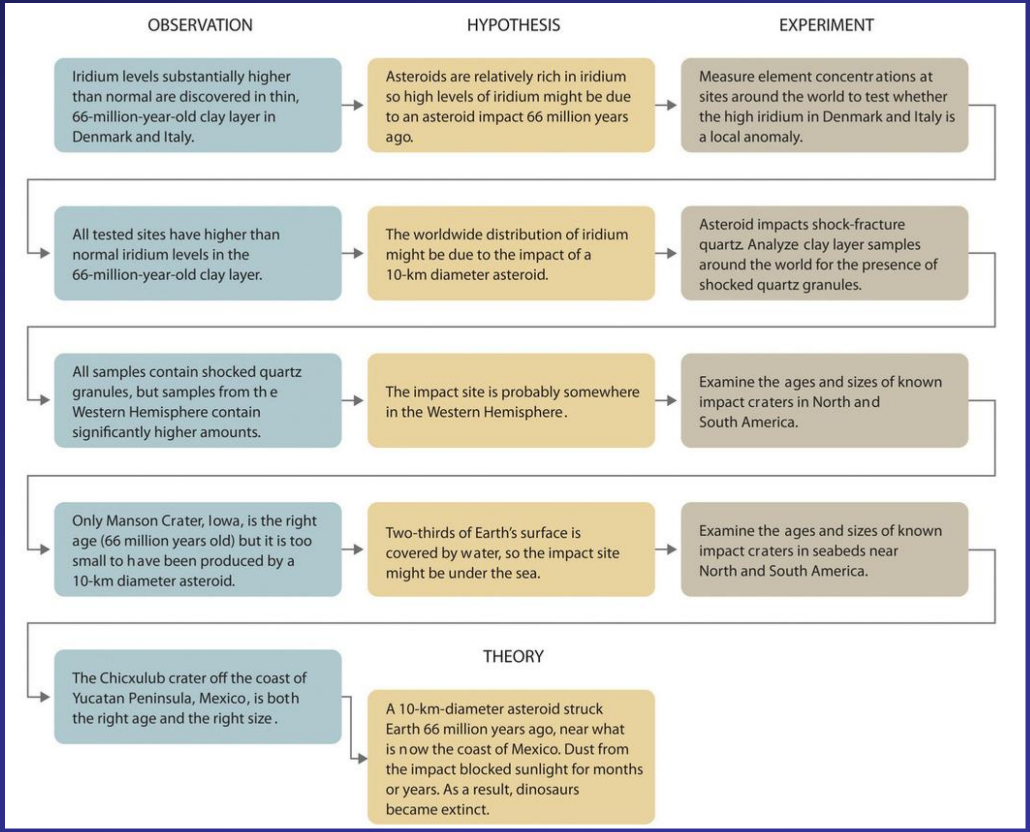
Scientific Method

Asteroid Theory and Dinosaur Extinction

Development of a Theory

Observation → Hypothesis → Experiment

repeated cycles



Atomic Theory

- A couple of millennia* ago, Greek philosophers talked about matter as made of atoms
  Tiny, indivisible, solid objects
- But it was only a couple of centuries ago (1800s) that experimental science really propelled humanity forward
- English chemist John Dalton (researcher, professor)
  - Studied combustion: carbon reacting with oxygen
    Elements were already known for millennia
  - Knew water had elements hydrogen and oxygen
  - Proposed a theory based on experimental results that "the known elements are actually composed of atoms"

*Science is also about history, a history showing learning through trial-and-error & progression of thought and knowledge

Dalton's Atomic Theory

1. All matter made of indivisible atoms
   - Atoms are smallest units of matter
   - Atoms cannot be created, divided, or destroyed (later revised with the discovery of subatomic particles)
2. All atoms of a given element are identical
   - Atoms of the same element have same mass and properties
   - later revised—atoms of the same element can have different masses known as isotopes
3. Compounds are formed by a combination of atoms of different elements

   A given compound always contains the same kinds and ratios of atoms
4. Chemical reactions involve the rearrangement of atoms

   Atoms are neither created nor destroyed in a chemical reaction—only rearranged

Atoms are about 5.4×10^{-10} m in diameter

= 0.54 nanometer (nm) or 5.4 angstrom (Å)

Subatomic Structure

Chemists see the atom structure having the important properties of mass and (electric) charge

- Electrons
  - mass = 9.109×10^{-31} kg, 5.486×10^{-4} amu
  - charge = -1
- Protons
  - mass = 1.673×10^{-27} kg, 1.007 amu, 1836 times electron mass
  - charge = +1
- Neutrons
  - mass = 1.675×10^{-27} kg, 1.009 amu, 1.001 times proton mass
  - charge = 0

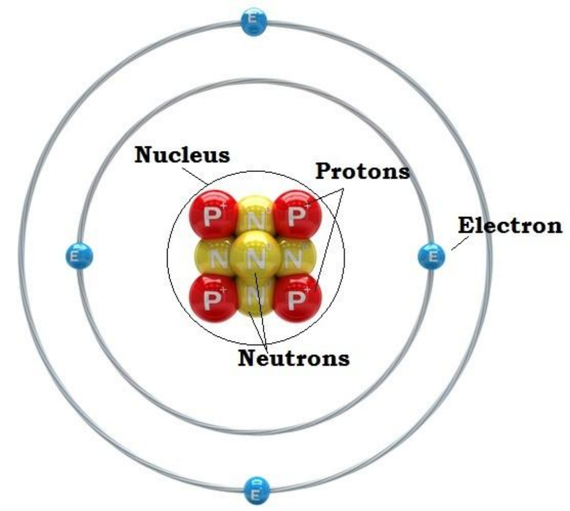
Table 2.3.1: Properties of Subatomic Particles

Particle	Symbol	Mass (amu)	Relative Mass (proton = 1)	Relative Charge	Location
proton	p^+	1	1	+1	inside the nucleus
electron	e^-	5.45×10^{-4}	0.00055	−1	outside the nucleus
neutron	n^0	1	1	0	inside the nucleus

Nucleus & Orbitals

- Protons and neutrons organized in the nucleus
- Electrons spatially located outside of the nucleus
- Electrons "orbit" the nucleus in orbitals but not like planets revolving around the sun
- Their position/location is determined by probabilities calculated by complex mathematical expressions
- Each orbital pairs two electrons of opposite spin

  Yes, electrons have a spin just as the Earth rotates on an axis, and this spin generates a magnetic field



Atomic Mass Units (amu)

Table 2.3.1: Properties of Subatomic Particles

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neutron	n^0	1	1	0	inside the nucleus

- Definition of "amu" is 1/12th of mass of carbon-12 atom (has 6 protons, 6 neutrons, 6 electrons)
- This is not equal to mass of one proton, which is actually equal to 1.007276 amu
- This is only of importance to physicists and is explained by the "mass deficit" which is the energy to that holds a nucleus together

Atomic Properties

- Atomic Number (the Z value)
  - *essentially defines the element*

    makes hydrogen, oxygen, carbon, chlorine, etc. what it is
  - = number of protons (in atom's nucleus)
- Mass Number (the A value)
  - = sum of count of protons and neutrons in atom's nucleus
  - Indicate the **isotope** form of element's atoms

Table 2.4.1: Atoms of the First Six Elements

Name	Protons	Neutrons	Electrons	Atomic Number (Z)	Mass Number (A)
Hydrogen	1	0	1	1	1
Helium	2	2	2	2	4
Lithium	3	4	3	3	7
Beryllium	4	5	4	4	9
Boron	5	6	5	5	11
Carbon	6	6	6	6	12

Atomic Properties

Names and Symbols

- Elements have names and 1- or 2-character symbols that represent the element
- Atoms are the physical part of the element
- Learn the names and symbols of common elements

Table 2.4.2: *Symbols and Latin Names for Elements*

Chemical Symbol	Name	Latin Name
Na	Sodium	Natrium
K	Potassium	Kalium
Fe	Iron	Ferrum
Cu	Copper	Cuprum
Ag	Silver	Argentum
Sn	Tin	Stannum
Sb	Antimony	Stibium
Au	Gold	Aurum
Pb	Lead	Plumbum

Isotopes

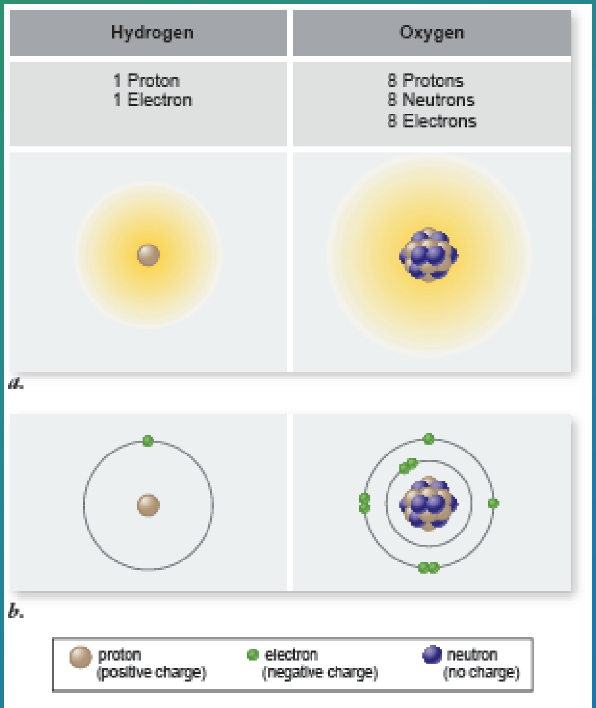
Elements can have different mass number (A) values. Chemistry is same though.

- Hydrogen = 1 proton (99.9885%)
- Deuterium (“hydrogen-2”) = 1 proton + 1 neutron (0.0115%)
- Tritium (“hydrogen-3”) = 1 proton + 2 neutrons (1 in 10^{18}) *radioactive (beta emitter)*

- Carbon-12 = 6 protons + 6 neutrons (98.93%)
- Carbon-13 = 6 protons + 7 neutrons (1.07%)
- Carbon-14 = 6 protons + 8 neutrons (trace)

Isotopic abundance values in parentheses

Elements



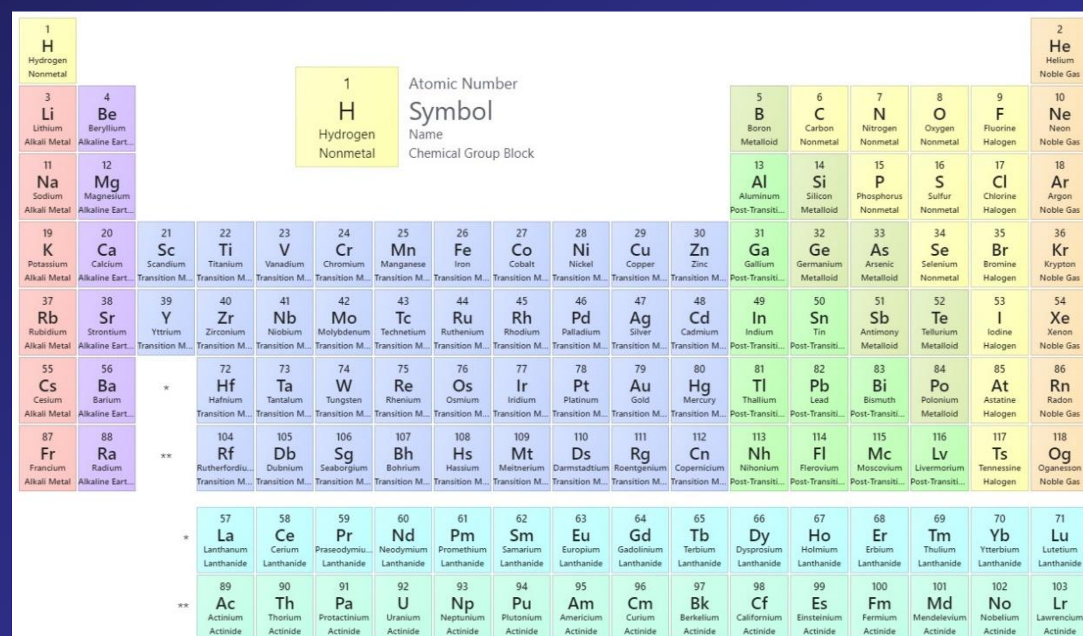
- Elements all have the same number of protons
- But elements can have different number of neutrons
- An element with different numbers of neutrons is an isotope of the element
- When referring to an isotope of an element, use this $\boxed{{}^{A}_{Z}X}$

Where

- × is element symbol (e. g., hydrogen = H)
- *Z* is atomic number, = # protons (*Z* = 1 for H)
- *A* is mass number, = #protons + #neutrons

Patterns of Matter: Periodic Table

- Observations
  - chlorine, bromine, iodine react with sodium
  - lithium, sodium, potassium react with other elements in similar ways
- Organizing elements with these properties by Mendeleev (also Meyer)



  - Symbols

    Element name (optional)
  - Atomic Number
  - Atomic Weight

    Not the mass number!

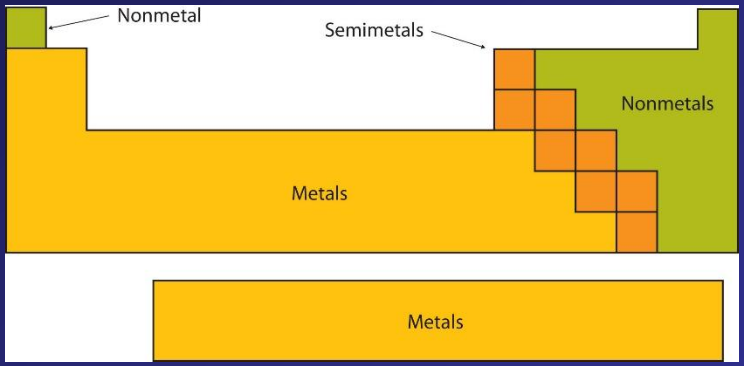
Features of Periodic Table

- **Periods**
  - The rows of the table
  - Number of elements in period not always same!
    - Pattern: 2, 8, 8, 18, 18, 32, 32 for the seven periods
    - Physical reason for this important in chemistry
    - Special periods: inner transition metals, lanthanides, actinides

- **Groups (“Families”)**
  - The columns of the table
  - Usually have similar chemistry (chemical properties)

Patterns of Matter: Periodic Table

Classes of elements



- Metals
  - "shiny", "silvery in color" (but varies)
  - usually electrical and heat conductors
  - malleable (hammer into sheets)
  - ductile (pulled into wires)
- Nonmetals
  - not shiny, brittle in solid form
  - poor electrical and heat conductors
- "Metalloids" (Semimetals)
  - between metal and nonmetal: B, Si, Ge, As, Sb, Te
  - metallic luster, solid at room temperature
  - brittle (not malleable)
  - semiconductors: useful when "doped" with impurities

- 3/4ths of elements are metals

Periodic Table of Elements

Biologists should know what elements are (1) metals and (2) nonmetals generally

Main groups | Transition metal groups | Main groups

Period	1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8	8B 9	10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1	1 H 1.00794																	2 He 4.00260
2	3 Li 6.941	4 Be 9.01218											5 B 10.81	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.1797
3	11 Na 22.98977	12 Mg 24.305											13 Al 26.98154	14 Si 28.0855	15 P 30.9738	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
4	19 K 39.0983	20 Ca 40.078	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
5	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.42	47 Ag 107.8682	48 Cd 112.41	49 In 114.82	50 Sn 118.710	51 Sb 121.757	52 Te 127.60	53 I 126.9045	54 Xe 131.29
6	55 Cs 132.9054	56 Ba 137.33	57 *La 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.9665	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra 226.0254	89 †Ac 227.0278	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (269)	109 Mt (268)	110 Ds (271)	111 Rg (272)	112 (285)	113 (284)	114 (289)	115 (288)	116 (292)		118 (294)

Lanthanides	58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.965	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9304	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967
Actinides	90 Th 232.0381	91 Pa 231.0399	92 U 238.0289	93 Np 237.048	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

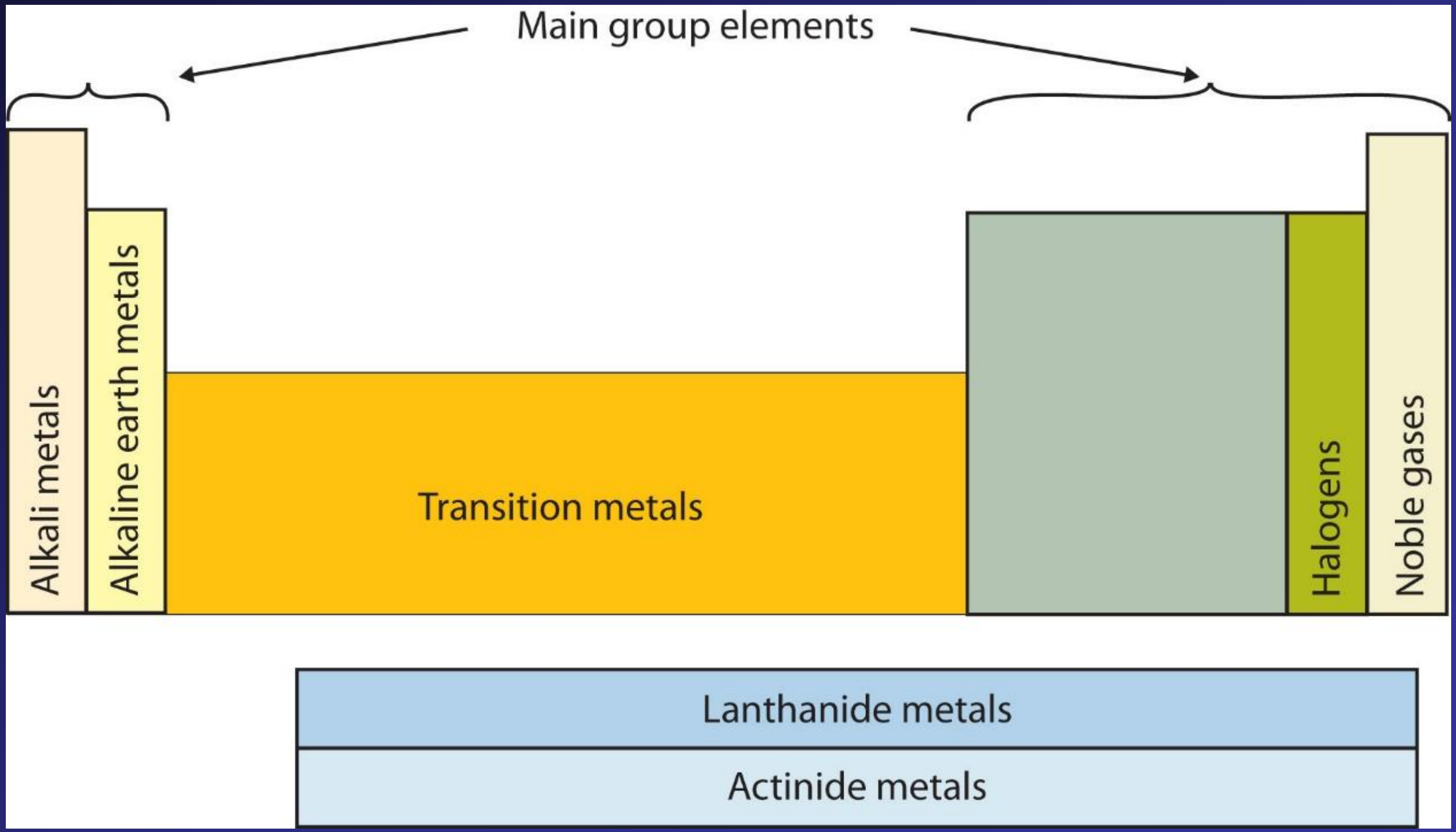
Metals | Metalloids | Nonmetals

The periodic table of the elements. Each element is identified by a one- or two-letter symbol and is characterized by an *atomic number*. The table begins with hydrogen (H, atomic number 1) in the upper left-hand corner and continues to the yet unnamed element with atomic number 118. The 14 elements following lanthanum (La, atomic number 57) and the 14 elements following actinium (Ac, atomic number 89) are pulled out and shown below the others.
Elements are organized into 18 vertical columns, or *groups*, and 7 horizontal rows, or *periods*. The two groups on the left and the six on the right are the *main groups*; the ten in the middle are the *transition metal groups*. The 14 elements following lanthanum are the *lanthanides*, and the 14 elements following actinium are the *actinides*; together these are known as the *inner transition metals*. Two systems for numbering the groups are explained in the text. Those elements (except hydrogen) on the left-hand side of the zigzag line running from boron (B) to astatine (At) are *metals*, those elements to the right of the line are *nonmetals*, and most elements abutting the line are *metalloids*.

McMurry et al, Fundamentals of General, Organic and Biological Chemistry, 6 Ed, p 58

Special **Groups** of Elements

Some groups of elements should be noted since their chemistry is commonly observed



Special **Groups** of Elements

Alkali Metals

Sodium:

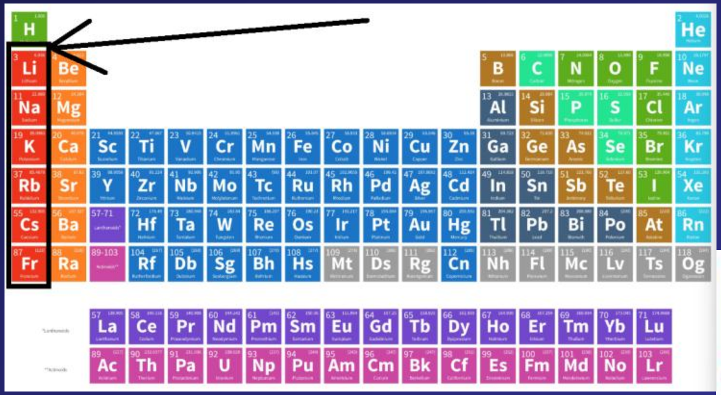
- table salt
- cellular function

Potassium:

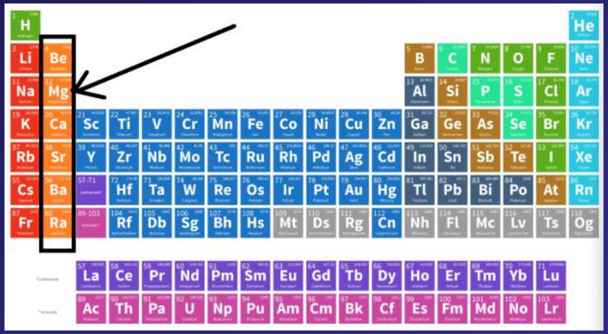
- cellular function (like sodium)

Lithium:

- used in "grease" lubricants
- batteries
- drugs to control neurological conditions affecting behavior (bipolar "disorder")



Special **Groups** of Elements



Alkaline Earth Metals

Magnesium:

- also important in cellular function
- Forms important minerals

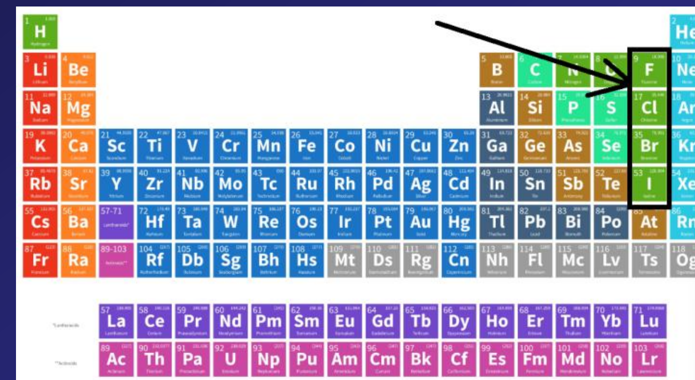
Calcium:

- Like magnesium, necessary for cell/tissue function
- Limestone is calcium carbonate

Others are rare and Ra is radioactive

Special **Groups** of Elements

Halogens



Term “halogen” → salt-forming

React with metals to form salts

Fluorine:

- the fluoride in toothpaste
- non-stick Teflon

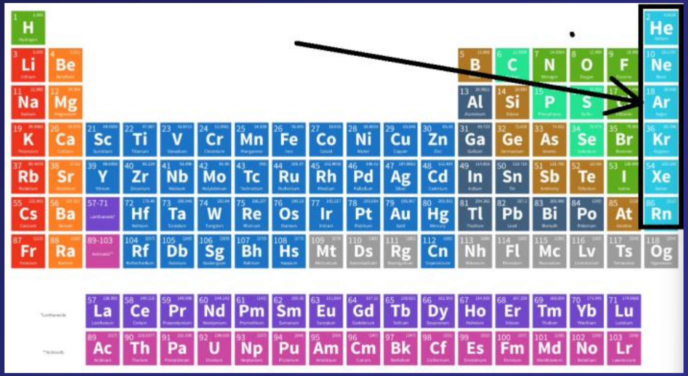
Chlorine:

- essential for cellular function
- a component of plastics (chlorides of carbon polymers)

Special **Groups** of Elements

Noble Gases

Also called "inert gases" and "rare gases"



Basically once thought to be chemically **unreactive**

Usually exist as single atoms, explains why gases
Neon used to make red lighting

But some form interesting compounds with nonmetals

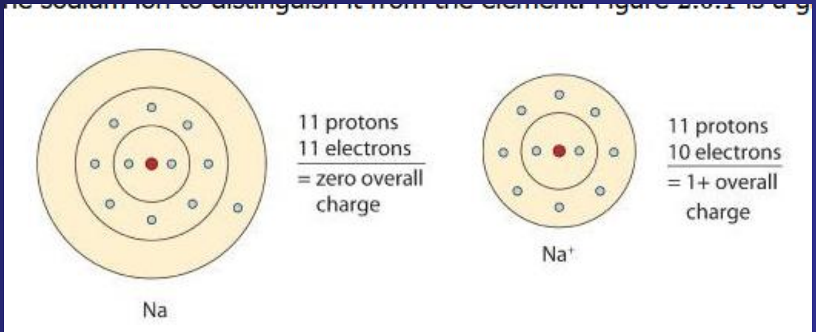
- Xenon hexafluoroplatinate ($XePtF_6$): first compound with noble gas ever produced
- Xenon difluoride (XeF_2): powerful fluorinating and oxidizing agent used in microprocessor production
- Krypton difluoride (KrF_2): used to make KrF excimer lasers for photolithography (ArF also used in this way)

Electric properties of atoms: Ions

- Ions
  - Neutral atom/particle: zero charge, plus=minus
  - Ions: positively or negatively charged atoms/particles
- Cations – is a POSITIVELY charged ion

  Lose an electron

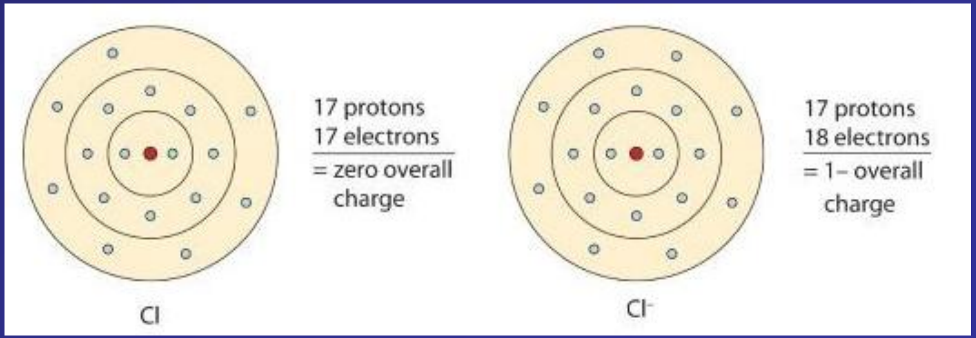
  $Na \rightarrow Na^+ + e^-$



- Anions – is a NEGATIVELY charged ion

  Gain an electron

  $e^- + Cl \rightarrow Cl^-$



Isotopes

- Isotopes are forms of an atom with the same proton number (Z) but different mass number (A)
- That is, they are forms of an element with different numbers of **neutrons** in the atom

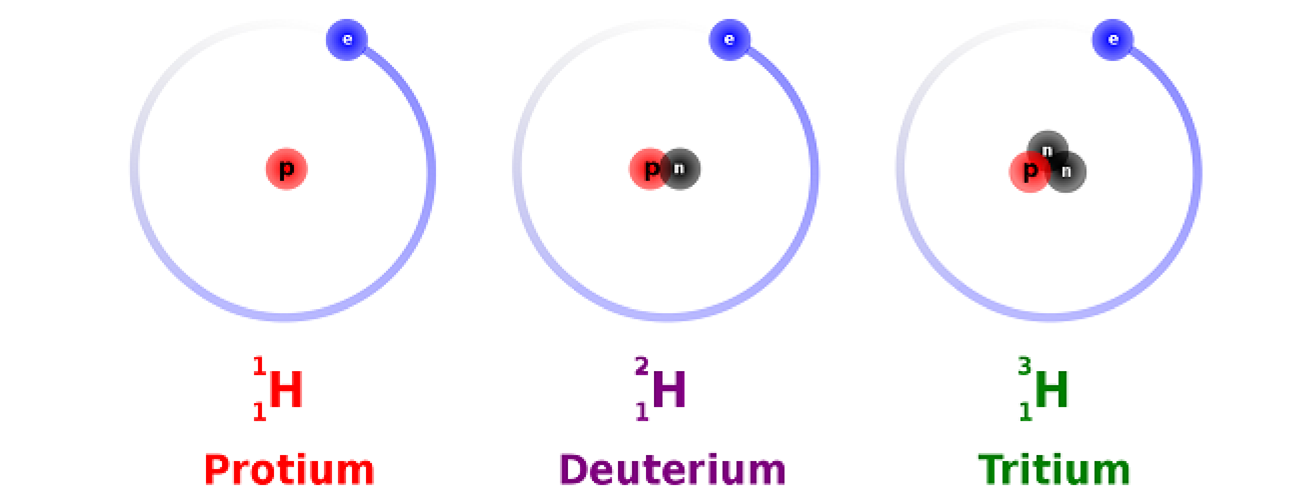


Figure 2.7.1: The three most stable isotopes of hydrogen: protium (A = 1), deuterium (A = 2), and tritium (A = 3). (CC SA-BY 3.0; Balajijagadesh via Wikipedia).

Isotopes

- Lithium has only one atomic number (Z = 3)

  This is the number of protons an element's atoms has
- Lithium can have two mass numbers
  - 3 neutrons: A = 6 (= 3 protons + 3 neutrons)

    $$^{6}_{3}\mathrm{Li}$$
  - 4 neutrons: A = 7 (= 3 protons + 4 neutrons)

    $$^{7}_{3}\mathrm{Li}$$

Why not Li with 2 or 5 neutrons? Because we only report on what exists naturally

Representing Isotopes

Isotopes can written in two ways

Nuclear Symbol

$$^{12}_{6}\mathrm{C},\ ^{13}_{6}\mathrm{C},\ ^{14}_{6}\mathrm{C}$$

But the atomic number subscript (Z) is unnecessary if the element symbol indicates it

$$^{12}\mathrm{C},\ ^{13}\mathrm{C},\ ^{14}\mathrm{C}$$

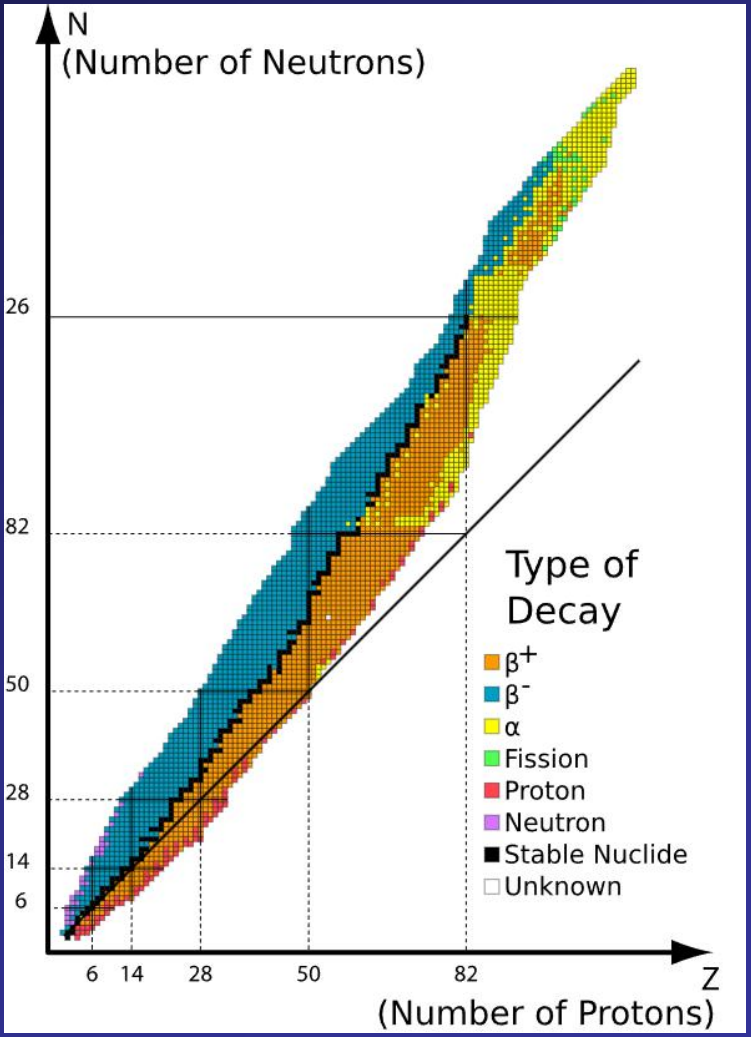
Or as the “<element-name>-<mass-number>”

Carbon-12, Carbon-13, Carbon-14

Isotope Stability

- The stability of the atomic nucleus (of elements) depends on a ratio of neutrons to protons
- Carbon has two stable isotopes, ^{12}C and ^{13}C. But ^{14}C is unstable and radioactive
- The trend at right shows that nuclei will have more and more neutrons than protons in the nucleus as the Z gets larger!

That is $\frac{\text{neutrons}}{\text{protons}} > 1$



Atomic Mass (Atomic Weight)

- Book defines atomic mass as the "weighted average mass of atoms in a naturally occurring sample of the element"
- Its units are atomic mass units (amu)
- Relative abundance: fraction of element which is a given isotope (fraction might be as a percentage)
- Note that all the relative abundances should add up to 1 (100%)

$$\sum (\text{relative abundance of isotope})_i \times (\text{isotope mass})_i$$

What book calls "atomic mass" most properly call "atomic weight". Atomic mass refers to an isotope's actually mass (in amu)

Atomic Weight Calculation

Hydrogen Atomic Weight Calculation

- Protium (^1H)
  - Abundance: ~99.985%
  - Atomic Mass: 1.0078 amu
- Deuterium (^2H or D)
  - Abundance: ~0.015%
  - Atomic Mass: 2.0141 amu
- Tritium (^3H or T)
  - Abundance: trace
  - Atomic Mass: 3.0160 amu

$$0.99985 \times 1.0078 + 0.0015 \ \times 2.0141 = 1.0079 \text{ amu}$$

Atomic Weight Calculation

Carbon Atomic Weight Calculation

- Carbon-12 (^{12}C)
  - Abundance: ~98.93%
  - Atomic Mass: 12.0000 amu
- Carbon-13 (^{13}C)
  - Abundance: ~1.07%
  - Atomic Mass: 13.0034 amu
- Carbon-14 (^{14}C)
  - Abundance: trace
  - Atomic Mass: 14.0032 amu

$$0.9893 \times 12.0000 + 0.0107 \times 13.0034 = 12.0107 \text{ amu}$$

Atomic Weight Calculation

Boron Atomic Weight Calculation

- Boron-10 (^{10}B)
  - Abundance: ~19.9%
  - Atomic Mass: 10.0129 amu
- Boron-11 (^{11}B)
  - Abundance: ~80.1%
  - Atomic Mass: 11.0093 amu

$$0.199 \times 10.0129 + 0.801 \times 11.0093 = 10.811 \text{ amu}$$

Atomic Weight Calculation

Neon Atomic Weight Calculation

- Neon-20 (^{20}Ne)
  - Abundance: ~90.48%
  - Atomic Mass: 19.9924 amu
- Neon-21 (^{21}Ne)
  - Abundance: ~0.27%
  - Atomic Mass: 20.9938 amu
- Neon-22 (^{22}Ne)
  - Abundance: ~9.25%
  - Atomic Mass: 21.9914 amu

$$0.9048 \times 19.9924 + 0.0027 \times 20.9938 + 0.0925 \times 21.9914 = 20.180 \text{ amu}$$