Early Ideas about Matter

atom

- The smallest piece of the element with all the chemical properties of the element
- an old and new idea

Greeks

- Discontinuists
  - Democritus
- Continuists
  - Aristotle

Discontinuists

- Democritus
- Believed there was a smallest piece
- “atomos” = indivisible

Continuists

- Continuists thought there was no “smallest piece”
- they believed a bar of gold, for example, could be cut into smaller pieces forever

Aristotle's ideas

- There are four elements
  – earth, air, fire, and water
- all matter is composed of these four elements in different proportions

The Alchemists

- Tried to turn lead into gold
  - put more fire into it
  - the “medicine stone” would “cure” the Pb
- developed many lab techniques and apparatus

The Renaissance

- A new approach to science
- experiment to test if the hypothesis is true
- many of Aristotle's ideas were shown to be wrong

Law of Conservation of Mass

- Lavoisier> France, 1790’s
- Matter (or mass) is neither created nor destroyed in an ordinary chemical reaction

Lavoisier did three important things:

1. brought in an entire new language for chemistry
2. established the correct identity of the elements and distinguished them from compounds, showing that those are combinations of elements
3. introduced the art of precise measurements.

- He turned chemistry into a physical science and can properly regarded as the father of modern chemistry.

Law of Definite Proportions

- In a given compound, elements are always combined in the same proportion by mass.
- Ex: H_2O is always 11% H, 89% O by mass.

Dalton's Atomic Theory

- All matter is composed of atoms
  - atoms are indestructible
  - "billiard ball" model
- In a chemical reaction, atoms are rearranged
  - conservation of mass

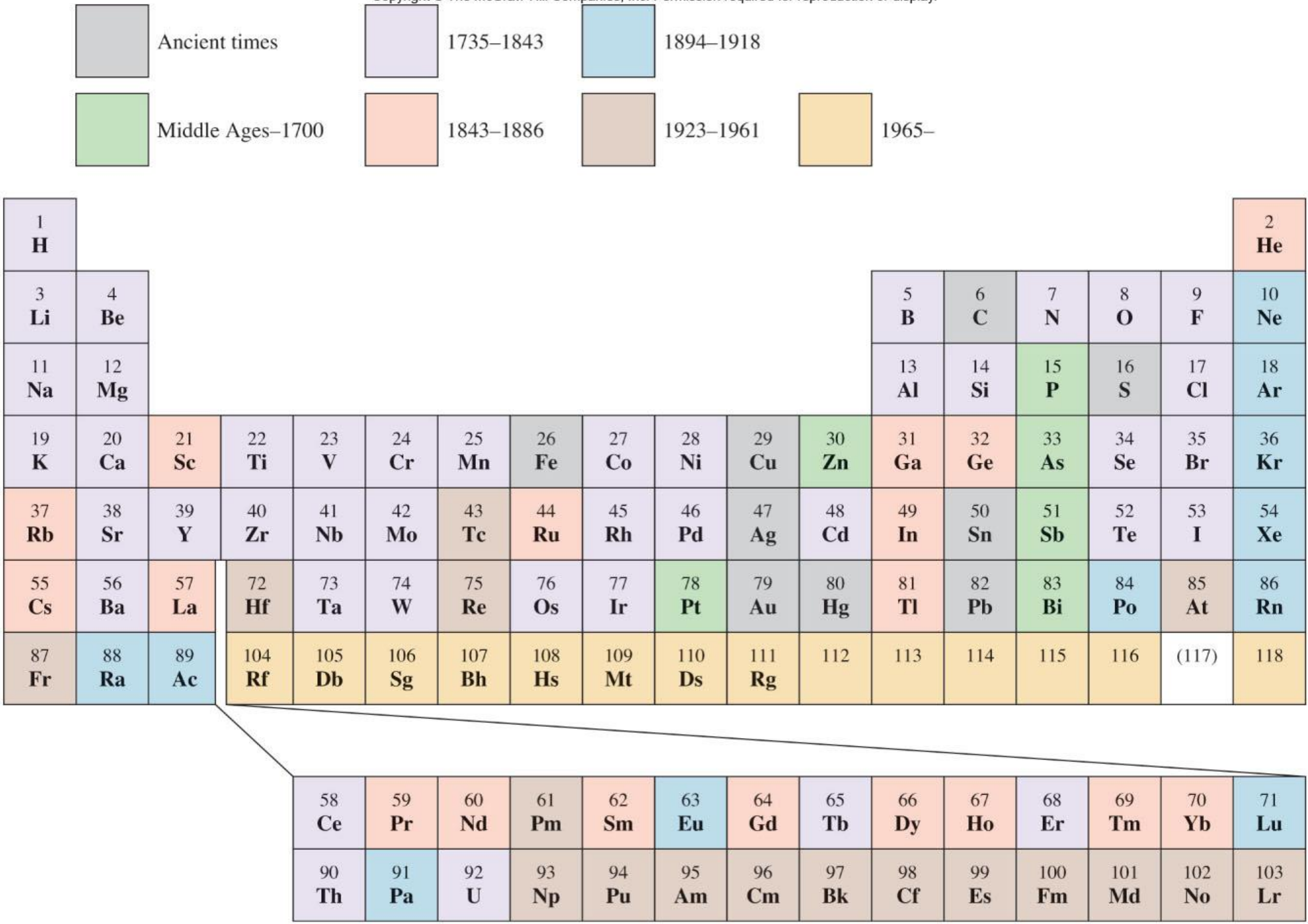
John Dalton

- All atoms of the same element are identical
- Atoms of one element are different from the atoms of any other element
  - elements could be identified and distinguished from each other

- Atoms combine to form compounds in small whole number ratios.
  - Ex: could be XY, X_2Y, XY_2, etc, but never $X_{1 1/2}Y$

What came next?

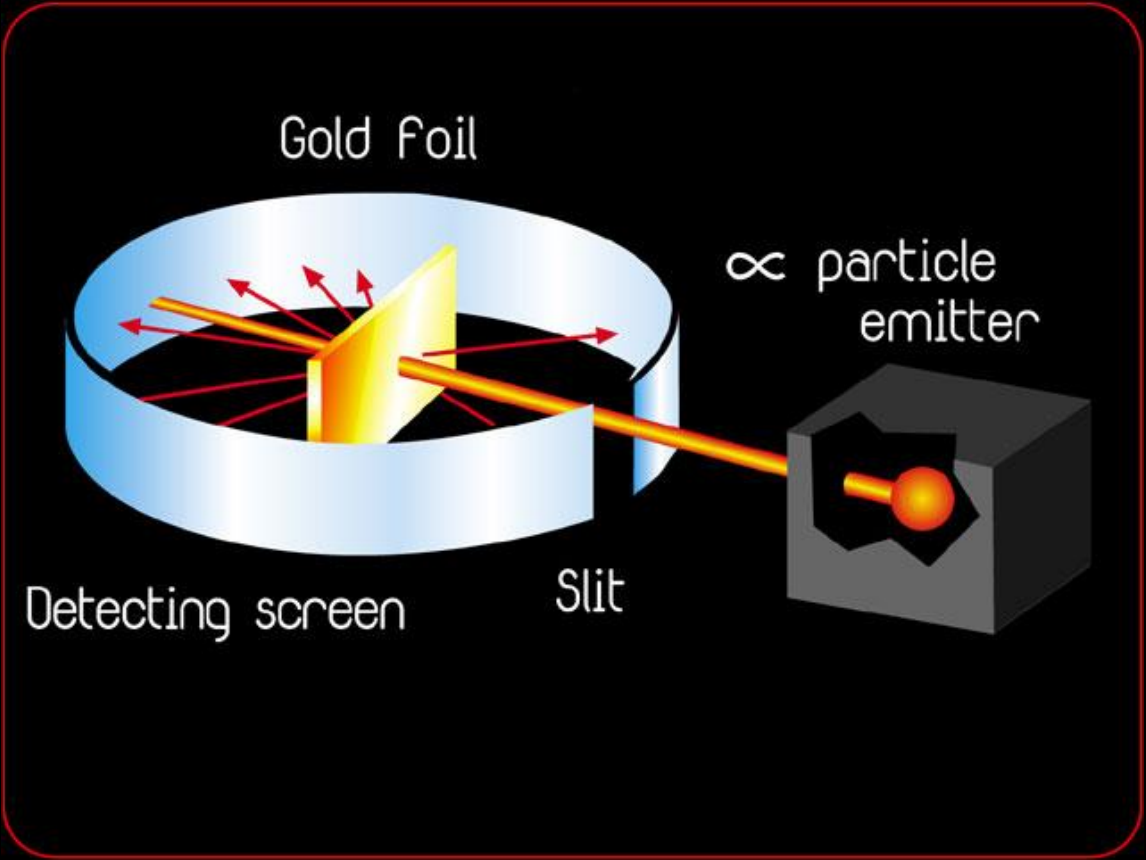
- 49 new elements were discovered between 1801 - 1900
- new particles were discovered
  - alpha, beta, gamma - radiation
  - particles smaller than atoms


Ancient times
1735–1843
1894–1918
Middle Ages–1700
1843–1886
1923–1961
1965–
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 La
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 Ac
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112
113
114
115
116
(117)
118
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr

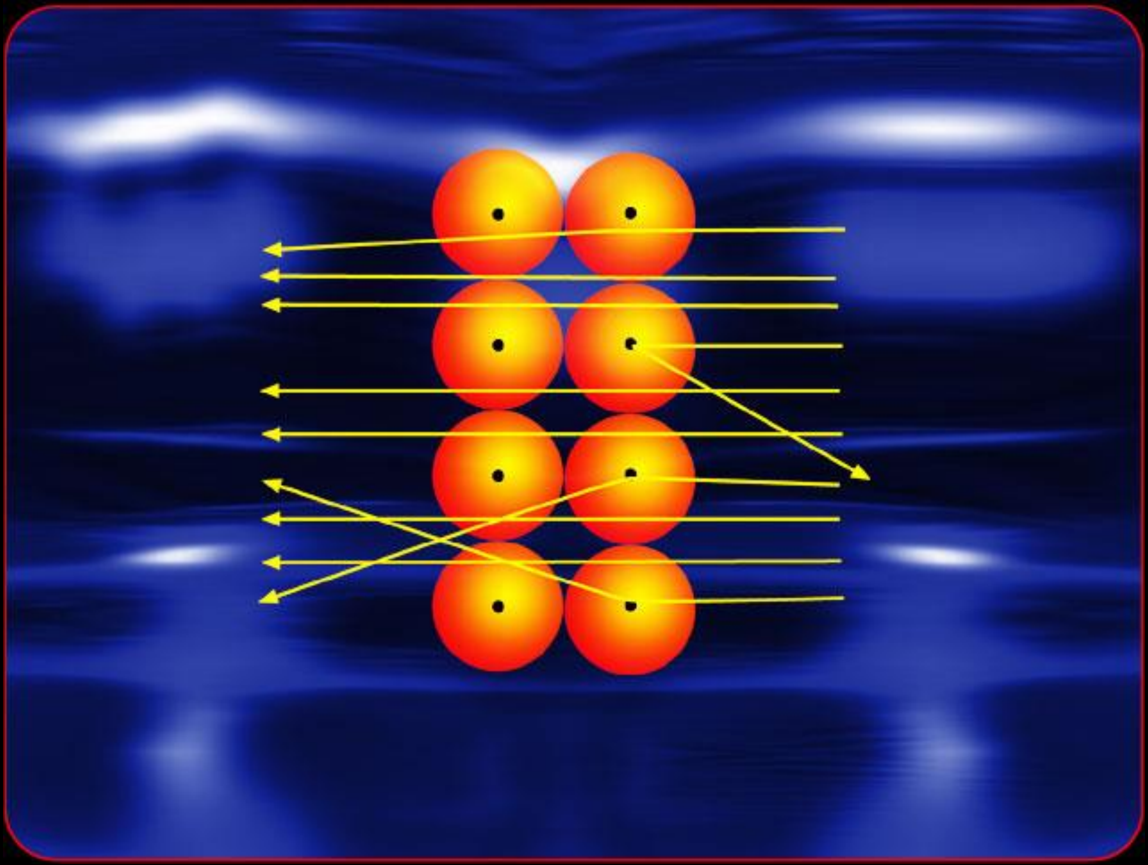
- 1897: JJ Thomson discovered electrons
  - smaller than atoms
  - negatively charged
    - Robert Millikan
  - problem with Dalton's model

- 1910 Rutherford's Gold Foil Experiment
  - nuclear model of atom
- http://www.shsu.edu/~chm_tgc/sounds/pushmovies/l2ruther.gif/

Gold Foil experiment setup



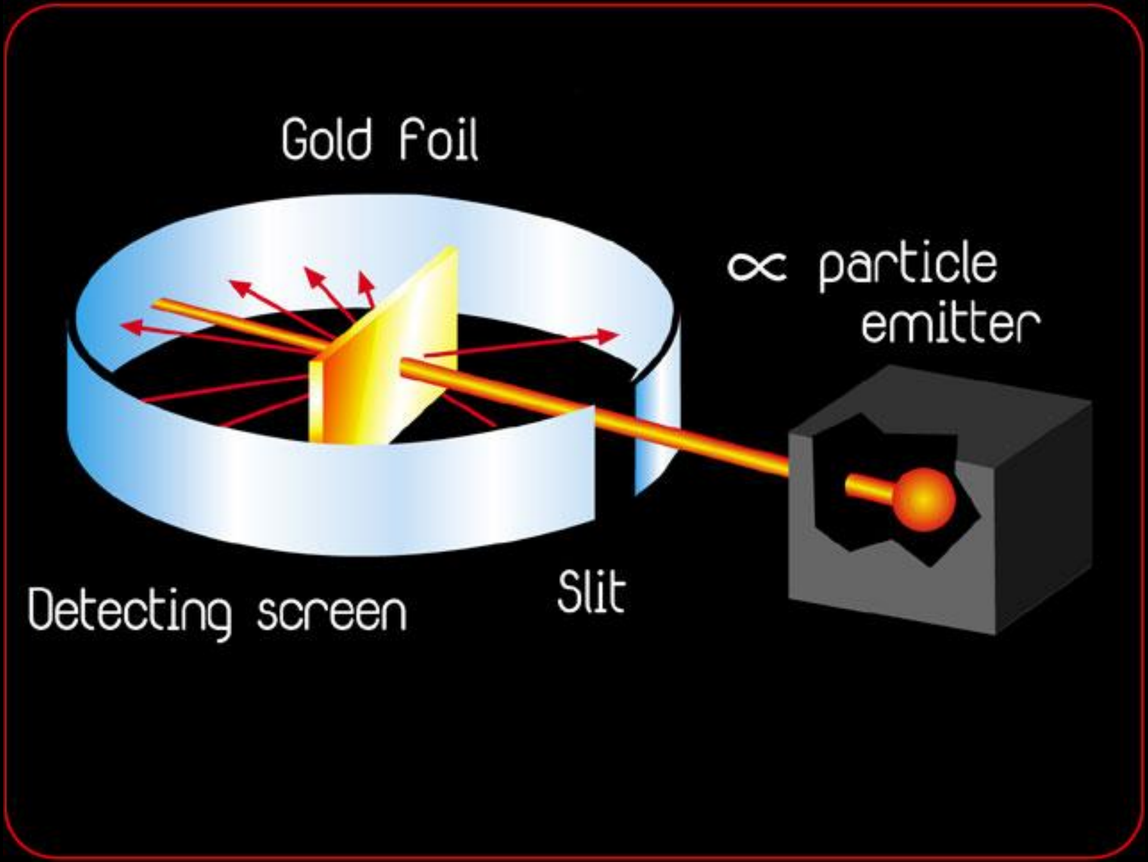
Gold Foil Experiment - results



online model

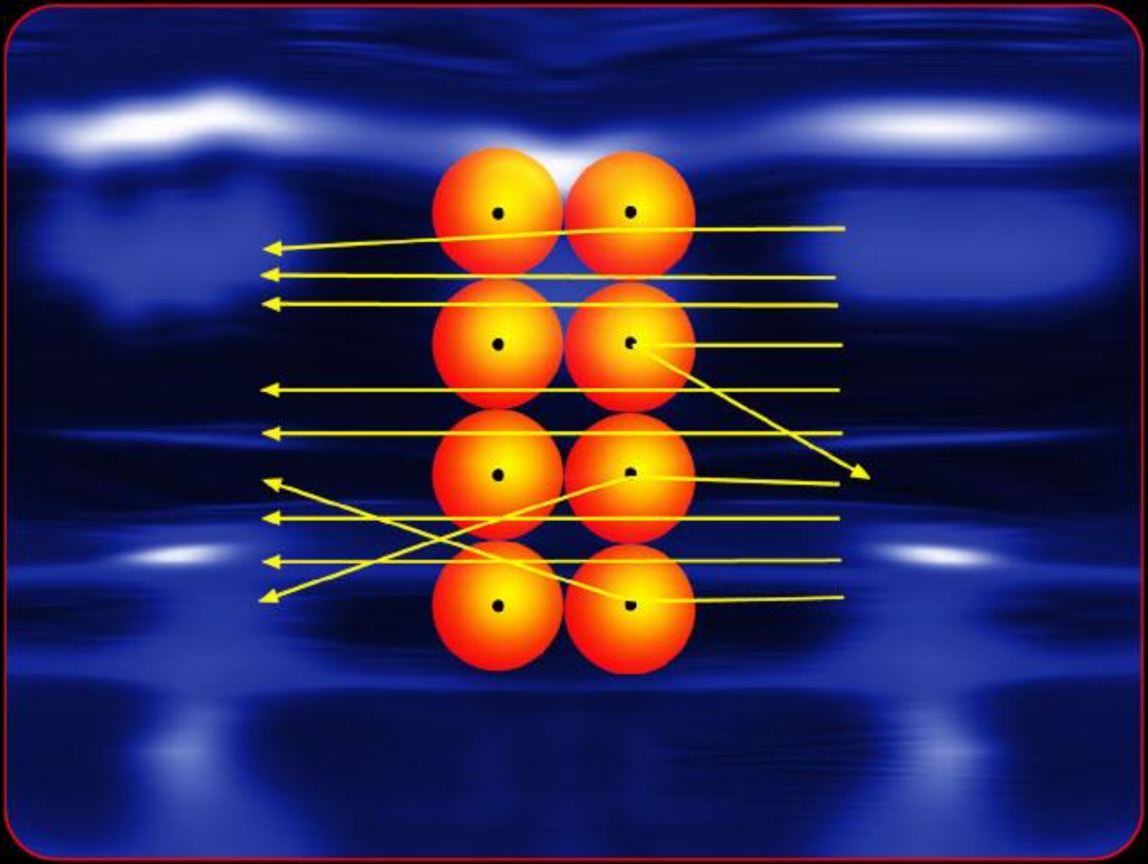
Early Ideas about Matter

Gold Foil experiment setup



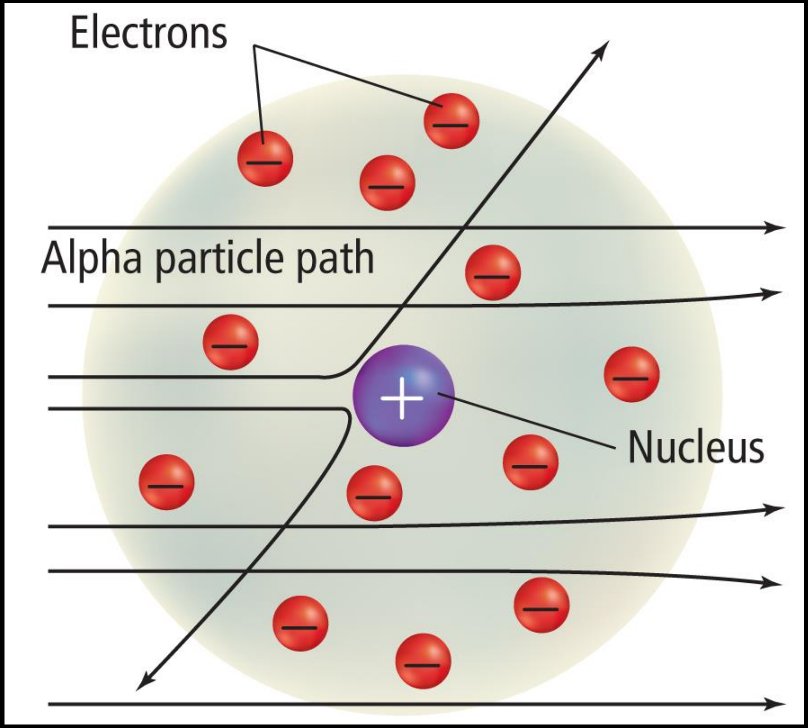
online model

Gold Foil Experiment - results



online model

- The repulsive force between the positively charged nucleus and positive alpha particles caused the deflections.



Modern atom

- Nucleus
  - is geometric center of the atom
  - very small and dense
  - nearly all of the atom’s mass
  - gives the atom its identity
  - protons (+) and neutrons
  - Nucleus held together by the “strong force”

- Electron cloud
  - gives the atom its size
  - mostly empty space
  - electrons
  - electrons do not “orbit” like planets; more like bees/beehive

Summary of the subatomic particles

Summary of the subatomic particles

particle		where?	Mass	who?
Proton	p^+	Nucleus	1.007amu	Rutherford
Neutron	n^o	Nucleus	1.008amu	Chadwick
Electron	e^-	Electron cloud	0.00055 amu	Thomson

Atomic Number (Z)

- the **number of protons** in the nucleus of an atom
- gives the atom it's identity
- also, equal to the number of *electrons* in a *neutral* atom

Mass Number (A)

- Equal to the number of protons **plus** the number of neutrons in the nucleus of an atom
- #n° = mass # - atomic #
- #n° = A - Z

Important note!

- The atomic number of an element is on the periodic table, but *the mass number is usually not*!
- The location of the numbers on the periodic table is at the printer's discretion

- The good news:
  - all atoms of the same element have the same atomic number
- The bad news:
  - not all atoms of the same element have the same mass number
- What is different?
  - The number of neutrons

isotopes

- Atoms of the same element with different mass numbers
  - – different numbers of neutrons
- different *versions* of the same element
- **no** difference in chemical properties
- only fundamental difference is in mass

Isotope symbols

- The elements symbol, plus...
- the mass # (A) is written in the upper left corner
- the atomic # (Z) is written in the lower left corner

$$^{82}_{36}\mathrm{Kr}$$

Examples of isotope symbols

- Compare carbon-12, carbon-13, and carbon-14
- each have the same number of protons, but a different number of neutrons

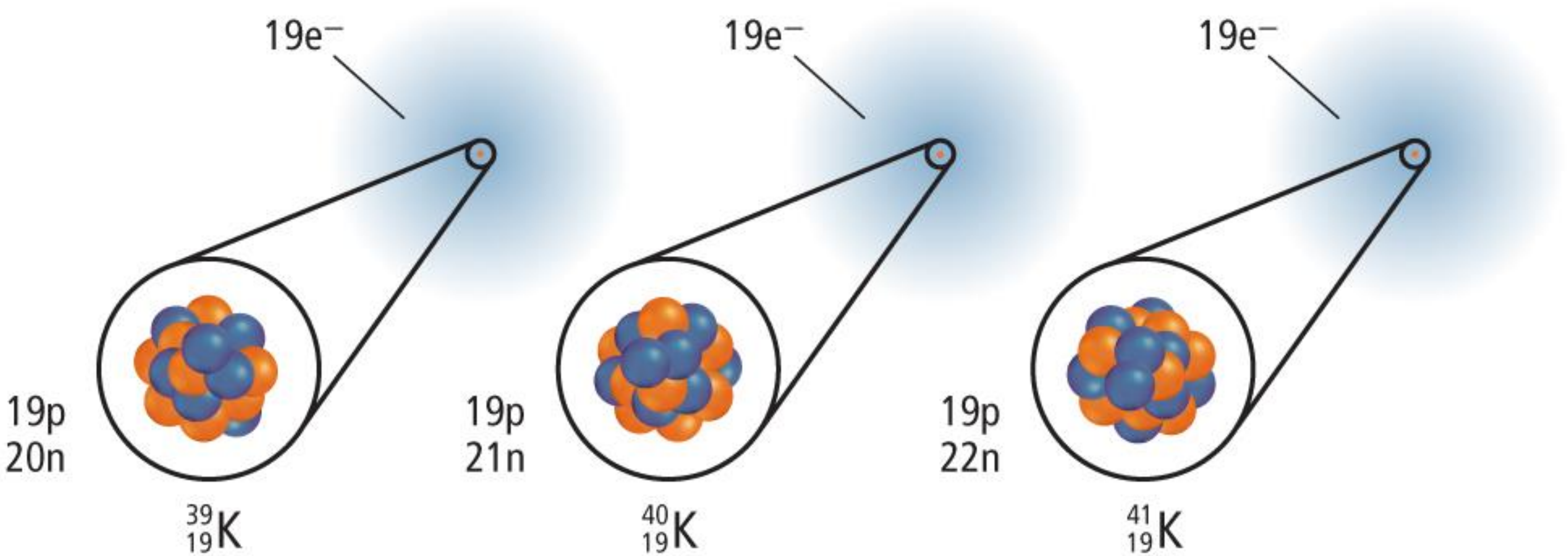
Examples of isotope symbols

$^{12}_{6}C$	$6p^+$	$6n^o$
$^{13}_{6}C$	$6p^+$	$7n^o$
$^{14}_{6}C$	$6p^+$	$8n^o$

Early Ideas about Matter

Isotopes and Mass Number

	Potassium-39	Potassium-40	Potassium-41
Protons	19	19	19
Neutrons	20	21	22
Electrons	19	19	19



Ion

- An atom that is no longer neutral
  - $\#p^{+} \neq \#e^{-}$
- The atom either <u>gains</u> or <u>loses</u> ***electrons***
- The nucleus is not directly involved in <u>ionization</u>
- *The number of protons does not change*

How does an atom become an ion?

- If the atom gains electrons, it becomes negatively charged
- Called an **ANION**
- ***Usually nonmetals do this***

How does an atom become an ion?

- If the atom loses electrons, it becomes positively charged
- Called an **CATION**
- ***Usually metals do this***

Ex 1: If an aluminum atom, with it's 13 protons and 13 electrons loses three electrons…

- It now has a charge of (+13) + (-10) = +3

Ex 2: If a sulfur atom, with it's 16 protons and 16 electrons gains two electrons…

- It now has a charge of (+16) + (-18) = -2

Nuclear Reactions

- Nuclear reactions are different from other types of reactions.
- Involve changes in the nucleus of the atom
  - protons (p+) and neutrons (n°)
- The location of the atom (which compound it is in) has no effect

Radioactivity

- The process where the nucleus of an atom undergoes changes and releases energy, particles, or both

Radioisotopes

- Isotopes of an element that are radioactive
  - due to unstable nuclei
- Undergo radioactive decay
  - Nucleus falls apart, not grows larger
- Unstable nuclei emit radiation to attain more stable atomic configurations

Types of radiation

- Alpha particles
- Beta particles
- Gamma radiation
- “Positron” emission at times

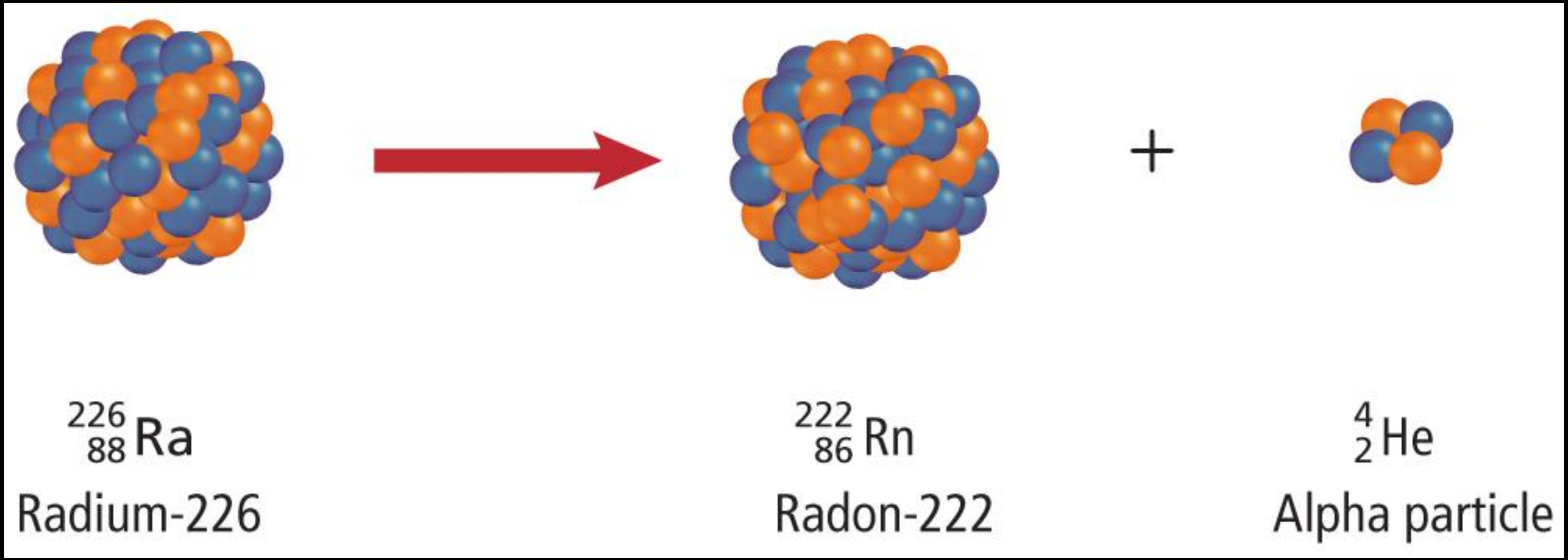
Alpha particles

- Symbolized as:

  ${}^{4}_{2}He$ α ${}^{4}_{2}\alpha$

- Charge of +2
- Mass ~4 amu
  - Heaviest of the particles

Types of Radiation

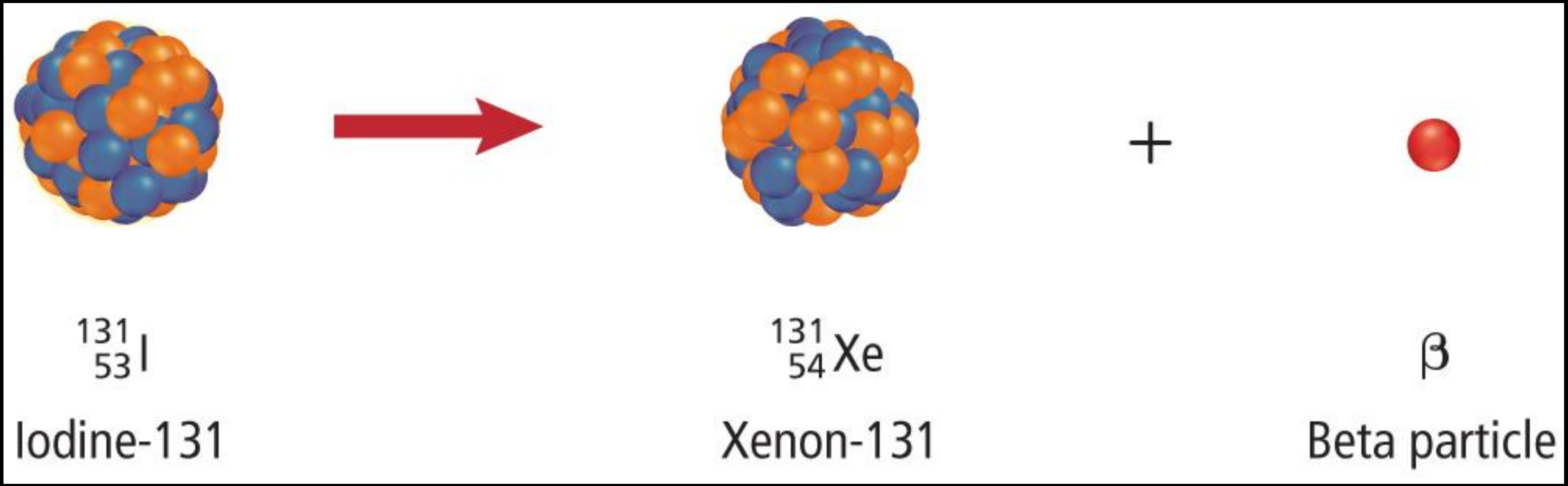


Beta particles

- Symbolized as

  $^{0}_{-1}e^{-}$ β $^{0}_{-1}\beta$
- Charge of -1
- Mass ~ 0.00055amu
  - Actually an electron emitted from the nucleus

Types of Radiation



Gamma radiation

- Symbolized as ${}^{0}_{0}\gamma$ or just γ
- Not a particle
- No charge, no mass
- High energy electromagnetic radiation (“light”)
- Also known as a type of “photon”

	α	β	γ
Penetrating power	~0.05mm	~4mm	Very high
Shielding	Paper, clothes, dead skin	Metal foil	Pb, concrete (incomplete)
energy	~5 MeV	~1 MeV	~1 MeV

Nuclear reactions

- The total of all the mass numbers of the reactants equals the total of all the mass numbers of the products
- The same holds true for the atomic numbers
- Actual mass is not conserved
  - Matter is transformed into energy

Symbols in nuclear reactions

- Alpha particle
  $^{4}_{2}He$ or $^{4}_{2}\alpha$
- Beta particle
  $^{0}_{-1}e$ or $^{0}_{-1}\beta$
- Gamma radiation
  $^{0}_{0}\gamma$
- Neutrino
  $^{0}_{0}\nu$
- Proton
  $^{1}_{1}p^{+}$ or $^{1}_{1}H$
- Neutron
  $^{1}_{0}n^{o}$
- Electron
  $^{0}_{-1}e$
- Positrons
  $^{0}_{+1}e$

Writing Nuclear reactions

1) The nuclide (atom) that decays is the one on the left-hand side of the equation.
2) The order of the nuclides on the right-hand side can be in any order.
3) The neutrino symbol is the Greek letter "nu."
   $^{0}_{0}\nu$
4) The mass number and atomic number of a neutrino are zero.

Alpha (α) Decay

1) The nucleus of an atom splits into two parts.

2) One of these parts (the alpha particle) goes zooming off into space.

3) The nucleus left behind has its

- atomic number reduced by 2 and its
- mass number reduced by 4
- (that is, 2 p^+ and 2 n^0 have left the nucleus).

Alpha (α) Decay

$$^{222}_{88}Ra \longrightarrow$$

Alpha (α) Decay

$$^{222}_{88}Ra \longrightarrow \; ^{4}_{2}He + \; ^{218}_{86}Rn$$

$$^{208}_{84}Po \longrightarrow$$

Alpha (α) Decay

$$^{222}_{88}Ra \longrightarrow \, ^{4}_{2}He + \, ^{218}_{86}Rn$$

$$^{208}_{84}Po \longrightarrow \, ^{4}_{2}He + \, ^{204}_{82}Pb$$

Beta (β) Decay

1) A neutron inside the nucleus of an atom breaks down, changing into a proton.

2) It emits an electron and an anti-neutrino which go zooming off into space.

3) The atomic number goes UP by one and *mass number remains unchanged*.

Beta (β) Decay

$$^{14}_{6}C \longrightarrow$$

Beta (β) Decay

$$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$$

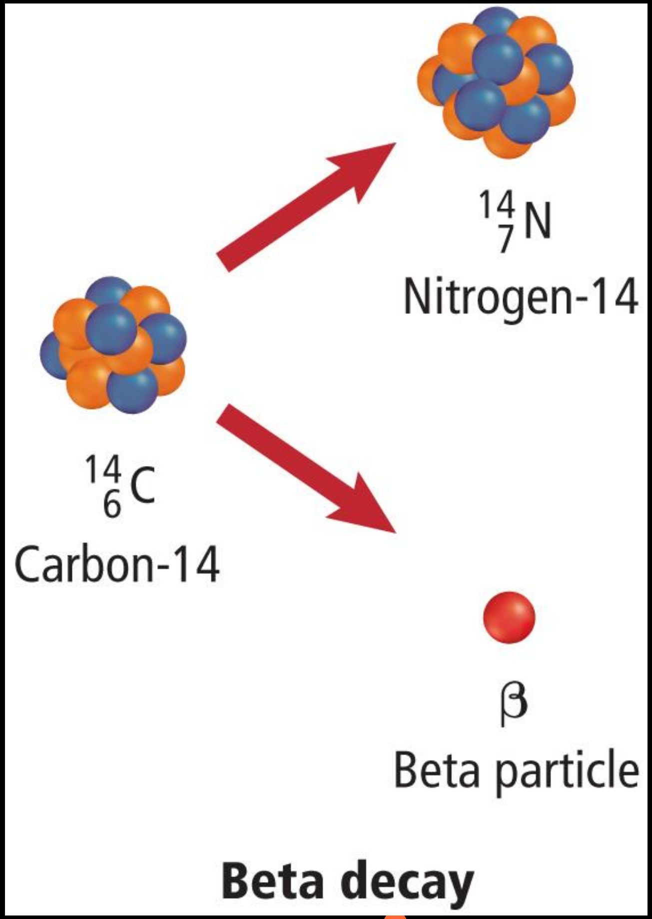
$$^{131}_{53}I \longrightarrow$$

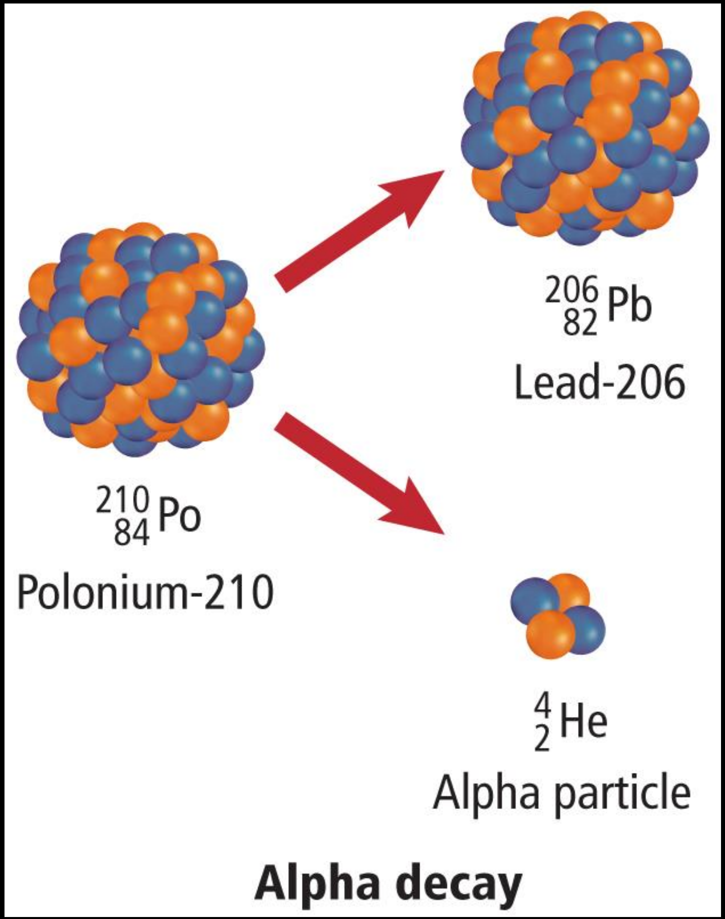
Beta (β) Decay

$${}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e + {}^{0}_{0}\overline{\nu}$$

$${}^{131}_{53}I \longrightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e + {}^{0}_{0}\overline{\nu}$$

Types of Radioactive Decay (cont.)





Nuclear Energy

- Fusion: Light nuclei can fuse together to form heavier nuclei.
- Most (if not all) of the reactions in the Sun are fusion.
- Example: $^{1}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$
- High energies are required to overcome repulsion between nuclei before these reactions can occur.

Nuclear Energy

- High energies are achieved by high temperatures: the reactions are “thermonuclear”.
- Fusion of tritium and deuterium requires about 40,000,000K:
  - $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$
- These temperatures can be achieved in a nuclear explosion.
- An atom bomb generates the heat needed for fusion of a hydrogen bomb.

Nuclear Energy: **Fusion**

- The He nucleus contains 2 neutrons and 2 protons for a calculated mass of 4.03190 amu.
- The measured mass of this nucleus is 4.0015 amu.
- We have 0.0304 amu "missing".
- This "missing matter" is converted to energy according to $E = mc^2$ when hydrogen nuclei collide in the Sun.
- **This is about 2.7 billion kJ per mole.**

Nuclear Energy: **Fusion**

- 1 kg of hydrogen fused into helium yields about the same amount of energy as burning 20 million kg of coal.
- This could be a great source of energy, and it's relatively safe since the products of fusion are not radioactive, but we can't sustain the necessary temperatures quite yet.

Nuclear Energy: **Fission**

- The splitting of heavy nuclei into lighter products is called nuclear fission.
- Just as in fusion, there is a small amount of "missing mass" that gets converted into energy according to $E=mc^2$.

◆ *Example*:

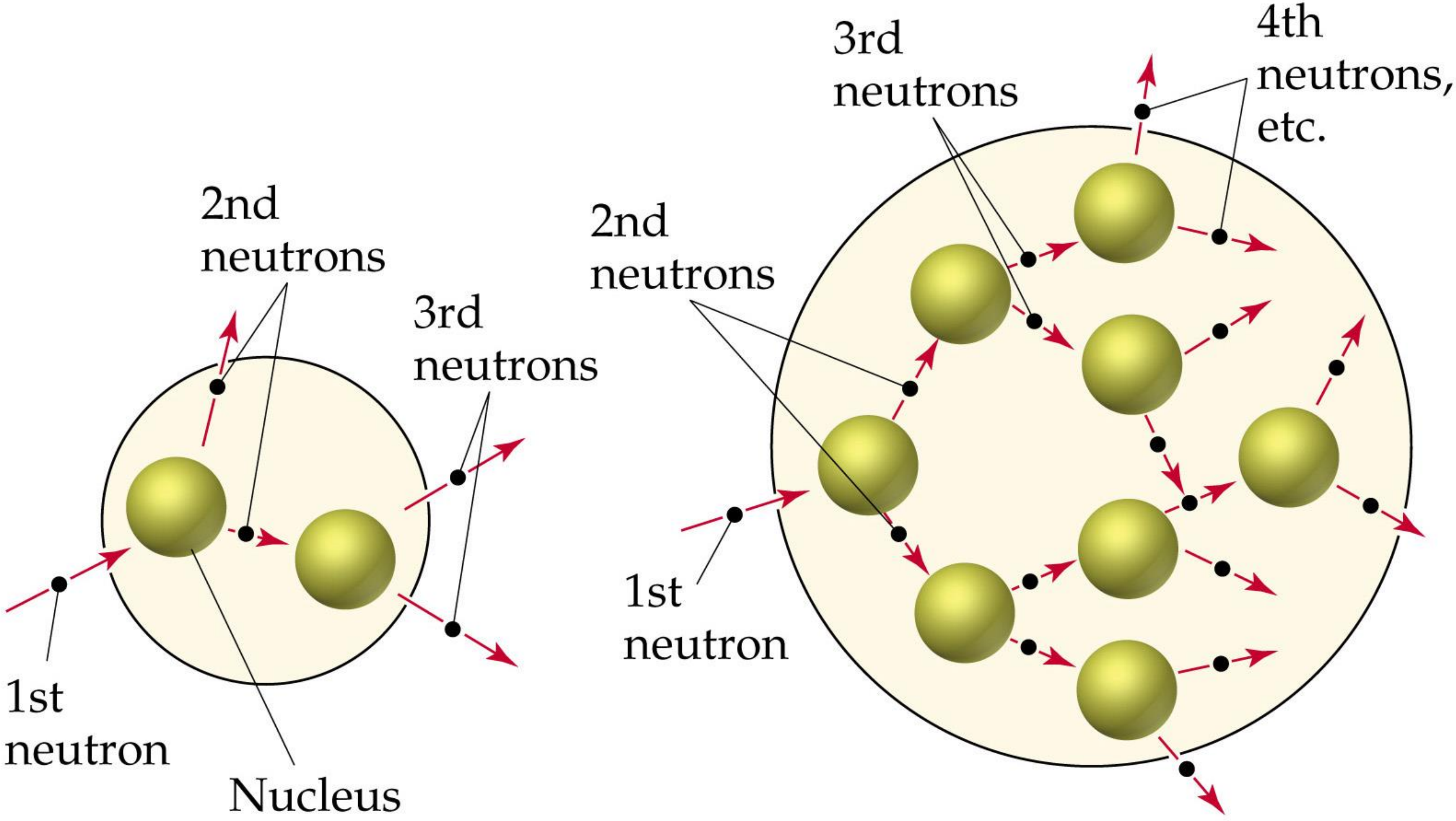
$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3^{1}_{0}n$$

Nuclear Energy: **Fission**

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3^{1}_{0}n$$

- Notice that the reaction needs neutrons in order to start the process.
- Also notice that once the reaction proceeds, 3 neutrons are produced which can further initiate other fission reactions.
- This is the basis for nuclear "chain reactions".
- To maintain the chain reaction with a constant rate of fission, a critical mass of U-235 is needed…(about 1 kg.)

Nuclear Fission



Subcritical mass
(chain reaction stops)

Supercritical mass
(chain reaction accelerates)

Nuclear Energy: **Fission**

- Nuclear power plants use fissionable substances like ^{235}U to generate heat.
- The heat boils water, which turns a turbine… (fan blades), which turns a generator… (large magnet & coils of wire) which generates electricity.
- Fission capture by ^{235}U occurs only with *slow* neutrons (2200 m/s) and a moderator is needed to slow the neutrons down, usually graphite or water.

Nuclear Energy: **Fission**

- Control rods contain cobalt or boron plus other metals and can be used to regulate the neutron capture.
- Neutrons escape the reactor. But, the larger the reactor, the less likely it is that neutrons will escape.
- This puts a limit on reactor size… (no atomic powered cars or planes. They would be too small with too many escaping neutrons.)

Nuclear Fission Reactor