

# Chapter 4: Atoms and Elements

Atoms are EXTREMELY SMALL particles out of which all **known** matter is made.

- They are the smallest particle of a chemical element that still have the properties of that element.

How small is a typical atom?

- A typical atom is about one MILLIONTH of a millimeter across. (A **million** of them laid in a line would measure 1 mm across!)



## Historical Development of Atomic Structure

- Early Greek philosophers (Leucippus, Democritus) proposed small, indivisible particles called "atomos"
- 1808 - JOHN DALTON PROPOSES ATOMIC THEORY  
(theory soon widely accepted)

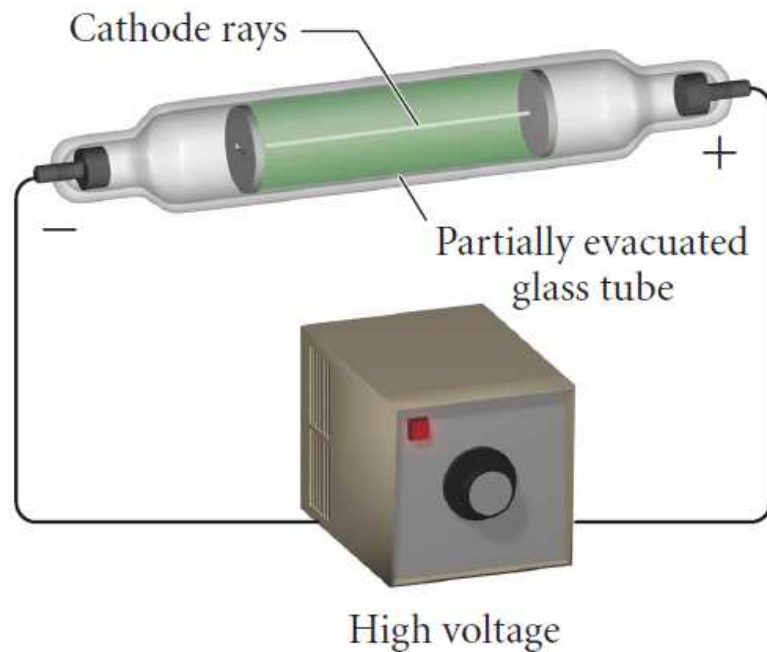
### Atomic Theory

- 1) Each element is made of tiny indestructible particles called "Atoms".
- 2) All atoms of an element are the same.
- 3) Atoms combine in simple, whole number ratios to make compounds.

# Discovery of the Electron

(J. J. Thomson, late 1800s)

- Used a cathode ray tube which produces a beam of electrons



Cathode rays could be deflected by magnetic fields and charged plates.

- Thomson concluded that since the cathode rays were **deflected** by the negatively charged plate and **attracted** to the positively charged plate that cathode rays consisted of negative particles called **ELECTRONS**

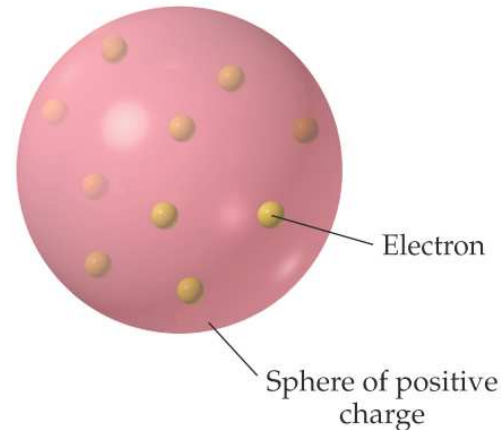
# Plum Pudding Model

J.J. Thomson determined that electrons are :

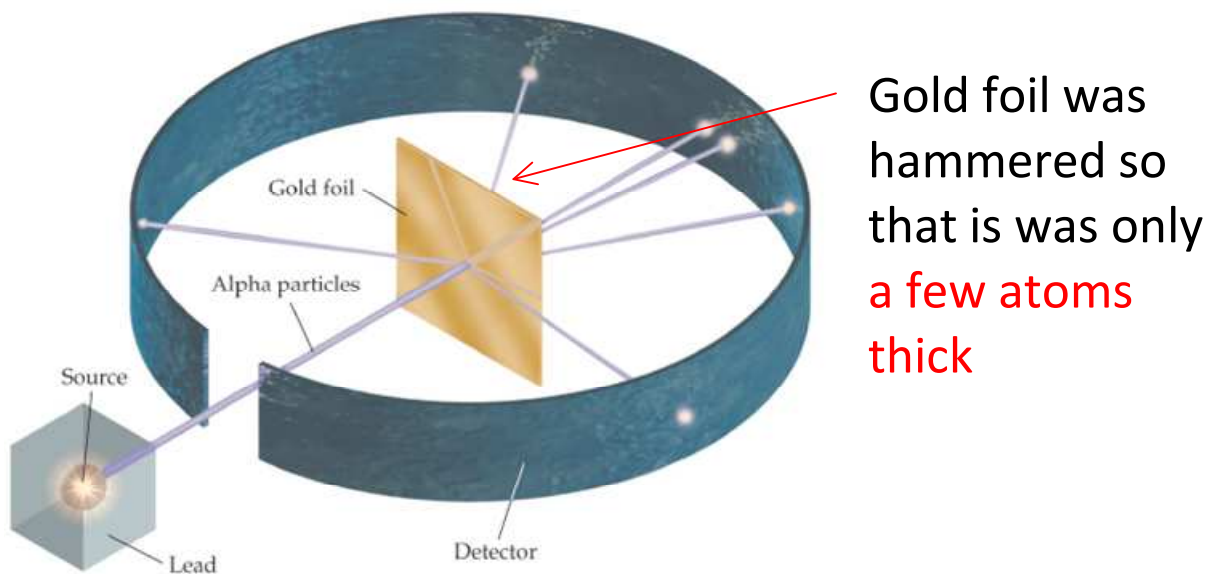
- Negatively charged
- Smaller than atoms
- Fundamental particle in all matter

Since atoms are neutral, Thomson proposed "**Plum Pudding**" model for atomic structure

- electrons held within positively charged sphere.



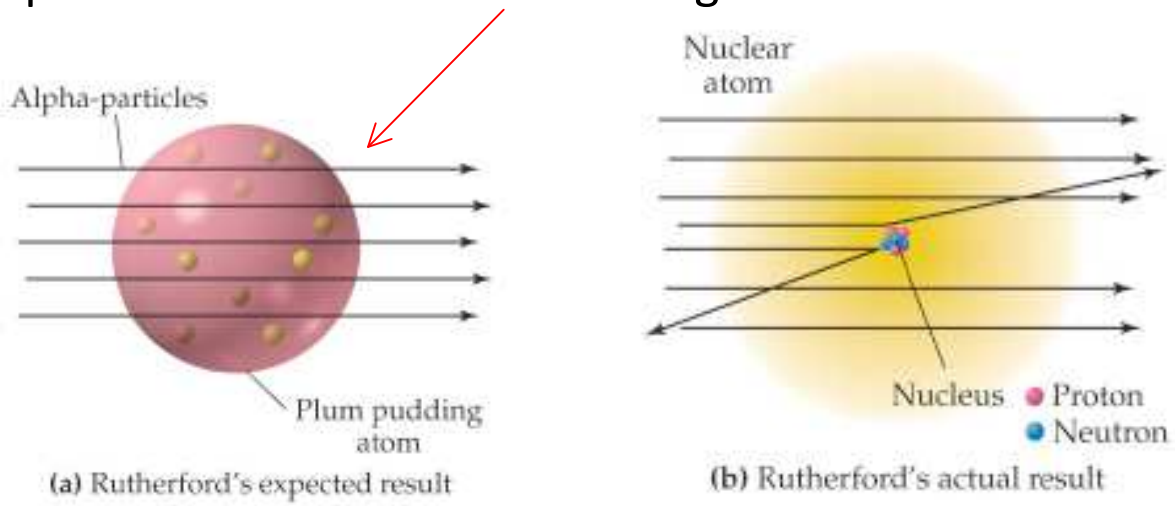
In 1909 Rutherford performed the GOLD FOIL EXPERIMENT to test the plum pudding model



Positively charged particles shot at the foil - most went straight through, while some were **strongly** deflected

## Discovery of the Nucleus

If the Plum Pudding model was correct the positive particles should've flown through the foil.



But this wasn't the case!

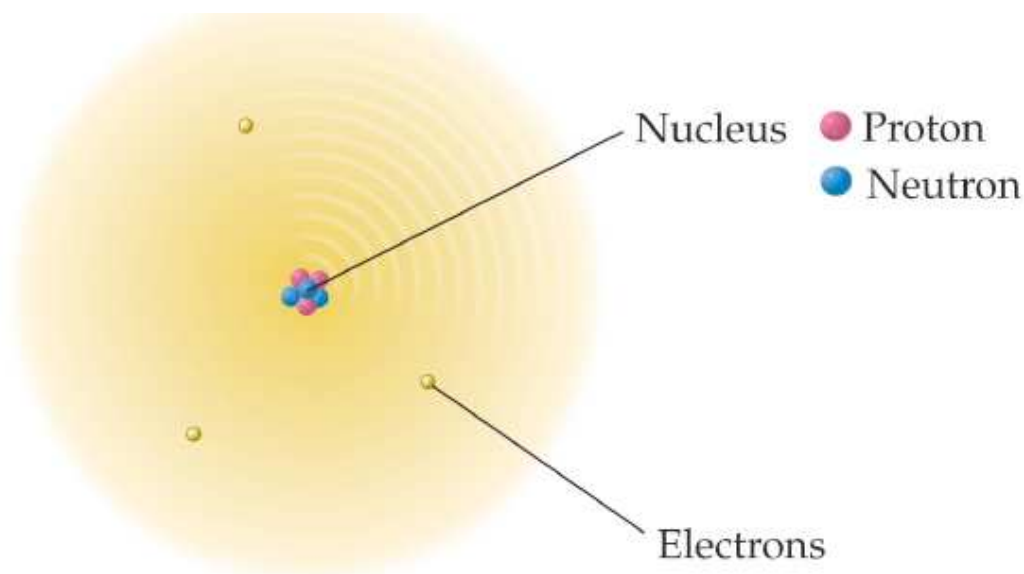
Rutherford's result supported the

### Nuclear model of the atom

- All the positive charge and most of the mass of the atom is concentrated in a very small volume, the **nucleus**.
- Electrons occupy the rest of the space in the atom which is approximately **100,000** times larger than the nucleus.
  - If the nucleus were the size of a baseball, then the diameter of the electron cloud would be approx. 2.5 miles!

### ATOMS ARE MOSTLY EMPTY SPACE

# Modern Model of the Atom



## Subatomic Particles: the building blocks from which all atoms are made

<u>Particle</u>	<u>Symbol</u>	<u>Charge</u>
Proton	$p^+$	+1
Neutron	$n^0$	0
Electron	$e^-$	-1

- The nucleus consists of protons and neutrons
- 99.9% of the mass of an atom is in the nucleus  
(p & n mass almost equivalent)
- Electrons are approx. **1/2000** the mass of a proton or neutron
- Electrons are dispersed in a region around the nucleus that is very large (compared to the small, compact nucleus) called the **ELECTRON CLOUD**
- The number of electrons is equal to the number of protons in a **neutral atom**.

## Electrical Charge

- Positive and negatively charged objects **ATTRACT** each other ( $p^+$  and  $e^-$  attracted to one another).
- Like charges **repel** each other.
- When a proton and electron are paired they are charge-neutral.

## Elements

Every atom has a characteristic number of protons in its nucleus which **determines the identity of the atom**.

- If 2 atoms differ in the number of protons present, they **MUST** be 2 different elements. If the two atoms possess the **same # of protons**, they must be the **SAME ELEMENT**.

**Atomic Number (Z)** = number of protons in the nucleus of an atom

**# of protons = # of electrons in a neutral atom of that element**

The elements are arranged on the Periodic Table in order of **increasing atomic number**

# Periodic Table

## The Periodic Table of Elements

1																	14 Si 28.09 silicon	51 Sb 121.75 antimony																
2	Li 6.94 lithium	Be 9.01 beryllium											13 Al 26.98 aluminum	14 Si 28.09 silicon	15 P 30.97 phosphorus	16 S 32.07 sulfur	17 Cl 35.45 chlorine	18 Ar 39.95 argon																
3	Na 22.99 sodium	Mg 24.31 magnesium	3B	4B	5B	6B	7B	8B		11B	2B	31 Ga 69.72 gallium	32 Ge 72.61 germanium	33 As 74.92 arsenic	34 Se 78.96 selenium	35 Br 79.90 bromine	36 Kr 83.80 krypton																	
4	K 39.10 potassium	Ca 40.08 calcium	21 Sc 44.96 scandium	22 Ti 47.88 titanium	23 V 50.94 vanadium	24 Cr 52.00 chromium	25 Mn 54.94 manganese	26 Fe 55.85 iron	27 Co 58.93 cobalt	28 Ni 58.69 nickel	29 Cu 63.55 copper	30 Zn 65.39 zinc	48 In 114.82 indium	49 Sn 118.71 tin	50 Sb 121.75 antimony	51 Te 127.60 tellurium	52 I 126.90 iodine	53 Xe 131.29 xenon																
5	Rb 85.47 rubidium	Sr 87.62 strontium	39 Y 88.91 yttrium	40 Zr 91.22 zirconium	41 Nb 92.91 niobium	42 Mo 95.94 molybdenum	43 Tc (99) technetium	44 Ru 101.07 ruthenium	45 Rh 102.91 rhodium	46 Pd 106.42 palladium	47 Ag 107.87 silver	80 Cd 112.41 cadmium	81 Tl 204.38 thallium	82 Pb 207.2 lead	83 Bi 208.98 bismuth	84 Po (209) polonium	85 At (210) astatine	86 Rn (222) radon																
6	Cs 132.91 cesium	Ba 137.33 barium	56 La 138.91 lanthanum	57 Ce 140.12 cerium	58 Pr 140.91 praseodymium	59 Nd 144.24 neodymium	60 Pm (145) promethium	61 Sm 150.36 samarium	62 Eu 151.96 europium	63 Gd 157.25 gadolinium	64 Tb 158.93 terbium	65 Dy 162.50 dysprosium	66 Ho 164.93 holmium	67 Er 167.26 erbium	68 Tm 168.93 thulium	69 Yb 173.05 ytterbium	70 Lu 174.97 lutetium	71 Hf 178.49 hafnium	72 Ta 180.95 tantalum	73 W 183.85 tungsten	74 Re 186.21 rhenium	75 Os 190.2 osmium	76 Ir 192.22 iridium	77 Pt 195.08 platinum	78 Au 196.97 gold	79 Hg 200.59 mercury	80 Tl 204.38 thallium	81 Pb 207.2 lead	82 Bi 208.98 bismuth	83 Po (209) polonium	84 At (210) astatine	85 Rn (222) radon		
7	Fr (223) francium	Ra (226) radium	87 Ac (227) actinium	88 Th (232) thorium	89 Pa (231) protactinium	90 U (238) uranium	91 Np (237) neptunium	92 Pu (244) plutonium	93 Am (243) americium	94 Cm (247) curium	95 Bk (247) berkelium	96 Cf (251) californium	97 Es (252) einsteinium	98 Fm (257) fermium	99 Md (288) mendelevium	100 Dn (289) dubnium	101 Uu (289) unbinilium	102 Uub (289) unbinilium	103 Uut (289) unbinilium	104 Uuq (289) unbinilium	105 Uup (289) unbinilium	106 Uuq (289) unbinilium	107 Uuh (289) unbinilium	108 Uuo (289) unbinilium	109 Uuq (289) unbinilium	110 Uuq (289) unbinilium	111 Uuq (289) unbinilium	112 Uuq (289) unbinilium	113 Uuq (289) unbinilium	114 Uuq (289) unbinilium	115 Uuq (289) unbinilium	116 Uuq (289) unbinilium	117 Uuq (289) unbinilium	118 Uuo (289) unbinilium

Copyright © 2006 Pearson Prentice Hall, Inc.

- ALL silicon atoms contain \_\_\_\_ protons
  - ALL gold atoms contain \_\_\_\_ protons
  - How many electrons does a neutral oxygen atom contain?
  - Will a Fe atoms with 24 electrons be electrically neutral?
- In 1869 Dimitri Mendeleev noticed a repeating pattern of properties **every 8 elements** when elements arranged in order of relative mass.
  - Exceptions: Te & I
  - Predicted undiscovered elements
  - Modern Periodic Table - ordered by **increasing atomic number**



Dimitri Mendeleev (Russian)



# Periodic Table Sections

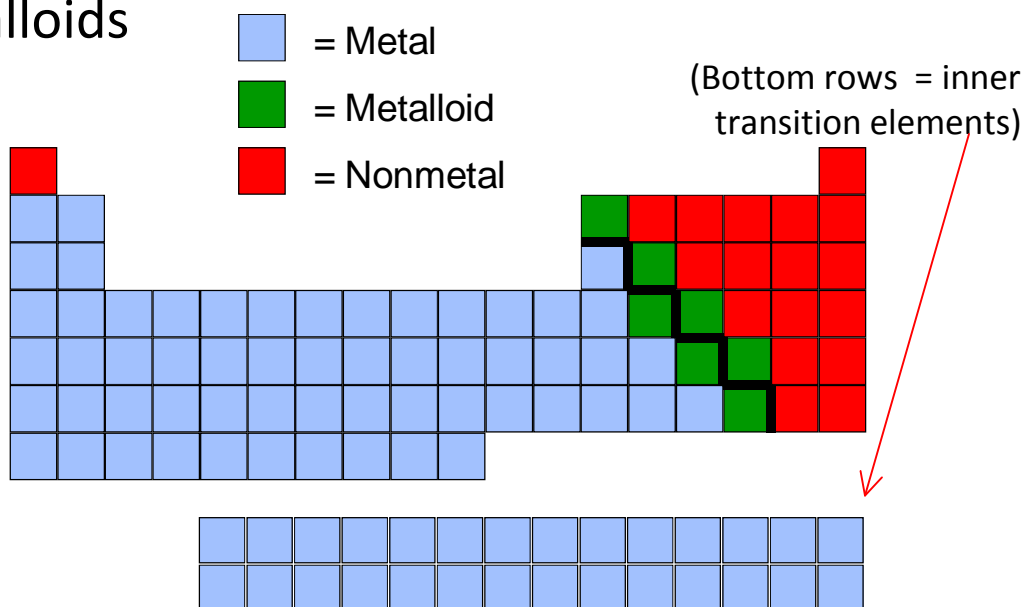
The image shows a standard periodic table with the following labels:

- Main group elements:** Located on the far left (Groups 1A and 2A) and far right (Groups 3A through 8A).
- Transition elements:** Located in the middle, between Groups 2A and 3A.
- Group number:** Indicated by a blue arrow pointing to Group 1A.
- Periods:** Labeled on the left side of the table from 1 to 7.

**Vertical Column = Group**  
**Horizontal Row = Period**

Elements with similar chemical and physical properties are in the same column (group).

Elements are classified as metals, nonmetals or metalloids



## Metals

High luster  
 Thermally and electrically conductive  
 Malleable  
 Solids (except Hg)

## Nonmetals

No luster  
 Poor thermal and electrical conductivity  
 Not malleable  
 May be solid, liquid or gas

## Metalloids

Have characteristics intermediate between metals and nonmetals  
 SEMICONDUCTORS



## Element Classifications

Classify the following elements as a metal, nonmetal or metalloid:

Xenon, Xe

Tungsten, W

Chlorine, Cl

Arsenic, As

Hydrogen, H

Uranium, U

Which of the elements above is a main group element?  
A transition element? An inner transition element?

Recall: **Elements with similar chemical and physical properties are in the same group.**



= Alkali metals



= Halogens



= Alkali earth metals



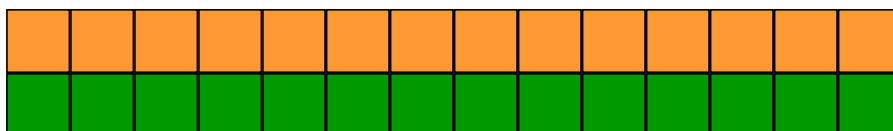
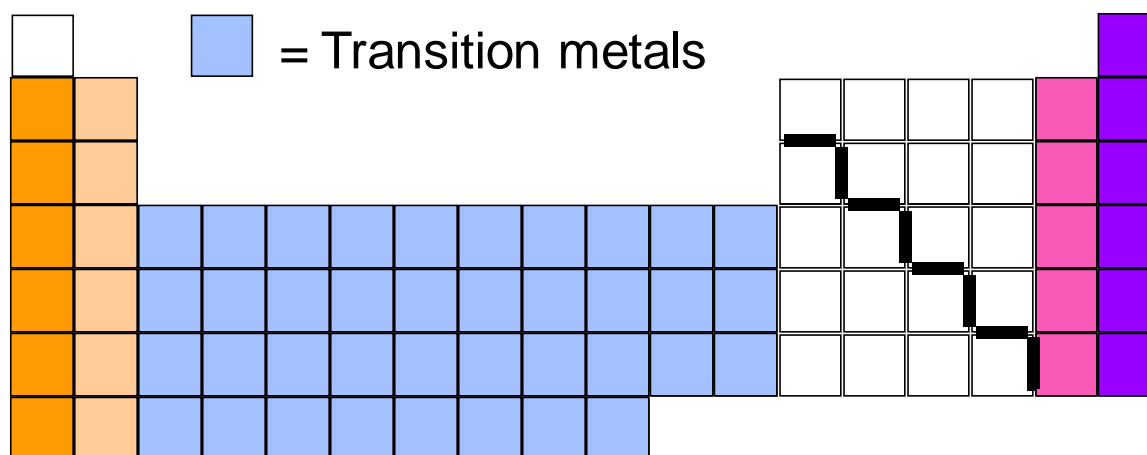
= Lanthanides



= Noble gases



= Actinides



## Ions

A neutral atom becomes charged by either gaining or losing 1 or more electrons to become an **ION**

- CATIONS - ions with a positive charge  
formed by *losing electrons*
- ANIONS - ions with a negative charge  
formed by *gaining electrons*

$$\text{Ion charge} = \# \text{ protons} - \# \text{ electrons}$$

Nonmetals form ANIONS

Cl atom = 17 p<sup>+</sup> & 17 e<sup>-</sup>; Cl<sup>-</sup> ion = 17 p<sup>+</sup> & 18 e<sup>-</sup>

N atom = 7 p<sup>+</sup> & 7 e<sup>-</sup>; N<sup>3-</sup> ion = 7 p<sup>+</sup> & 10 e<sup>-</sup>

(Gained 3 electrons)

Metals form CATIONS

Na atom = 11 p<sup>+</sup> & 11 e<sup>-</sup>; Na<sup>+</sup> ion = 11 p<sup>+</sup> & 10 e<sup>-</sup>

Ca atom = 20 p<sup>+</sup> & 20 e<sup>-</sup>; Ca<sup>2+</sup> ion = 20 p<sup>+</sup> & 18 e<sup>-</sup>

(Lost 2 electrons)

# Valence Electrons

⇒ highest energy electrons in an atom

The number above each **main group column** gives the number of valence electrons for elements in that group

1A

	2A										3A		5A	6A	7A	
Li <sup>+</sup>	Be <sup>2+</sup>												N <sup>3-</sup>	O <sup>2-</sup>	F <sup>-</sup>	
Na <sup>+</sup>	Mg <sup>2+</sup>										Al <sup>3+</sup>		P <sup>3-</sup>	S <sup>2-</sup>	Cl <sup>-</sup>	
K <sup>+</sup>	Ca <sup>2+</sup>										Ga <sup>3+</sup>		As <sup>3-</sup>	Se <sup>2-</sup>	Br <sup>-</sup>	
Rb <sup>+</sup>	Sr <sup>2+</sup>										In <sup>3+</sup>			Te <sup>2-</sup>	I <sup>-</sup>	
Cs <sup>+</sup>	Ba <sup>2+</sup>															

- **Metals** of group **IA, IIA and IIIA** lose one or more electrons to get the same number of valence electrons as the **previous noble gas**.
- **Nonmetals** of groups **VA, VIA, and VIIA** gain one or more electrons to get the same number of valence electrons as the **nearest noble gas**.

**Note:**

- Metallic elements are neutral atoms
- Metals in compounds are cations

## Isotopes

Atoms of the same element **MUST** have the same number of protons. However, they often vary in the number of neutrons.

Mass number (A) = # of protons and # of neutrons in a given nucleus

## ISOTOPES

Atoms with the same **atomic number** (# of protons) but different **mass numbers** (# of neutrons)

Symbol:



A = Mass number  
Z = Atomic number  
X = Element symbol

Ex. 3 naturally-occurring isotopes of carbon:

${}^1_6\text{C}$  → Isotope of carbon that has 6 protons and 6 neutrons; **carbon-12**

${}^{13}_6\text{C}$  → Isotope of carbon that has 6 protons and 7 neutrons; **carbon-13**

${}^{14}_6\text{C}$  → Isotope of carbon that has 6 protons and 8 neutrons; **carbon-14**

How can we determine the number of neutrons in an isotope of a particular element?

# Isotopes

Complete the following table:

	Atomic Number	Mass Number	Number of protons	Number of electrons	Number of neutrons
Calcium-40					

Carbon-13

Aluminum-27<sup>+3</sup>

An atom has 12 protons and 13 neutrons:

Atomic # =

Isotope symbol =

Mass number =

#e<sup>-</sup> if neutral =

Element name =

#e<sup>-</sup> if stable ion =

Different isotopes of an element have differing natural abundances:

- Ex. Boron-10 20.0% natural abundance  
Boron-11 80.0% natural abundance

## Atomic Mass

Weighted average of the masses of all **naturally occurring isotopes** of an element

# Atomic Mass

(amu = atomic mass units)

<u>Atom</u>	<u>Mass number</u>	<u>Atomic mass</u>
copper-63	63	62.9396 amu
copper-65	65	64.9278 amu

(Atomic Mass and Mass number are NOT THE SAME THING)

A sample of natural copper contains...

69.17% copper-63

30.83% copper-65

**Atomic Mass** = (Fraction of isotope 1) x (Mass of Isotope 1)  
+ (Fraction of isotope 2) x (Mass of Isotope 2)  
+ etc...

where fraction of isotope = % abundance/100

Calculate the atomic mass of copper:

On periodic table:

Atomic # → 29  
Cu  
Atomic mass → 63.55

Mass number is not found  
on the periodic table