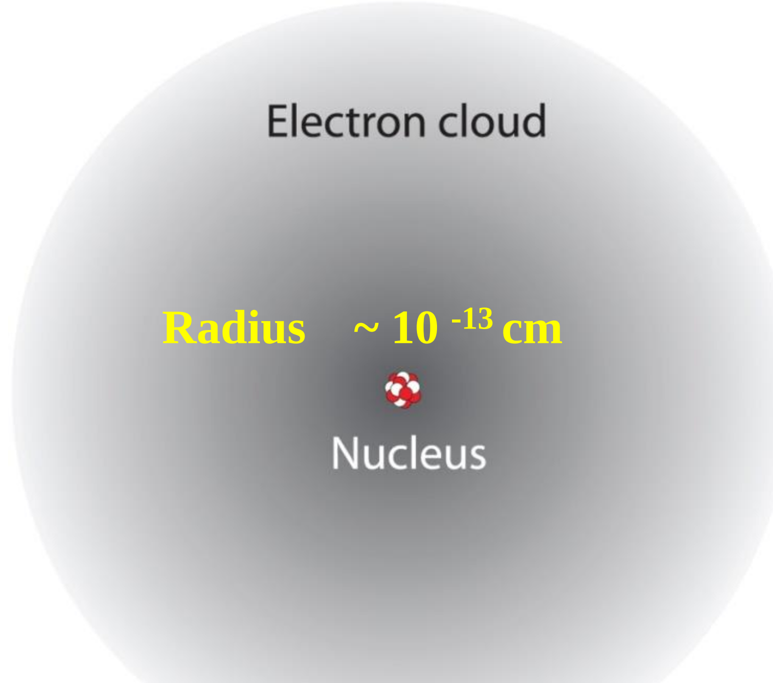
Chapter 21

Nuclear Chemistry

What is Nucleus?

made up of two kinds of **nucleons:**
protons and **neutrons**.



A **proton by itself can be stable** as its lifetime is too long to measure; .

A **neutron by itself is an unstable** particle (undergoes **β−decay** by turning into proton, electron, and electron antineutrino, with a **half-life** around 10 mins.

density: 1.6×10^{14} g/cm^3

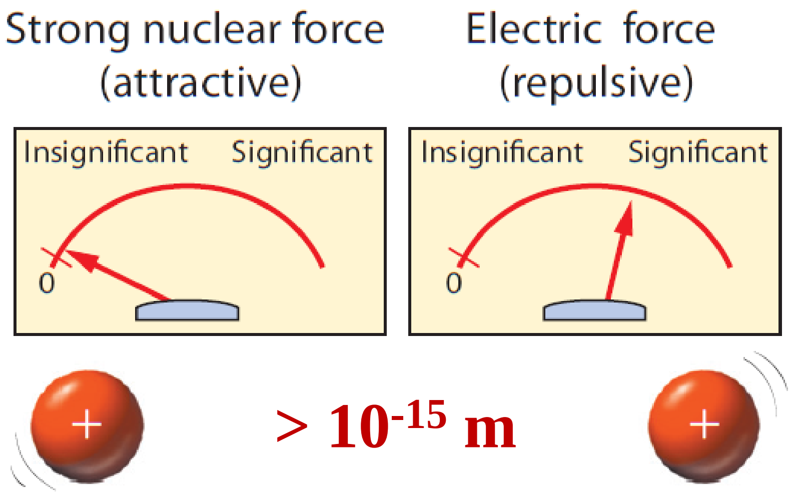
1.6726×10^{-27} kg/proton

1.6749×10^{-27} kg/neutron

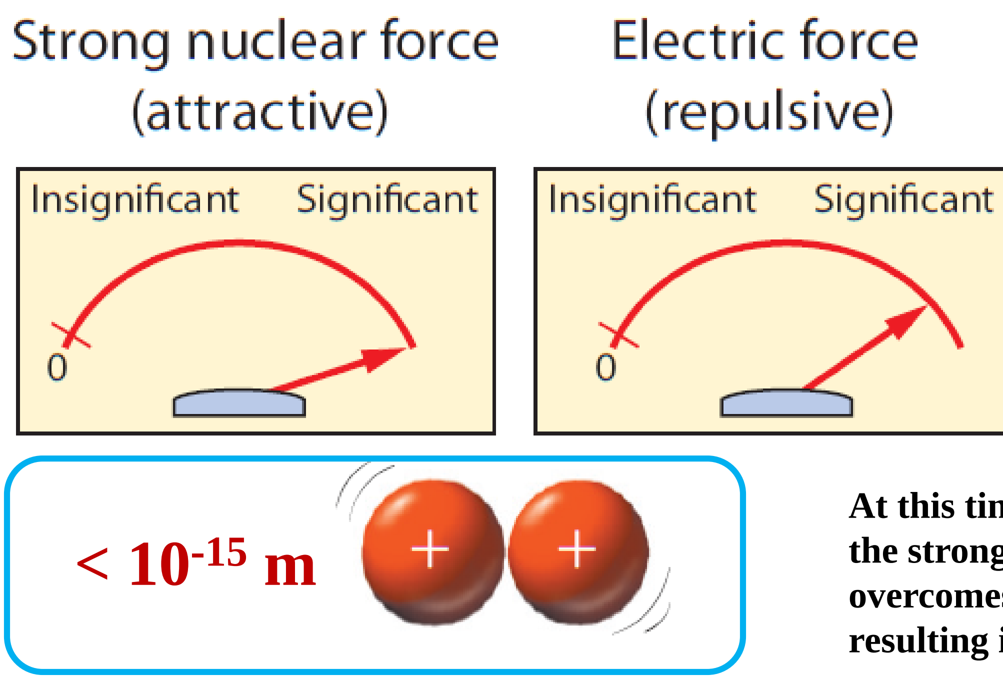
What is the (approximate) ratio of the atomic radius to the nuclear radius?

How is it possible that positively charged protons in the nucleus stay clumped together?

Very strong ***Nuclear Force*** between nucleons

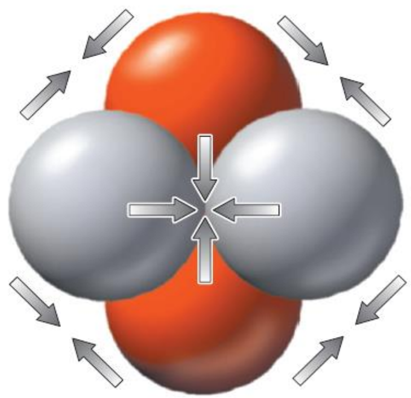


Protons far apart > 10^{-15} m may experience stronger repulsive force than the attractive strong nuclear force.



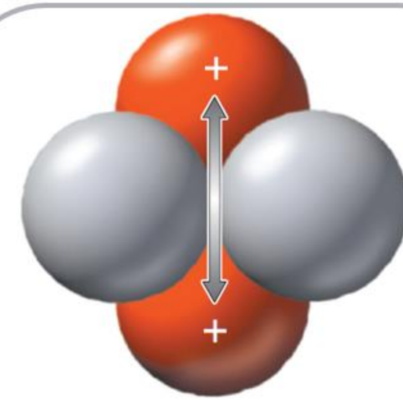
At this tiny separation distance, the strong nuclear force overcomes the electrical force, resulting in their staying together.

Attractive nuclear force effects only very short distances



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

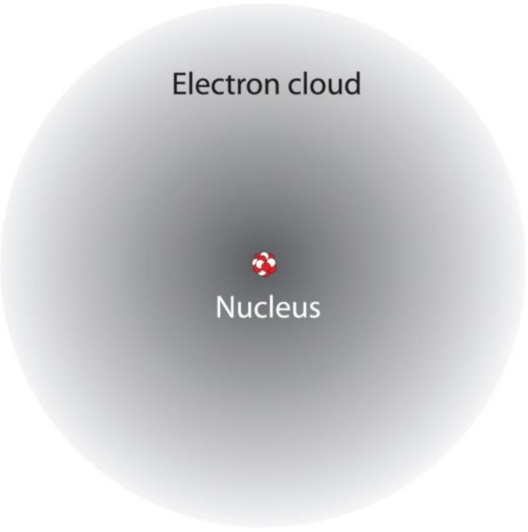
Repulsive electric forces effect over relatively long-ranges



Only protons repel one another by the electric force.

Neutrons serve as the "nuclear cement" holding an atomic nucleus together. Protons attract both protons and neutrons by the strong nuclear force. Protons also repel other protons by the electric force. Neutrons, on the other hand, have no electric charge and so attract protons and other neutrons only by the strong nuclear force. Therefore, the presence of neutrons adds to the attraction among nucleons and helps hold the nucleus together

Definitions



Nucleus: The central part of the atom which contains two nucleons (protons and neutrons).

Atom: **The nucleus and the surrounding electrons form an atom**.

Every atom of an element has the same number of protons---Atomic number (*Z*)

Isotopes: Atoms of the same elements can have different numbers of neutrons.

Isotopes are identified by their mass number (***A***).

Mass number = number of protons + neutrons

Nuclide: The nucleus of an isotope is called a nuclide**.**

Each nuclide is identified by a symbol.

$${}^{A}_{Z}E \quad \text{for example:} \quad {}^{238}_{92}U$$

Less than 10% of the known nuclides are nonradioactive;

Most nuclides are **radionuclides.**

Periodic Table of the Elements

118 elements but 2000 known nuclides

Isotopes: Not all **atoms of the same element** have the same mass, due to **different numbers of neutrons** in those atoms.

Only 279 are stable with respect to radioactive decay

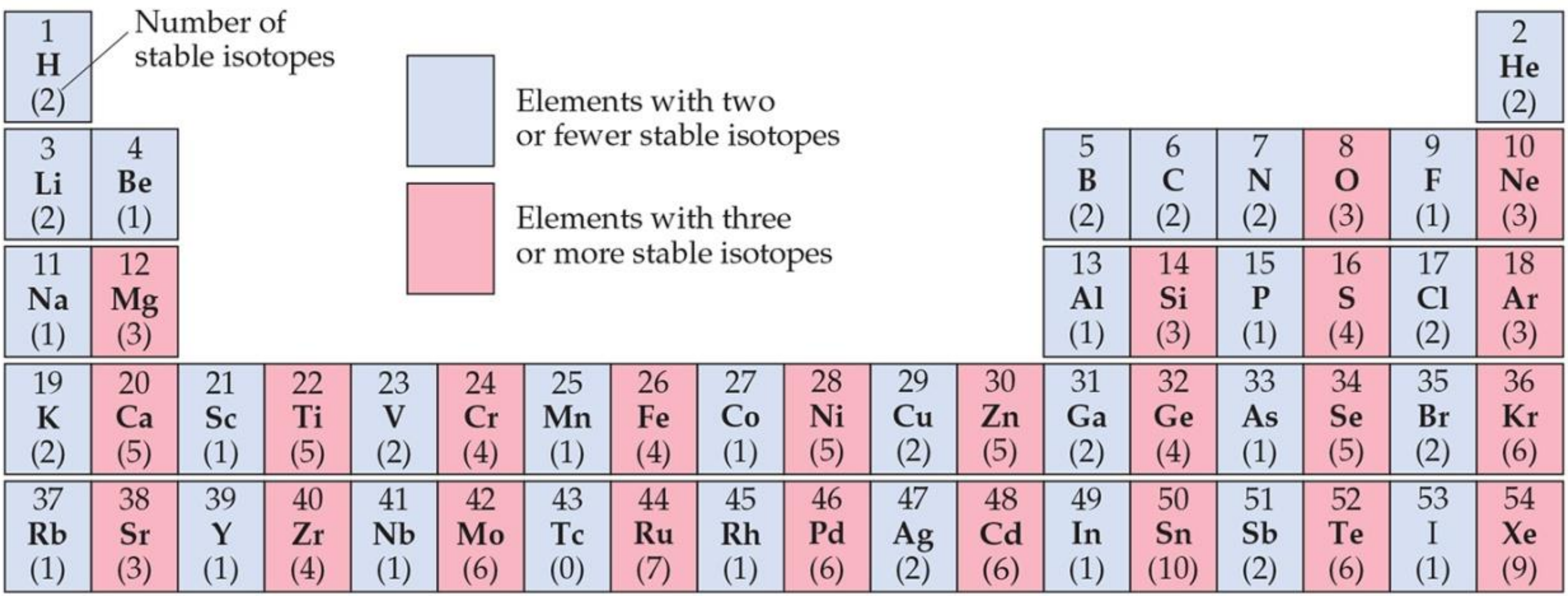


Fig. 21.3 Number of stable isotopes for elements 1-54.

<u>Stable</u> Nuclei Due to **ratio** of **p**rotons to **n**eutrons

<u>Unstable</u> Nuclei

contains an "off-balance" ratio of protons and neutrons

Radioactive decay — ***unstable nuclei*** are spontaneously transform to more stable nuclei.

Nuclides that are radioactive are called radionuclides, and atoms containing these nuclei are called radioisotopes.

All nuclides with 84 or more protons are <u>radioactive</u>,

Nuclear equation: $${}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

Discovery of Radioactivity: Marie Curie

- Marie Curie determined the rays were emitted from specific elements.

- She also discovered new elements by detecting their rays.
  - ✓ **Radium** named for its green phosphorescence
  - ✓ **Polonium** <u>named for her homeland</u>

- Because these rays were no longer just a property of uranium, she renamed it **radioactivity.**

Radioactivity

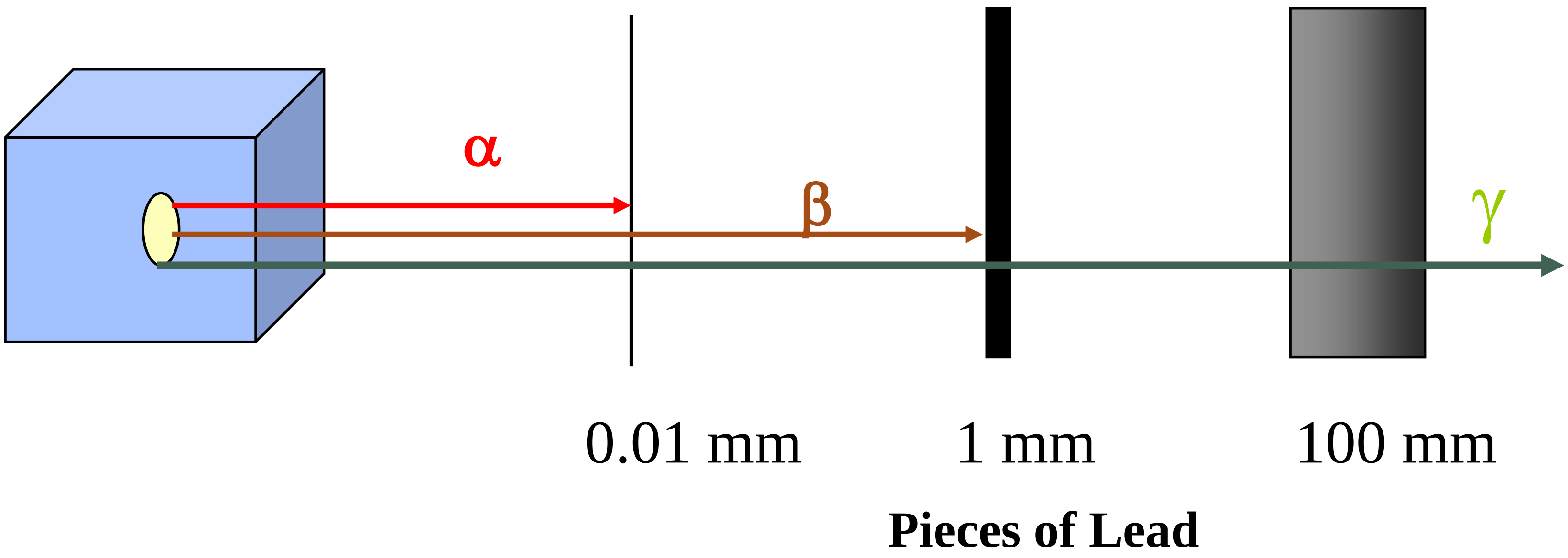
- **Radionuclides (**unstable nuclei) change or decay spontaneously, **emitting radiation**. They are said to be **radioactive**.
- Several ways for radionuclides decay into a different nuclide..

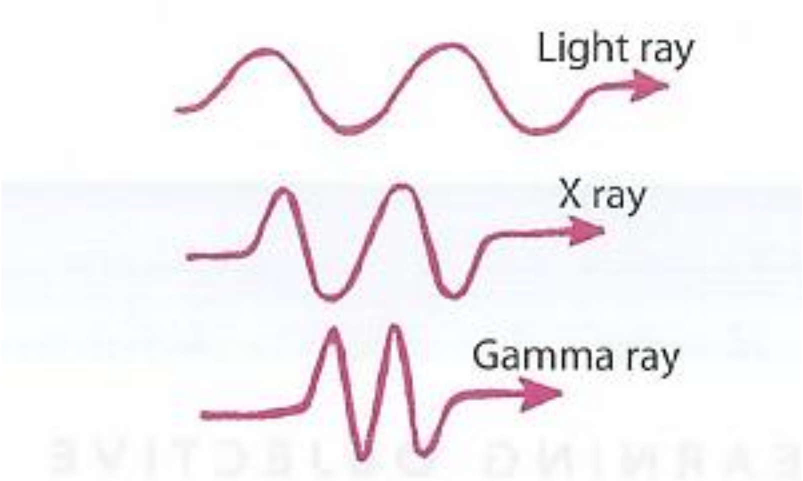
Most Common Kinds of Radiation Emitted by a Radionuclide

TABLE 21.1 Properties of Alpha, Beta, and Gamma Radiation

	Type of Radiation		
Property	α	β	γ
Charge	2+	1−	0
Mass	6.64×10^{-24} g	9.11×10^{-28} g	0
Relative penetrating power	1	100	10,000
Nature of radiation	${}_{2}^{4}He$ nuclei	Electrons	High-energy photons

Penetrating Ability of Radioactive Rays



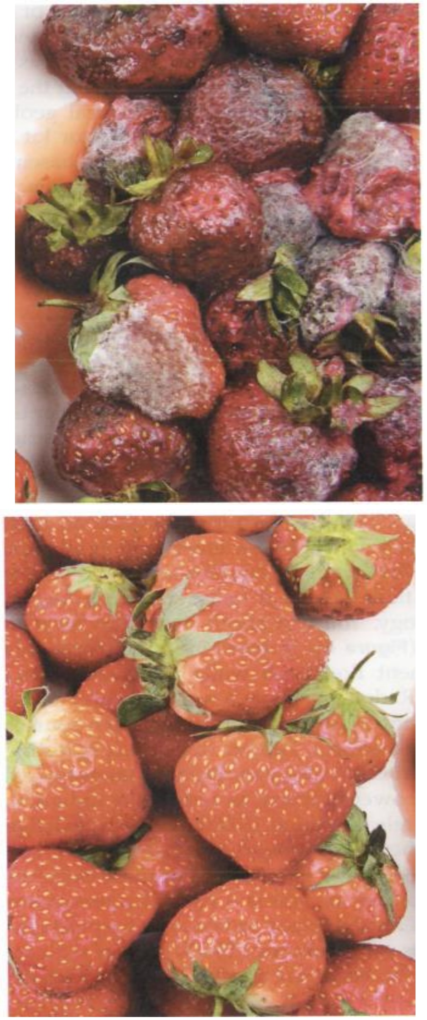


much higher in frequency and energy than UV-vis light and X-rays.

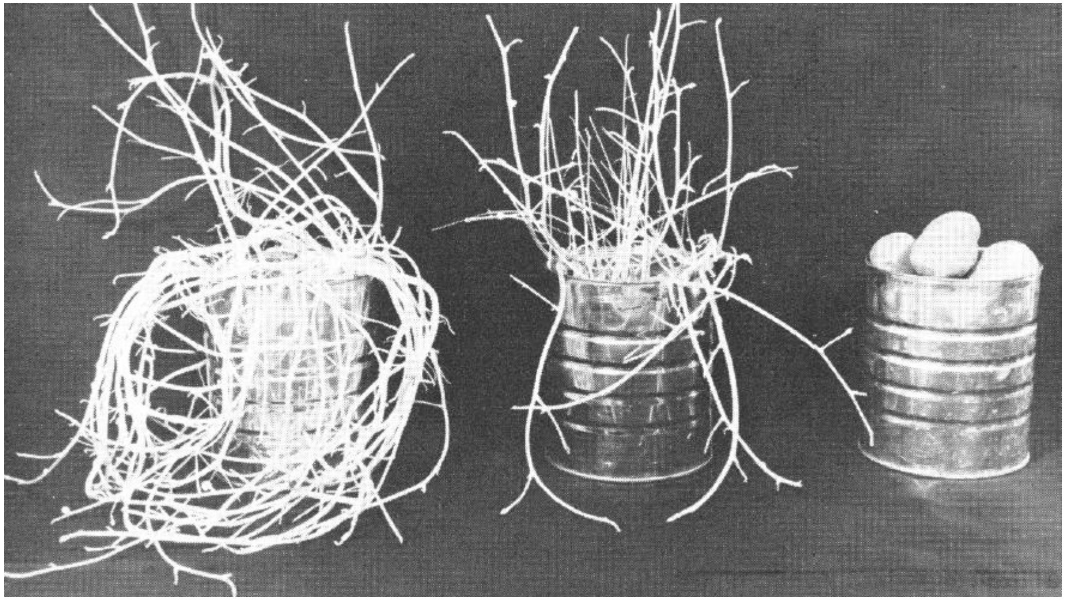
Food irradiation

1958 World first commercial food irradiation (spices) at Stuttgart, Germany

Gamma Radiation Effects on Fruits and Vegetables[1, 2]



Several million dollars are lost in the United States each year as a result of post harvest diseases of crops. Claim costs to railroads alone in 1958 amounted to $11 million. This work demonstrates that it is possible to extend the shelf-life of fresh fruits and vegetables at room as well as at refrigeration temperatures by gamma radiation, by surface pasteurization, sprout inhibition, and also by retarding the ripening processes. The information presented should be useful to researchers, shippers, packers, and processors.



Effect of radiation dose on the sprout inhibition of potatoes stored for five months at 50 ^{o}F. Left to right--non-irradiated; 4.65 X 10^3 rads; and 9.30 X 10^3 rads.

Most irradiated food is processed by gamma irradiation from **radioisotope.**

Types of Radioactive Decay

- **Alpha decay**
- **Beta decay**
- **Gamma emission**
- **Positron emission**
- **Electron capture**

TABLE 21.3 Types of Radioactive Decay

Type	Nuclear Equations	Change in Atomic Number	Change in Mass Number
Alpha emission	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$	−2	−4
Beta emission	${}^{A}_{Z}X \longrightarrow {}_{Z+1}^{A}Y + {}^{0}_{-1}e$	+1	Unchanged
Positron emission	${}^{A}_{Z}X \longrightarrow {}_{Z-1}^{A}Y + {}^{0}_{+1}e$	−1	Unchanged
Electron capture*	${}^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}_{Z-1}^{A}Y$	−1	Unchanged

*The electron captured comes from the electron cloud surrounding the nucleus.

- **In chemical equations, atoms and charges need to balance.**
- **In nuclear equations, atomic number and mass number need to balance.**

Alpha Decay

α particle is essentially a helium nucleus (^4_2He) composed of two protons and two neutrons with a charge of plus two.

Alpha decay is essentially loss of two protons and two neutrons):

$$^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^4_2He$$

balancing the equation:

– atomic number: 92 = 90 + 2; mass number: 238 = 234 + 4

$$^{230}_{90}Th \longrightarrow ^4_2He + ^{226}_{88}Ra$$

Alpha-particle production is a very common mode of decay for heavy radioactive nuclide.

Beta Decay

Beta decay is the loss of a β-particle (a high-speed electron emitted by the nucleus):

$$ {}^{0}_{-1}\beta \quad \text{or} \quad {}^{0}_{-1}e $$

$$ {}^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e $$

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

Balancing: atomic number: 53 = 54 + (–1); mass number: 131 = 131 + 0

The net effect is that one of the neutrons in nucleus is converted to a proton, reducing the neutron/proton ratio.

$$ \mathbf{n \rightarrow p + e^{-}} $$

the mass number of the decaying nucleus remains constant

Practice

21.9 Indicate the number of protons and neutrons in the following nuclei: (**a**) $^{239}_{94}Pu$, (**b**) $^{142}_{56}Ba$, (**c**) potassium-41.

21.10 Indicate the number of protons and neutrons in the following nuclei: (**a**) $^{214}_{83}Bi$, (**b**) $^{210}_{82}Pb$, (**c**) uranium-235.

21.11 What do these symbols stand for? (**a**) $^{1}_{1}p$, (**b**) $^{0}_{-1}e$, (**c**) $^{0}_{+1}e$

21.12 What do these symbols stand for? (**a**) $^{0}_{0}\gamma$, (**b**) $^{4}_{2}He$, (**c**) $^{1}_{0}n$.

21.13 Write balanced nuclear equations for the following processes: (**a**) radon-198 undergoes alpha emission; (**b**) thorium-234 undergoes beta emission; (**c**) copper-61 undergoes positron emission; (**d**) silver-106 undergoes electron capture.

21.14 Write balanced nuclear equations for the following transformations: (**a**) polonium-210 emits alpha particle; (**b**) neptunium-235 undergoes electron capture; (**c**) fluorine-18 emits beta particle; (**d**) carbon-14 decays by beta emission.

21.17 The naturally occurring radioactive decay series that begins with $^{235}_{92}U$ stops with formation of the stable $^{207}_{82}Pb$ nucleus. The decays proceed through a series of alpha-particle and beta-particle emissions. How many of each type of emission are involved in this series?

21.18 A radioactive decay series that begins with $^{232}_{90}Th$ ends with formation of the stable nuclide $^{208}_{82}Pb$. How many alpha-particle emissions and how many beta-particle emissions are involved in the sequence of radioactive decays?

21.29 Complete and balance the following nuclear equations by supplying the missing particle:

(a) $^{239}_{94}Pu + ^{1}_{0}n \longrightarrow ^{0}_{-1}e + ?$

(b) $^{238}_{92}U + ^{4}_{2}He \longrightarrow 3\,^{1}_{0}n + ?$

(c) $^{218}_{85}At \longrightarrow ^{0}_{-1}e + ?$

(d) $^{146}_{62}Sm \longrightarrow ^{142}_{60}Nd + ?$

(e) $^{118}_{53}I + ^{0}_{-1}e \longrightarrow ?$

21.30 Complete and balance the following nuclear equations by supplying the missing particle:

(a) $^{106}_{47}Ag + ^{0}_{-1}e \longrightarrow ?$

(b) $^{263}_{106}Sg \longrightarrow ^{4}_{2}He + ?$

(c) $^{216}_{84}Po \longrightarrow ^{212}_{82}Pb + ?$

(d) $^{10}_{5}B + ? \longrightarrow ^{7}_{3}Li + ^{4}_{2}He$