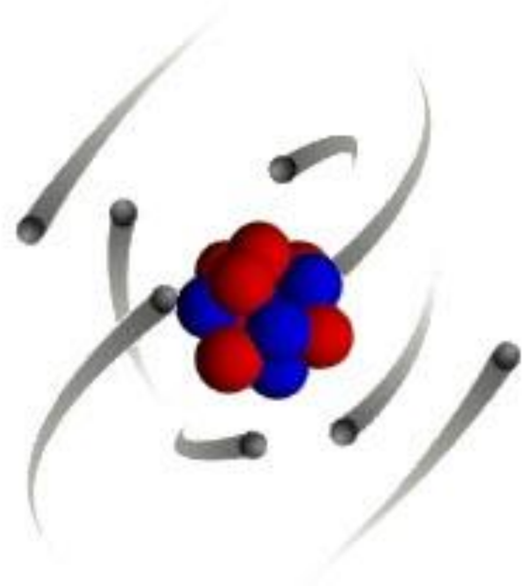
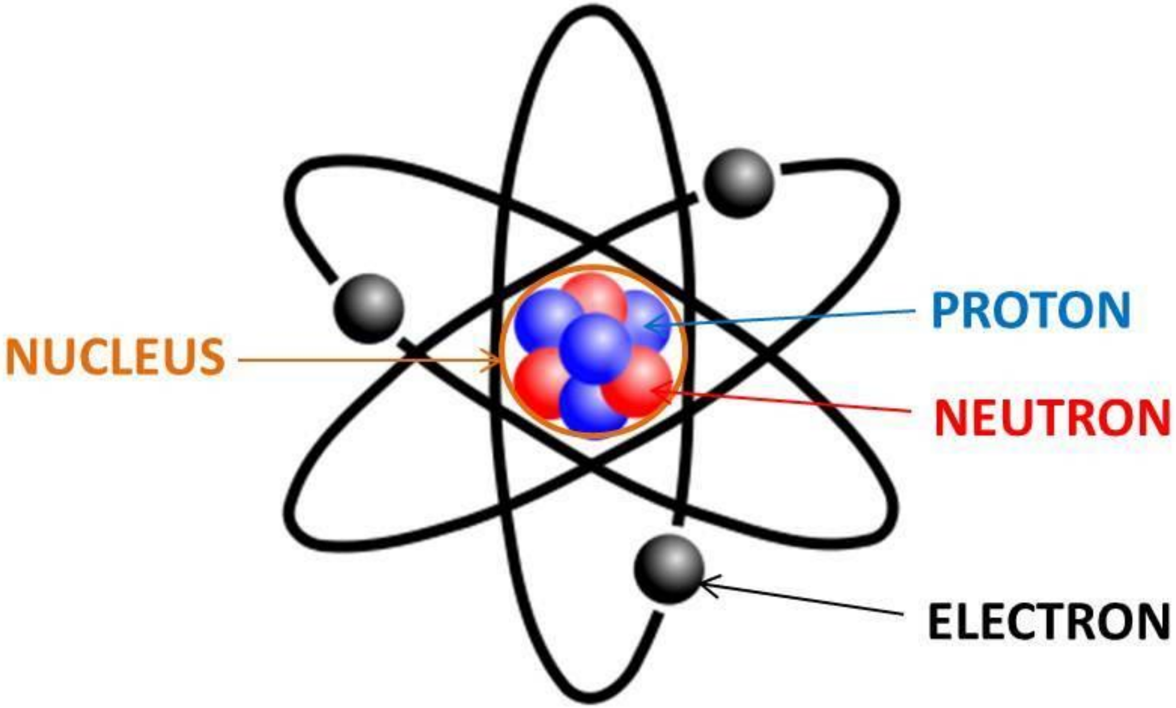


The ATOM & RADIOACTIVITY

Outline

- The atom
- Radioactivity
- The Atomic Nucleus and the Strong Nuclear Force
- Half-Life and Transmutation
- Radiometric Dating
- Nuclear Fission
- Mass–Energy Equivalence
- Nuclear Fusion

Atom



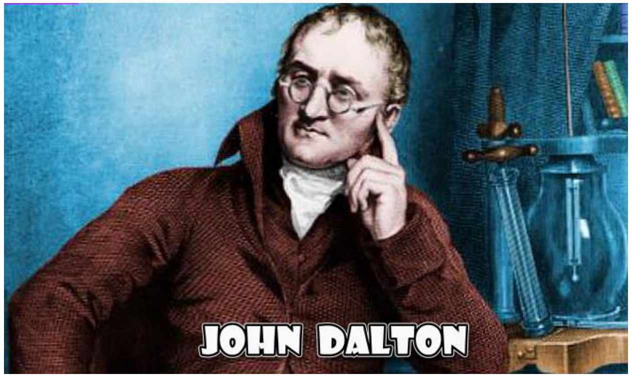
SUBATOMIC PARTICLE	SYMBOL	LOCATION	RELATIVE CHARGE	RELATIVE MASS
electron	e^-	outside nucleus	−1	1/1836
proton	p^+	inside nucleus	+1	1
neutron	n^0	inside nucleus	0	1

Atomic Structure Discovered

Ancient Greeks

- **Democritus** (460-362 BC) - indivisible particles called "atoms"
- Prevailing argument (Plato and Aristotle) - matter is continuously and infinitely divisible

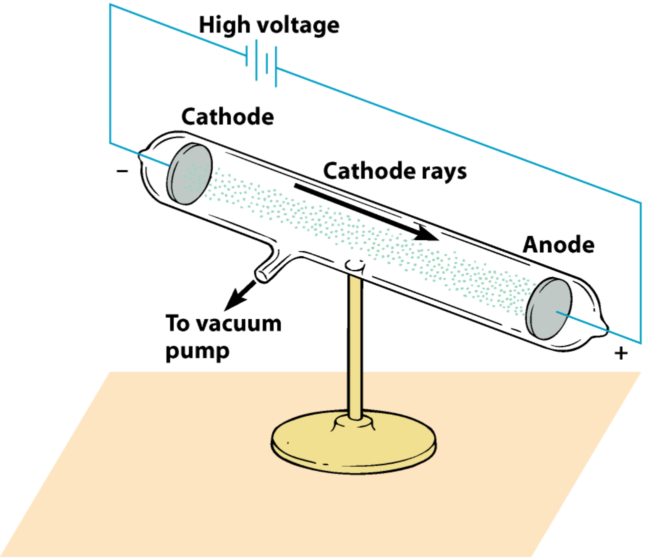
John Dalton (early 1800's) - reintroduced atomic theory to explain chemical reactions

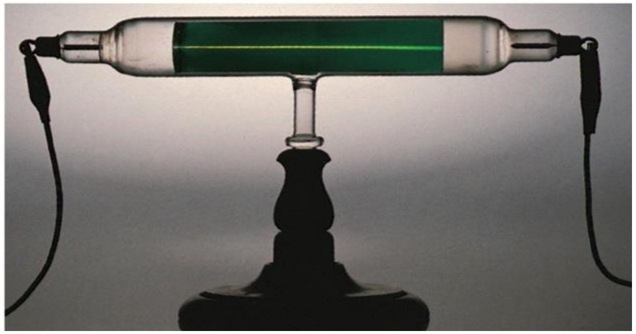


Discovery of the Electron

J. J. Thomson (late 1800's)

- Performed cathode ray experiments
- Discovered negatively charged electron
- Measured electron's charge-to-mass ratio
- Identified electron as a fundamental particle





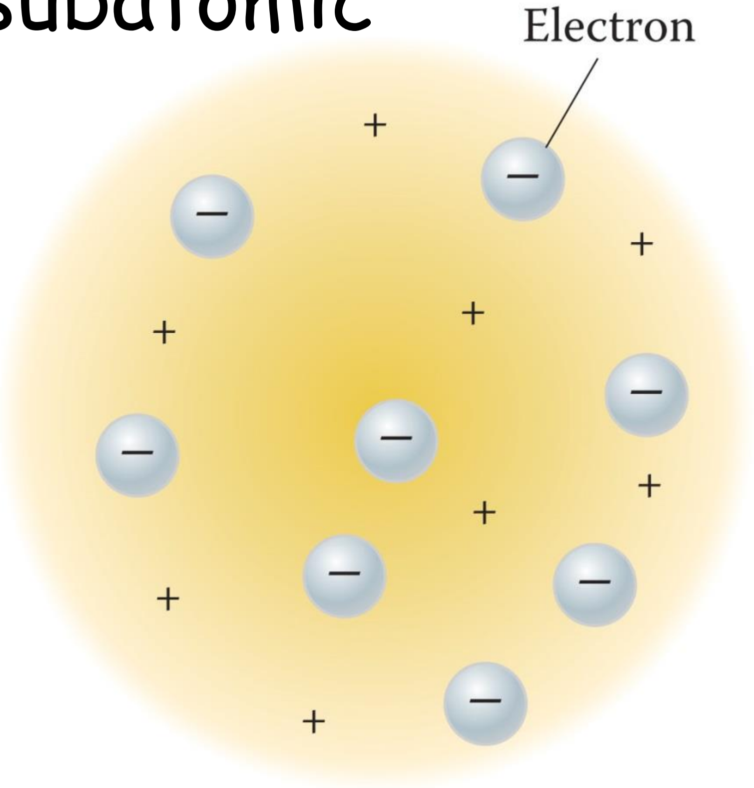
Cathode-Ray Tube

Thomson Model of the Atom

- Toward the end of the 1800s, evidence was seen that atoms were divisible.
- Two subatomic particles were discovered.
    1. Negatively charged ***electrons***, e^-.
    2. Positively charged ***protons***, p^+.
- An electron has a relative charge of **–1**, and a proton has a relative charge of **+1**.
- Found charge-to-mass ratio $\frac{q_e}{m_e}$

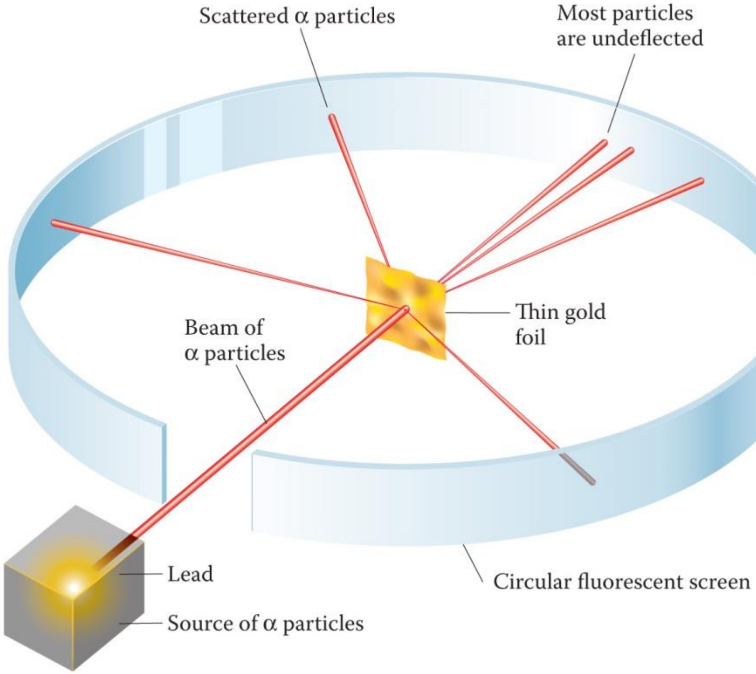
Thomson Model of the Atom, Continued

- J. J. Thomson proposed a subatomic model of the atom in 1903.
- Thomson proposed that the electrons were distributed evenly throughout a homogeneous sphere of positive charge.
- This was called the *plum pudding model* of the atom.



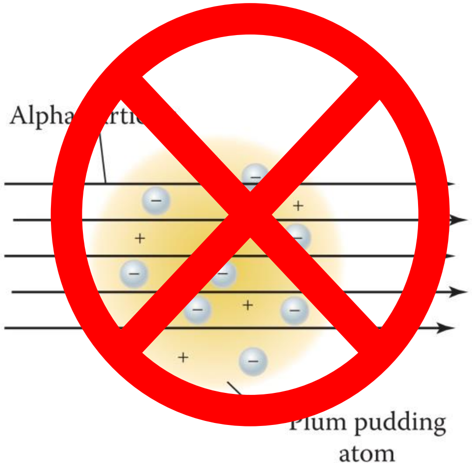
Rutherford Model of the Atom

- Rutherford fired alpha particles (positive particles) at thin gold foils. If the plum pudding model of the atom was correct, α particles should pass through undeflected.
- However, some of the alpha particles were deflected backward.

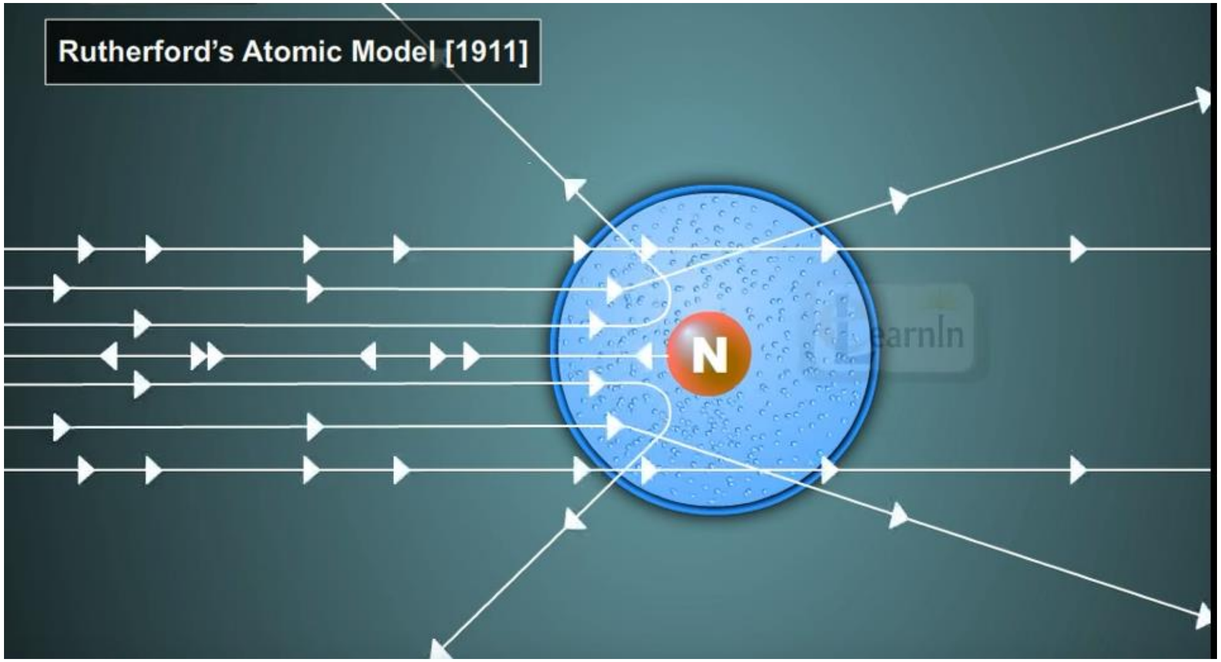


Rutherford Model of the Atom, Continued

- Most of the alpha particles passed through the foil because an atom is largely empty space.
- At the center of an atom is the ***atomic nucleus***, which contains the atom’s protons.



The alpha particles that bounced backward did so after striking the dense nucleus.

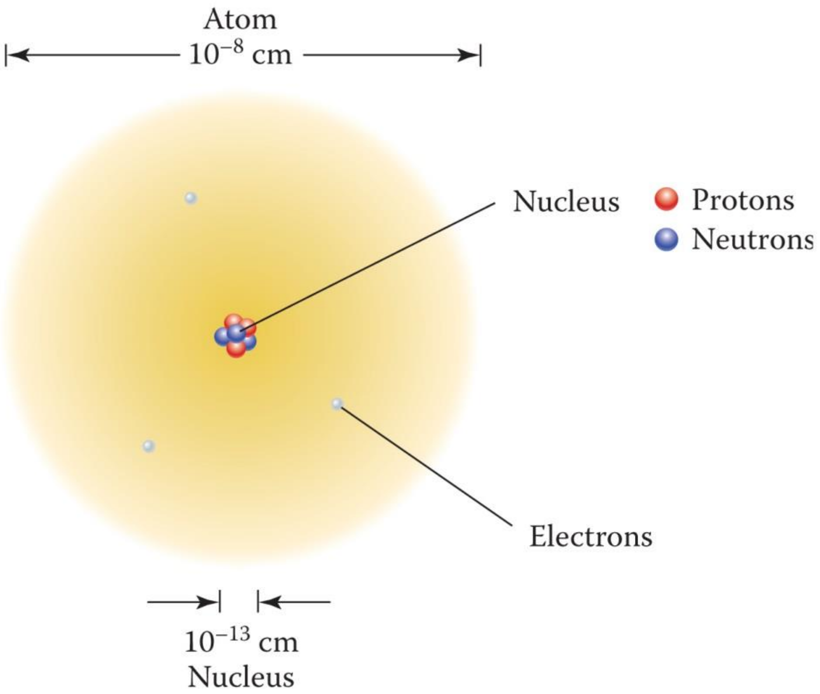


Rutherford Model of the Atom, Continued

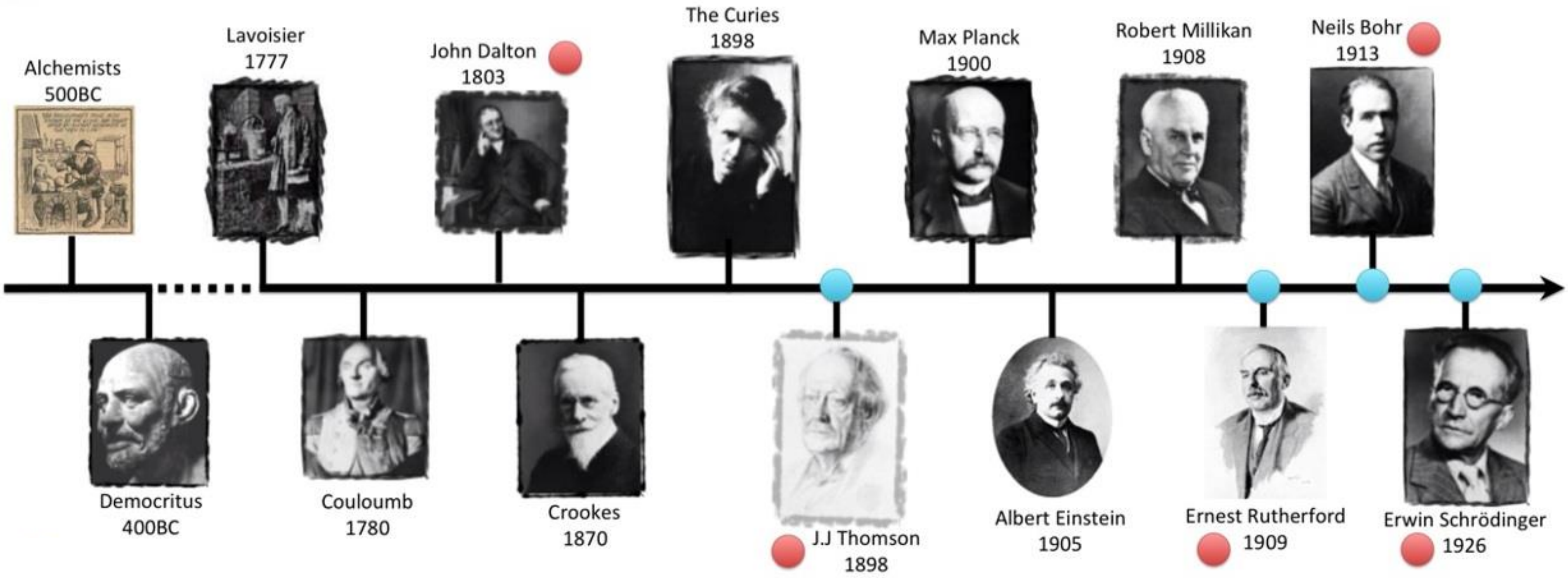
- Rutherford proposed a new model of the atom:

  The negatively charged electrons are distributed around a positively charged nucleus.

- An atom has a diameter of about 1 × 10^{-8} cm and the nucleus has a diameter of about 1 × 10^{-13} cm.
- If an atom were the size of the Superdome, the nucleus would be the size of a marble.



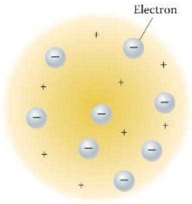
The atom

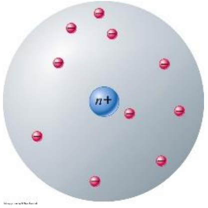

Alchemists
500BC
Democritus
400BC
Lavoisier
1777
Couloumb
1780
John Dalton
1803
Crookes
1870
The Curies
1898
J.J Thomson
1898
Max Planck
1900
Albert Einstein
1905
Robert Millikan
1908
Ernest Rutherford
1909
Neils Bohr
1913
Erwin Schrödinger
1926

The atom----a model

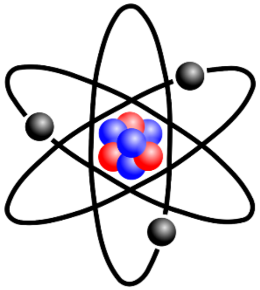
Greek
Atomos
~400BC

Dalton
1800AC

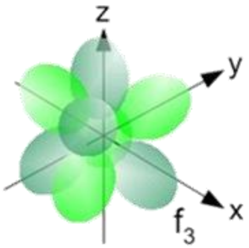




Thomson
+ Millikan
(Plum model)
Rutherford



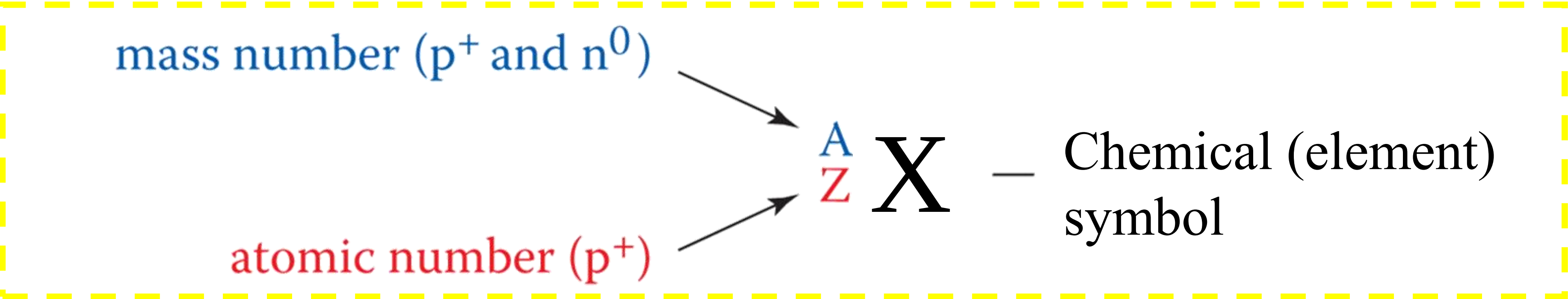
Orbits
Bohr model



Orbitals
Quantum

Atomic Notation

- Each element has a characteristic number of protons in the nucleus. This is the ***atomic number, Z.***
- The total number of protons and neutrons in the nucleus of an atom is the ***mass number, A.***
- We use ***atomic notation*** to display the number of protons and neutrons in the nucleus of an atom:



mass number (p^+ and n^0)

$${}^{A}_{Z}X$$ – Chemical (element) symbol

atomic number (p^+)

Mass number $${}^{2}_{1}\mathrm{H}$$ Chemical Symbol

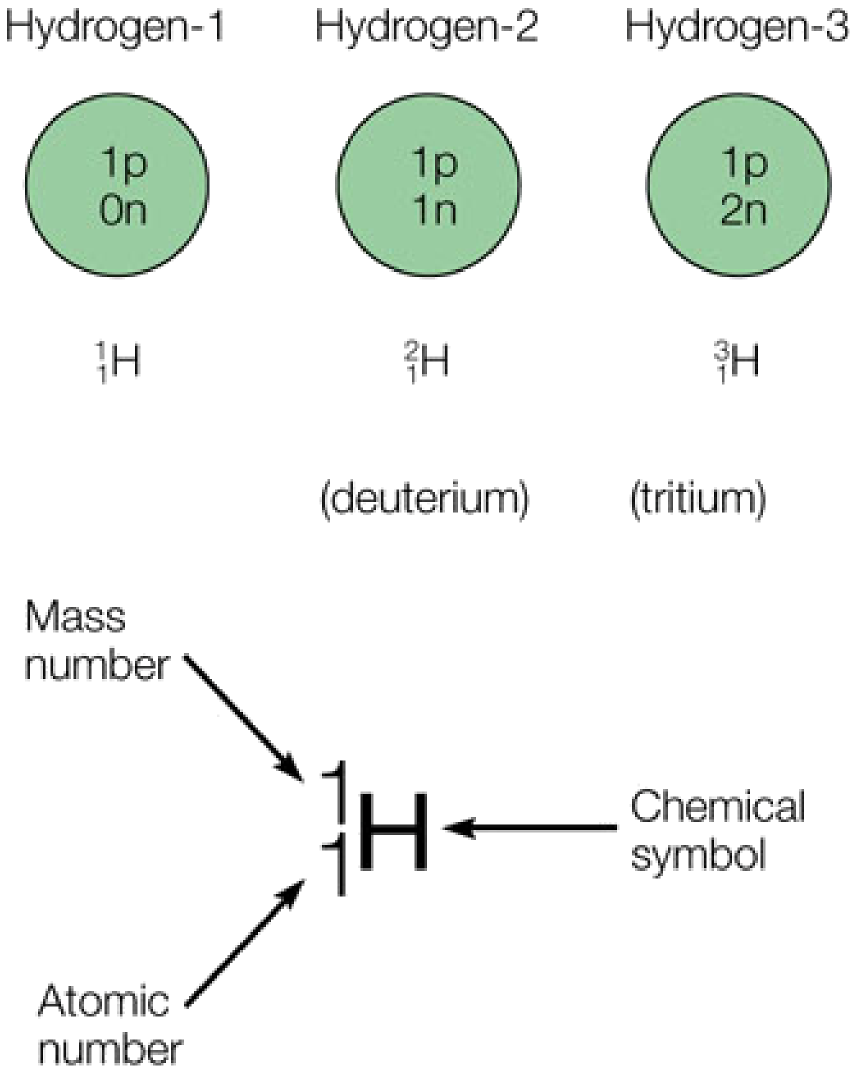
Atomic number

Using Atomic Notation

- An example: $^{29}_{14}\text{Si}$
- The element is silicon (symbol Si).
- The atomic number is 14; silicon has 14 protons.
- The mass number is 29; the atom of silicon has 29 protons + neutrons.
- The number of neutrons is $A - Z$ = 29 - 14 = 15 neutrons.

The Nuclear Atom

- Atomic number
  - Number of protons in nucleus
  - Elements distinguished by atomic number
  - 113 elements identified
  - Number of protons = number of electrons *in neutral atoms*
- **Isotopes**
  - Same number of protons; different number of neutrons



Learning Check

There are three naturally occurring isotopes of carbon: ^{12}C, ^{13}C, and ^{14}C. State the number of protons, neutrons, and electrons in each of these isotopes.

	$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$
#p			
#n			
#e			

Using Atomic Notation

If a neutral element has the following chemical symbol, how many electrons does it have?

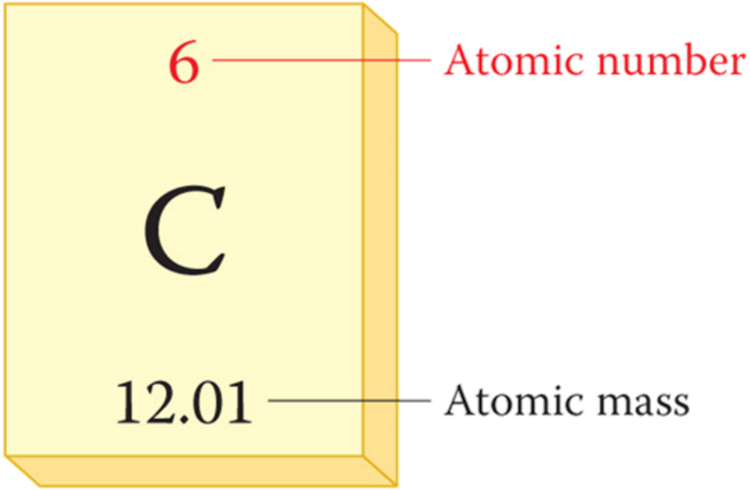
$${}^{235}_{92}\mathrm{U}$$

A) 92
B) 82
C) 235
D) 143
E) none of the above

The atom: atomic notation

Complete the following table.

Atomic Notation	Atomic Number	Mass Number	Number of p^+	Number of n^o	Number of e^-
		209	83		
				74	53
$^{53}_{24}Cr$					



Average mass

- The average mass is calculated by multiplying the mass for each isotope by the fraction of the isotope (%/100) and adding the numbers together.

Average mass= (mass of isotope 1)(fraction abundance of isotope 1) +
(mass of isotope 2)(fraction abundance of isotope 2) +…

All Isotopes are NOT Created Equal

$$(\text{isotope mass 1})\times(\text{abundance 1})+(\text{isotope mass 2})\times(\text{abundance 2})=\text{average atomic mass}$$

- ^{35}Cl = 34.9689 amu
  - % Abundance = 75.77% => 0.7577
- ^{37}Cl = 36.9659 amu
  - % Abundance = 24.23% => 0.2423

$$(\text{isotope mass 1})\times(\text{abundance 1})+(\text{isotope mass 2})\times(\text{abundance 2})=\text{average atomic mass}$$

34.9689 **x** 0.7577 + 36.9659 **x** 0.2423 = 35.45amu

Where have I seen this before?

Periodic Table gives *AVERAGE ATOMIC MASS* in amu!!

Average Atomic Mass

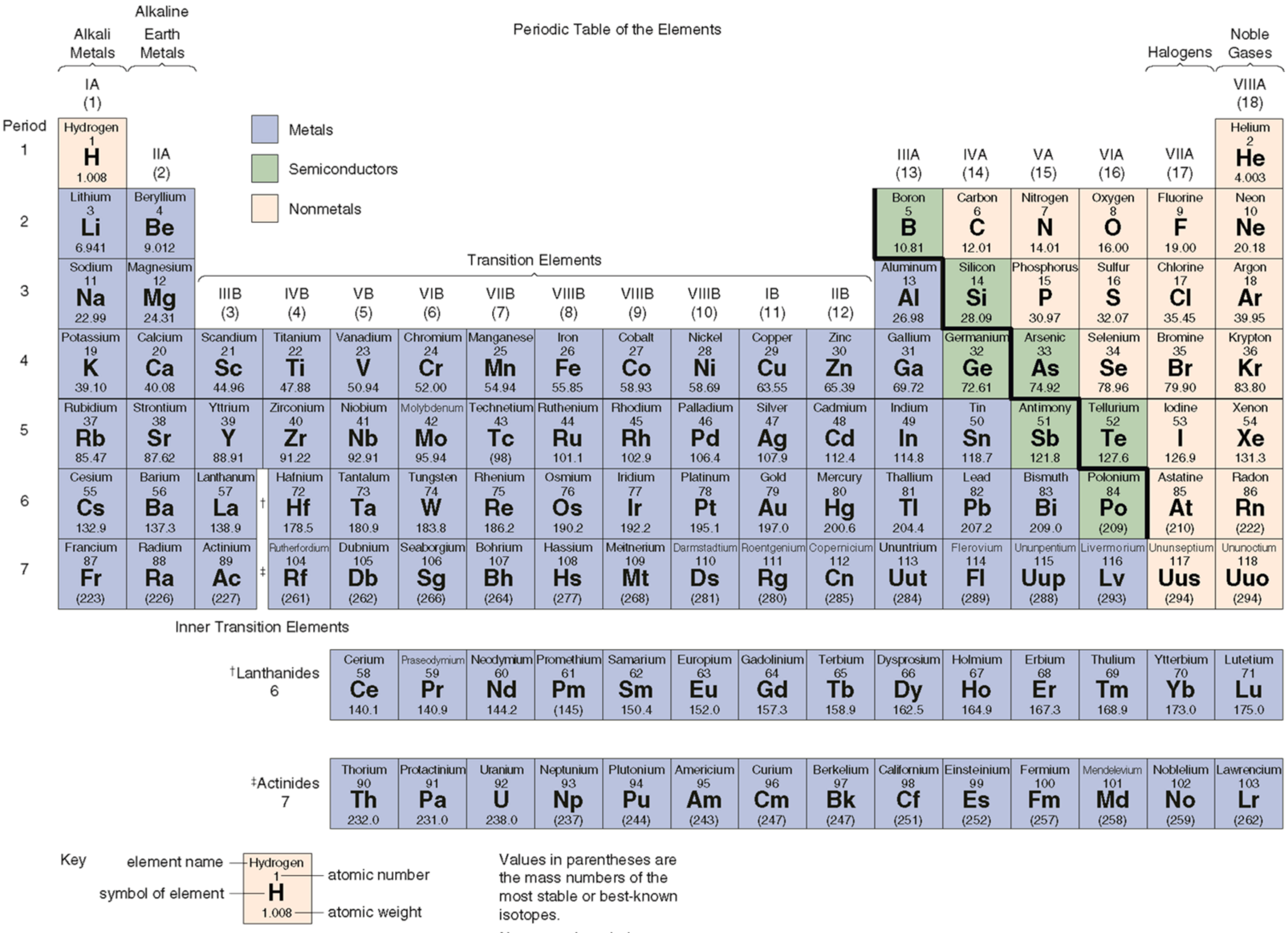
- Ex:
  Gallium has two isotopes:
  1. ^{69}Ga, with a mass of 68.926 amu and 60.11% abundance.
  2. ^{71}Ga, with a mass of 70.925 amu and 39.89% abundance.

Average mass= (mass of isotope 1)(fraction abundance of isotope 1) +
(mass of isotope 2)(fraction abundance of isotope 2) +…

The average atomic mass of copper is:

(68.926 amu)(0.6011) + (70.925 amu)(0.3989) = 69.72 amu

The Periodic Table



Periodic Table of the Elements

🟦 Metals
🟩 Semiconductors
🟧 Nonmetals

	Alkali Metals	Alkaline Earth Metals	Transition Elements														Halogens	Noble Gases
Period	IA (1)	IIA (2)	IIIB (3)	IVB (4)	VB (5)	VIB (6)	VIIB (7)	VIIIB (8)	VIIIB (9)	VIIIB (10)	IB (11)	IIB (12)	IIIA (13)	IVA (14)	VA (15)	VIA (16)	VIIA (17)	VIIIA (18)
1	Hydrogen 1 **H** 1.008																	Helium 2 **He** 4.003
2	Lithium 3 **Li** 6.941	Beryllium 4 **Be** 9.012											Boron 5 **B** 10.81	Carbon 6 **C** 12.01	Nitrogen 7 **N** 14.01	Oxygen 8 **O** 16.00	Fluorine 9 **F** 19.00	Neon 10 **Ne** 20.18
3	Sodium 11 **Na** 22.99	Magnesium 12 **Mg** 24.31											Aluminum 13 **Al** 26.98	Silicon 14 **Si** 28.09	Phosphorus 15 **P** 30.97	Sulfur 16 **S** 32.07	Chlorine 17 **Cl** 35.45	Argon 18 **Ar** 39.95
4	Potassium 19 **K** 39.10	Calcium 20 **Ca** 40.08	Scandium 21 **Sc** 44.96	Titanium 22 **Ti** 47.88	Vanadium 23 **V** 50.94	Chromium 24 **Cr** 52.00	Manganese 25 **Mn** 54.94	Iron 26 **Fe** 55.85	Cobalt 27 **Co** 58.93	Nickel 28 **Ni** 58.69	Copper 29 **Cu** 63.55	Zinc 30 **Zn** 65.39	Gallium 31 **Ga** 69.72	Germanium 32 **Ge** 72.61	Arsenic 33 **As** 74.92	Selenium 34 **Se** 78.96	Bromine 35 **Br** 79.90	Krypton 36 **Kr** 83.80
5	Rubidium 37 **Rb** 85.47	Strontium 38 **Sr** 87.62	Yttrium 39 **Y** 88.91	Zirconium 40 **Zr** 91.22	Niobium 41 **Nb** 92.91	Molybdenum 42 **Mo** 95.94	Technetium 43 **Tc** (98)	Ruthenium 44 **Ru** 101.1	Rhodium 45 **Rh** 102.9	Palladium 46 **Pd** 106.4	Silver 47 **Ag** 107.9	Cadmium 48 **Cd** 112.4	Indium 49 **In** 114.8	Tin 50 **Sn** 118.7	Antimony 51 **Sb** 121.8	Tellurium 52 **Te** 127.6	Iodine 53 **I** 126.9	Xenon 54 **Xe** 131.3
6	Cesium 55 **Cs** 132.9	Barium 56 **Ba** 137.3	Lanthanum 57 **La** 138.9 †	Hafnium 72 **Hf** 178.5	Tantalum 73 **Ta** 180.9	Tungsten 74 **W** 183.8	Rhenium 75 **Re** 186.2	Osmium 76 **Os** 190.2	Iridium 77 **Ir** 192.2	Platinum 78 **Pt** 195.1	Gold 79 **Au** 197.0	Mercury 80 **Hg** 200.6	Thallium 81 **Tl** 204.4	Lead 82 **Pb** 207.2	Bismuth 83 **Bi** 209.0	Polonium 84 **Po** (209)	Astatine 85 **At** (210)	Radon 86 **Rn** (222)
7	Francium 87 **Fr** (223)	Radium 88 **Ra** (226)	Actinium 89 **Ac** (227) ‡	Rutherfordium 104 **Rf** (261)	Dubnium 105 **Db** (262)	Seaborgium 106 **Sg** (266)	Bohrium 107 **Bh** (264)	Hassium 108 **Hs** (277)	Meitnerium 109 **Mt** (268)	Darmstadtium 110 **Ds** (281)	Roentgenium 111 **Rg** (280)	Copernicium 112 **Cn** (285)	Ununtrium 113 **Uut** (284)	Flerovium 114 **Fl** (289)	Ununpentium 115 **Uup** (288)	Livermorium 116 **Lv** (293)	Ununseptium 117 **Uus** (294)	Ununoctium 118 **Uuo** (294)

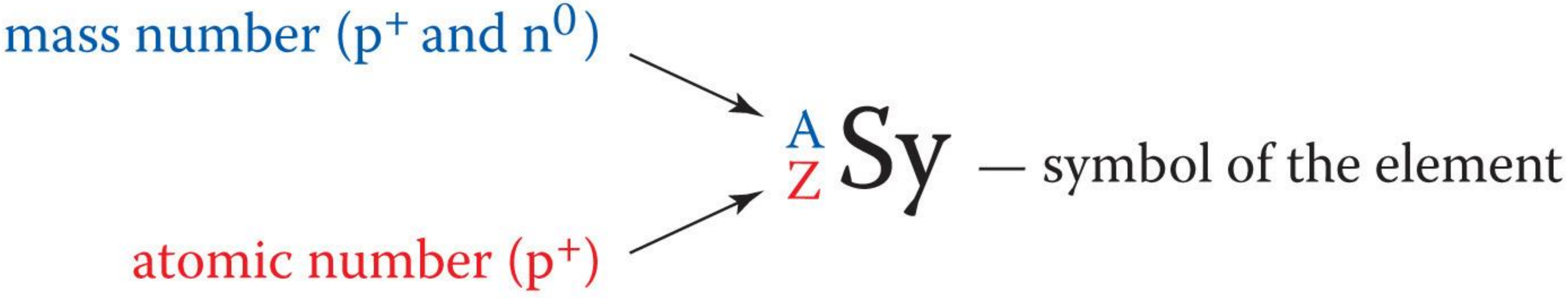
Inner Transition Elements

†Lanthanides 6	Cerium 58 **Ce** 140.1	Praseodymium 59 **Pr** 140.9	Neodymium 60 **Nd** 144.2	Promethium 61 **Pm** (145)	Samarium 62 **Sm** 150.4	Europium 63 **Eu** 152.0	Gadolinium 64 **Gd** 157.3	Terbium 65 **Tb** 158.9	Dysprosium 66 **Dy** 162.5	Holmium 67 **Ho** 164.9	Erbium 68 **Er** 167.3	Thulium 69 **Tm** 168.9	Ytterbium 70 **Yb** 173.0	Lutetium 71 **Lu** 175.0
‡Actinides 7	Thorium 90 **Th** 232.0	Protactinium 91 **Pa** 231.0	Uranium 92 **U** 238.0	Neptunium 93 **Np** (237)	Plutonium 94 **Pu** (244)	Americium 95 **Am** (243)	Curium 96 **Cm** (247)	Berkelium 97 **Bk** (247)	Californium 98 **Cf** (251)	Einsteinium 99 **Es** (252)	Fermium 100 **Fm** (257)	Mendelevium 101 **Md** (258)	Nobelium 102 **No** (259)	Lawrencium 103 **Lr** (262)

Key
element name — Hydrogen
atomic number — 1
symbol of element — **H**
atomic weight — 1.008

Values in parentheses are the mass numbers of the most stable or best-known isotopes.

Atomic Notation

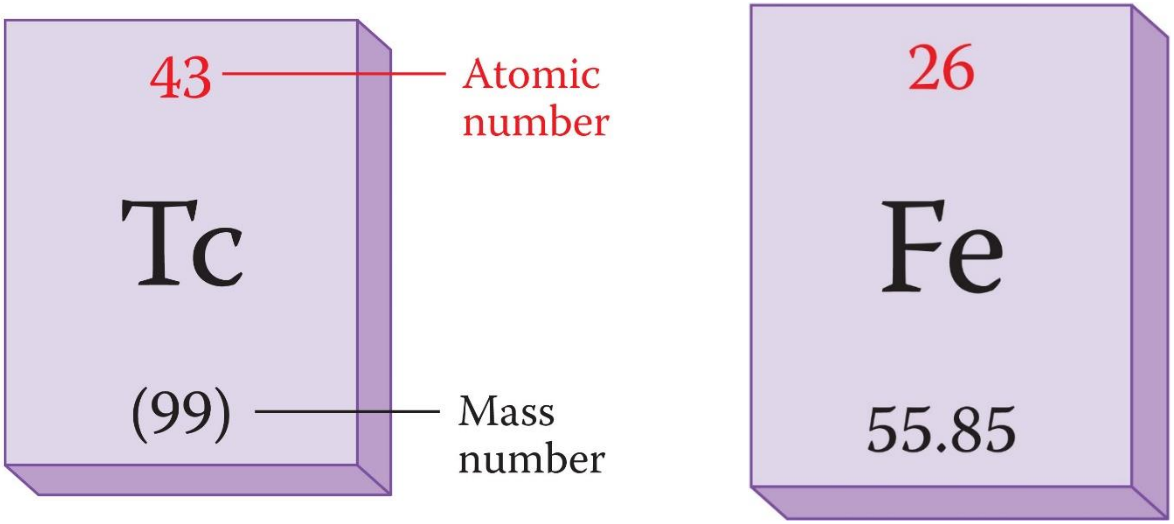


mass number (p^+ and n^0)

$^{A}_{Z}\text{Sy}$ — symbol of the element

atomic number (p^+)

Periodic Table Notation



Radioactivity

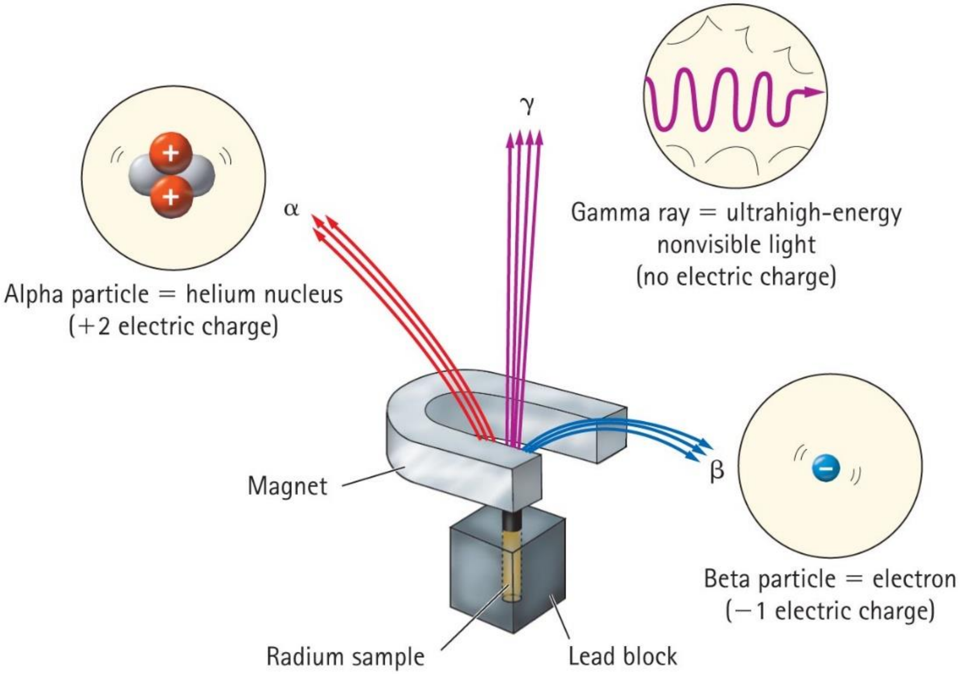
Radioactivity:

- Results from radioactive decay, which is the process whereby unstable atomic nuclei transform and emit radiation.
- Has existed longer than the human race.
- Most elements are not radioactive (99.9%)
- Elements greater than 82 may be radioactive

Radioactivity

Types of radiation:

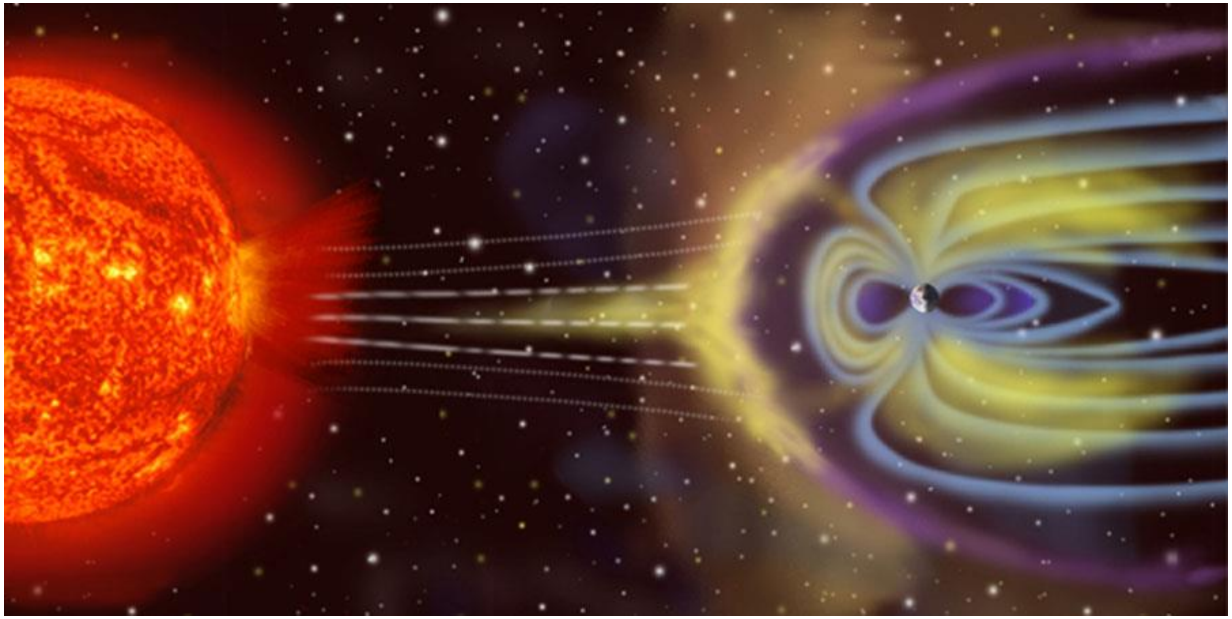
- alpha (α)—carries positive electrical charge
- beta (β)—carries negative electrical charge
- gamma (γ)—carries no charge



Radioactivity

Most radiation we encounter is:

- Natural background radiation that originates in Earth and space (cosmic rays from the Sun and stars).
- More intense at higher altitudes.



Radioactivity

Alpha particle:

- consists of two protons and two neutrons (a helium nucleus)
- loses energy quickly during interaction
- can be stopped easily by a few pieces of paper due to its large mass and double positive charge
- does not normally penetrate lightweight material (paper, clothing)
- causes significant damage to the surface of a material (living tissue) due to great kinetic energy
- picks up electrons and becomes harmless helium when traveling through air
- is deflected in the presence of magnetic or electric fields

Radioactivity

Beta particle:

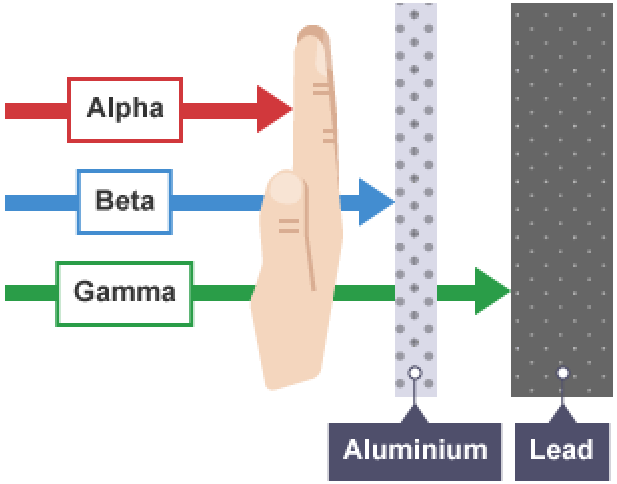
- is an ejected electron from a neutron
- has both a smaller mass and electric charge than an alpha particle, and moves faster
- loses energy at a slower rate in air and travels farther before stopping
- can be stopped by several sheets of aluminum foil
- penetrates fairly deeply into skin (potential for harming or killing living cells)
- once stopped, becomes an ordinary electron
- is deflected in the opposite direction to an alpha particle in the presence of magnetic and electric fields

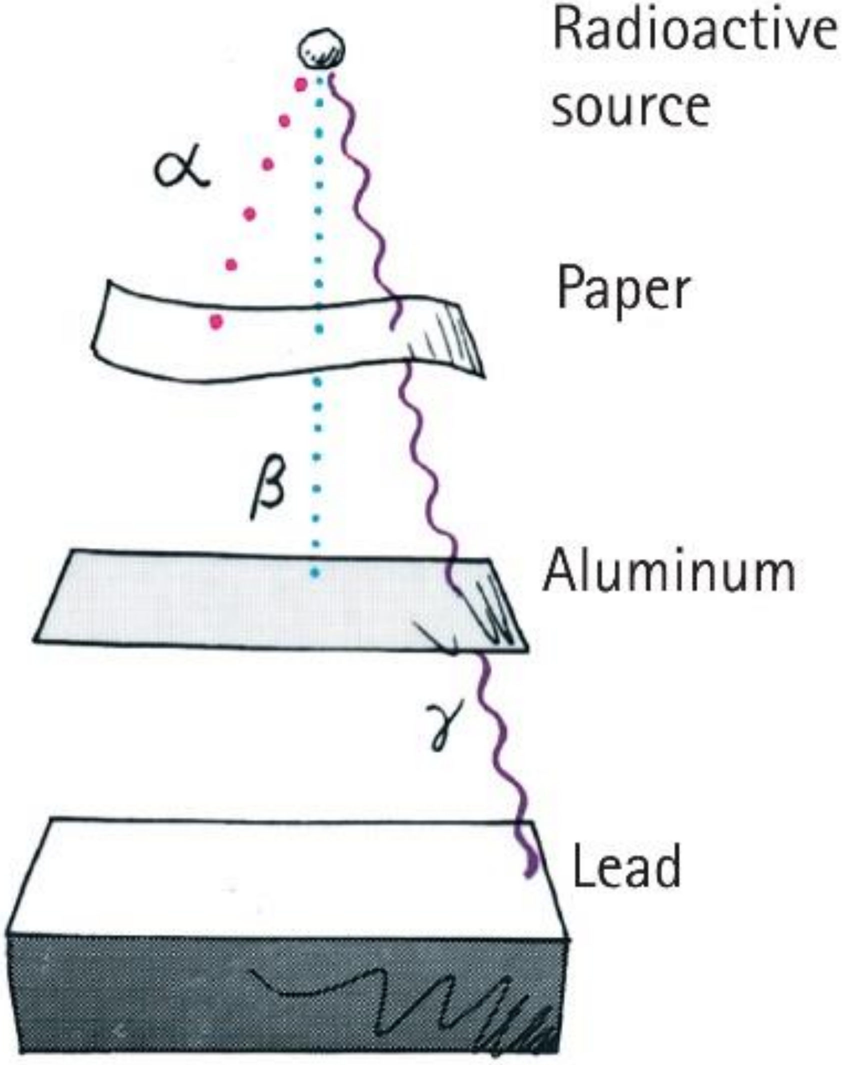
Radioactivity

Gamma rays:

- are high-frequency electromagnetic radiation
- are emitted when a nucleus in an excited state moves to a lower energy state
- are more harmful than alpha or beta particles
- are most penetrating because they have no mass or charge
- are pure energy, greater per photon than in visible or ultraviolet light and X-rays
- are unaffected by magnetic and electric fields, and therefore interact via direct hit with an atom

Radioactivity: Alpha, Beta and gamma rays





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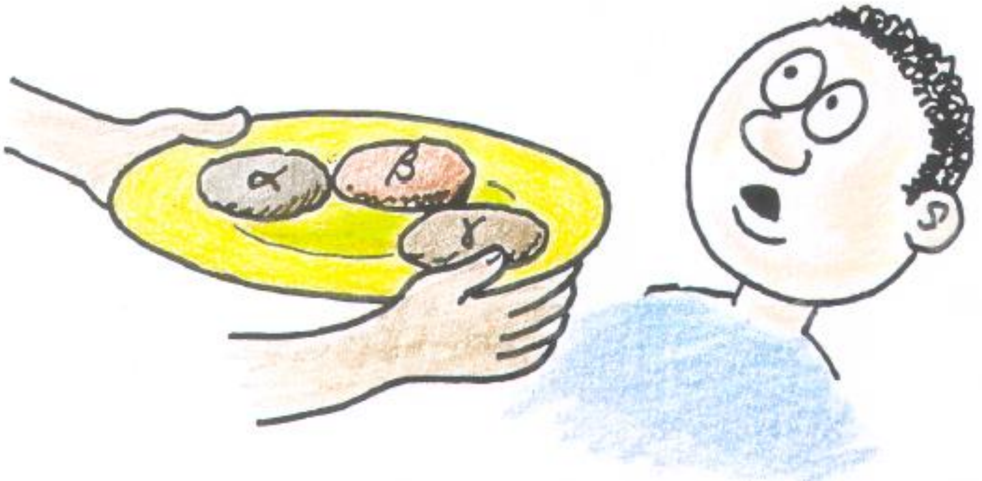
Radioactivity

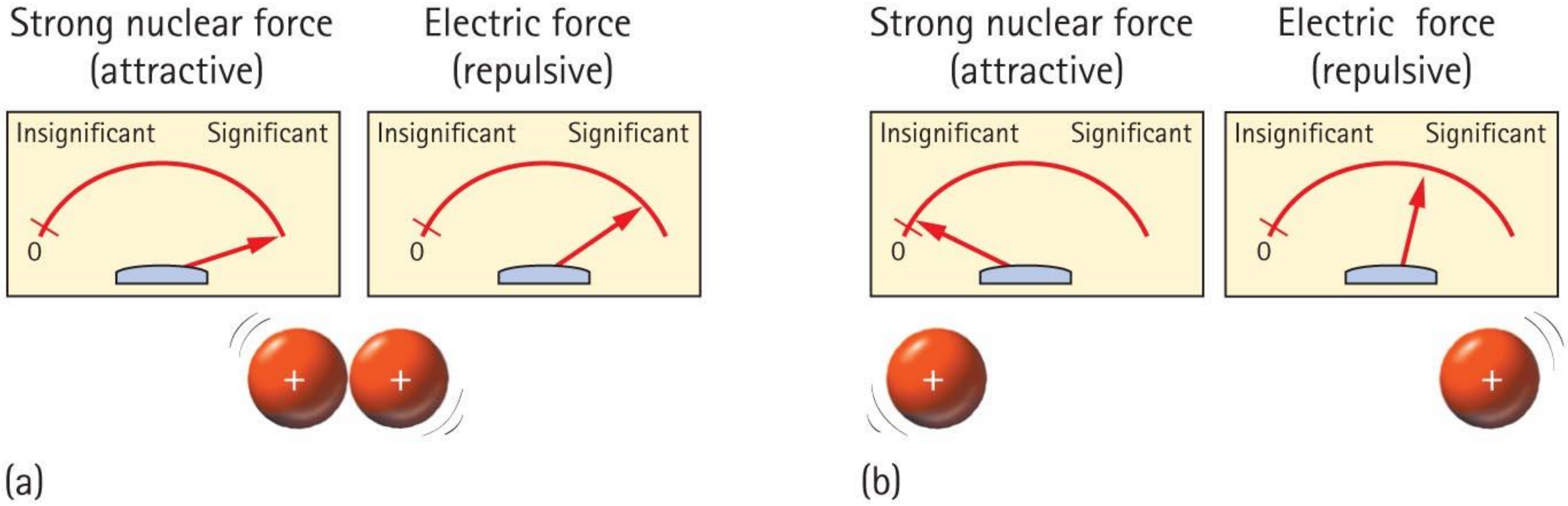
In class question

Suppose you are given three radioactive cookies—
one an alpha emitter,
one a beta emitter,
one a gamma emitter.
You must eat one, hold one in your hand, and put the other in your pocket.
How can you minimize your exposure to radiation?



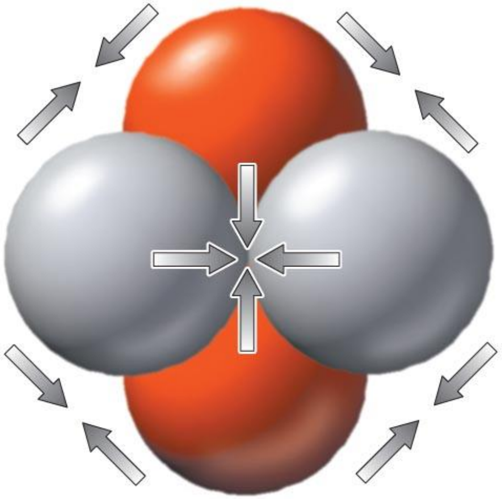
The Atomic Nucleus and the Strong Nuclear Force

The strong nuclear force : a very distance sensitive attraction between nucleons.

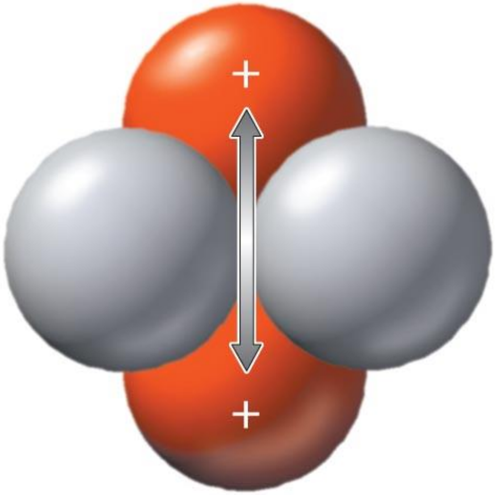


The Atomic Nucleus and the Strong Nuclear Force

The presence of neutrons helps hold the nucleus together.



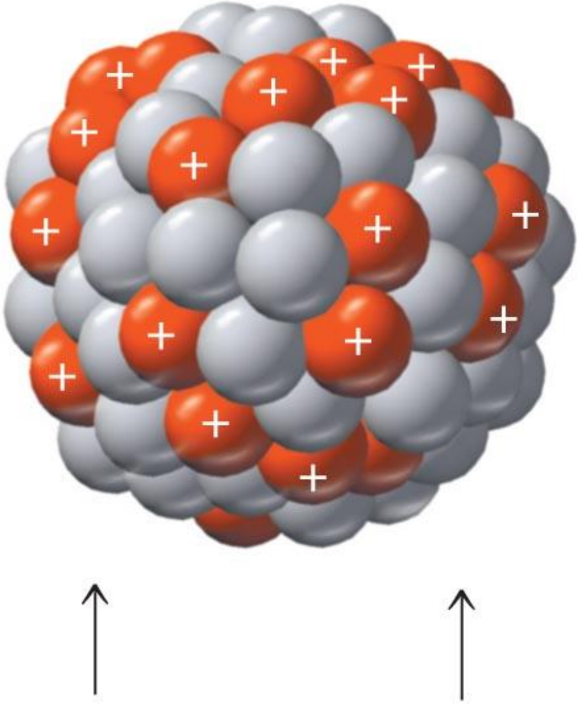
All nucleons, both protons and neutrons, attract one another by the strong nuclear force.



Only protons repel one another by the electric force.

The Atomic Nucleus and the Strong Nuclear Force

But in large nuclei, far-apart neutrons are less effective in holding a nucleus together.



(b) Nucleons far apart