Radioactivity
& Nuclear Energy

Review

Mass number (A): Protons + Neutrons

Atomic number (Z): Protons

Mass number → A

Atomic number → Z

$$^{A}_{Z}X$$

Isotopes: atoms with the same number of protons and electrons but different numbers of neutrons.

→ different mass number

Radioactive Decay

Radioactive: nucleus which spontaneously decomposes forming a different nucleus and producing one or more particles.

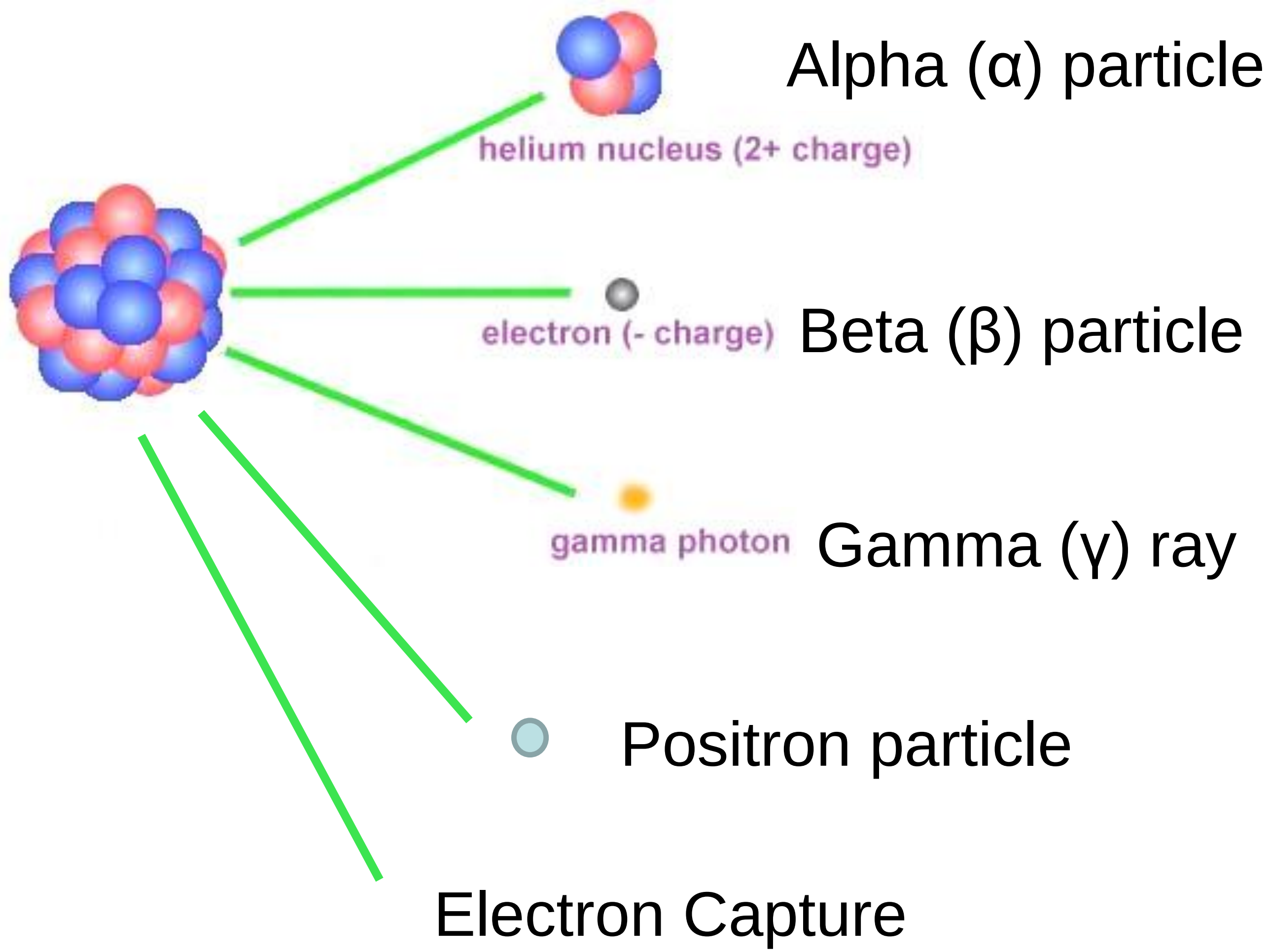
Nuclear Equation: shows the radioactive decomposition of an element.

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

β Particle

Mass # and Atomic # must be conserved.

Types of Radioactive Decay



Alpha (α) Particle

- Alpha particle – helium nucleus ($^{4}_{2}He$)

Examples:

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

$$^{230}_{90}Th \rightarrow {}^{4}_{2}He + {}^{226}_{88}Ra$$

- Net effect is loss of 4 in mass number and loss of 2 in atomic number. Mainly occurs in elements of atomic number 80 or higher.

Beta (β) Particle

- Beta particle – electron (${}^{0}_{-1}e$)

Examples:

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

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

- Net effect is to change a neutron into a proton.

Gamma (γ) Ray

- Gamma ray – high energy photon of light ($^{0}_{0}\gamma$)

No charge, No mass.

Example:

$$^{238}_{92}\mathrm{U} \rightarrow\ ^{4}_{2}\mathrm{He} +\ ^{234}_{90}\mathrm{Th} + 2\,^{0}_{0}\gamma$$

- Net effect is no change in mass number or atomic number.

Positron Particle

- Positron – particle with same mass as an electron but with a positive charge ($^{0}_{1}e$).

Example:

$$^{22}_{11}Na \rightarrow ^{0}_{1}e + ^{22}_{10}Ne$$

- Net effect is to change a proton into a neutron.

Electron Capture

- Process in which one of the inner-orbital electrons is captured by the nucleus to change a proton into a neutron.

Example:

$$^{201}_{80}\mathrm{Hg} + \,^{0}_{-1}\mathrm{e} \rightarrow \,^{201}_{79}\mathrm{Au} + \,^{0}_{0}\gamma$$

Inner-orbital electron

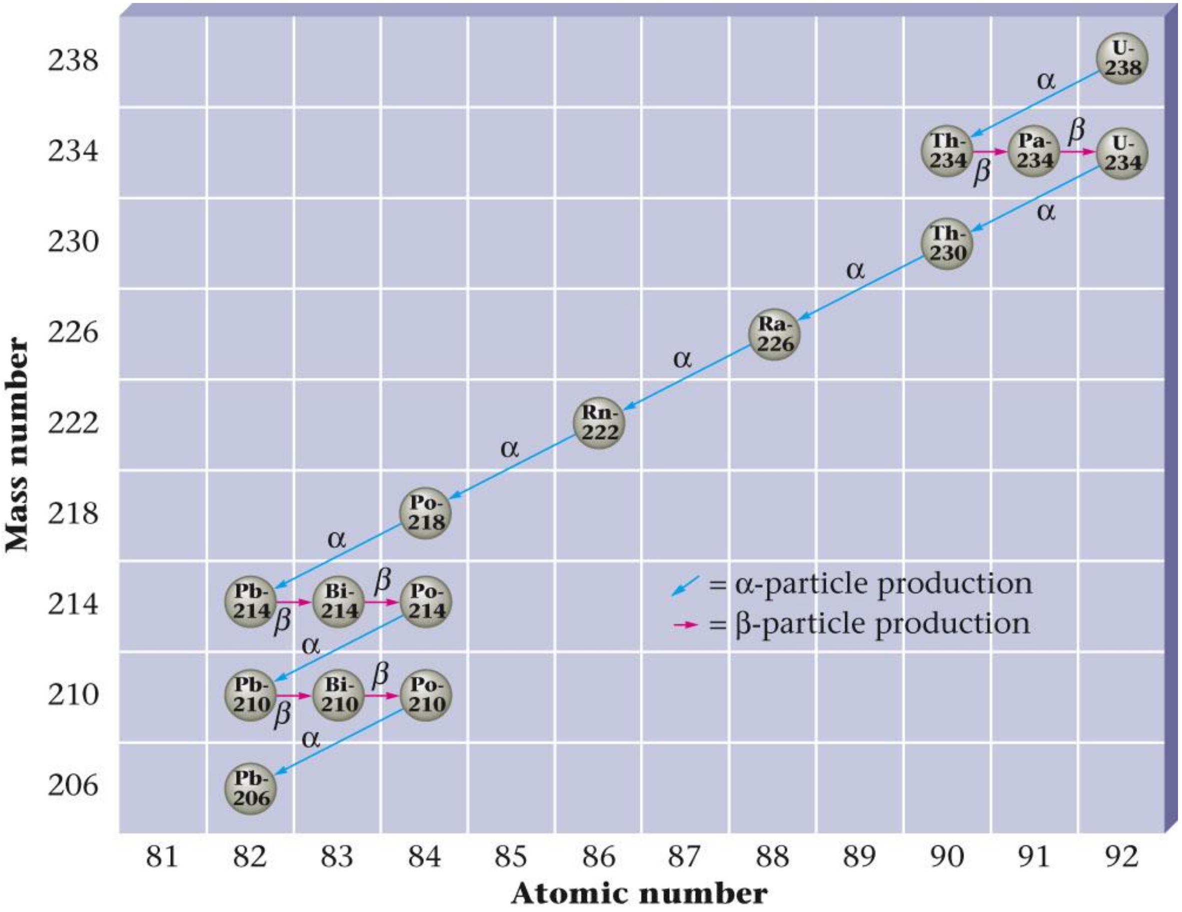
Types of Radioactive Decay

Table 19.1 Various Types of Radioactive Processes

Process	Example
β-particle (electron) production	$^{227}_{89}Ac \rightarrow ^{227}_{90}Th + ^{0}_{-1}e$
positron production	$^{13}_{7}N \rightarrow ^{13}_{6}C + ^{0}_{1}e$
electron capture	$^{73}_{33}As + ^{0}_{-1}e \rightarrow ^{73}_{32}Ge$
α-particle production	$^{210}_{84}Po \rightarrow ^{206}_{82}Pb + ^{4}_{2}He$
γ-ray production	excited nucleus $\rightarrow$ ground-state nucleus + $^{0}_{0}\gamma$ excess energy lower energy

Decay Series

Sometimes, a decay series occurs until a stable nuclide is formed.



Nuclear Transformation

- Change of one element to another.
- Bombard elements with particles.

Examples:

Rutherford 1919:

$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

Curie 1933:

$$^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{15}P + ^{1}_{0}n$$

Transuranium Elements

- Elements with atomic numbers greater than 92 (uranium) which have been synthesized by neutron or positive-ion bombardment.

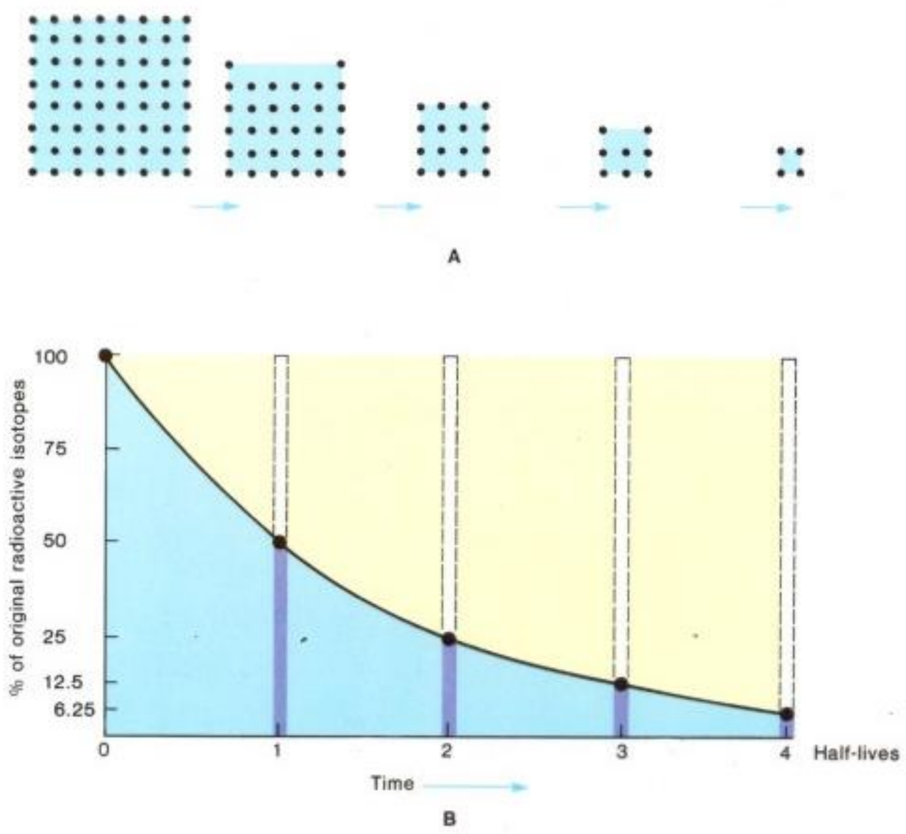
Table 19.2 Syntheses of Some of the Transuranium Elements

Neutron Bombardment	neptunium ($Z = 93$)	${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}e$
	americium ($Z = 95$)	${}^{239}_{94}Pu + 2\ {}^{1}_{0}n \rightarrow {}^{241}_{94}Pu \rightarrow {}^{241}_{95}Am + {}^{0}_{-1}e$
Positive-Ion Bombardment	curium ($Z = 96$)	${}^{239}_{94}Pu + {}^{4}_{2}He \rightarrow {}^{242}_{96}Cm + {}^{1}_{0}n$
	californium ($Z = 98$)	${}^{242}_{96}Cm + {}^{4}_{2}He \rightarrow {}^{245}_{98}Cf + {}^{1}_{0}n$ or
		${}^{238}_{92}U + {}^{12}_{6}C \rightarrow {}^{246}_{98}Cf + 4\ {}^{1}_{0}n$
	rutherfordium ($Z = 104$)	${}^{249}_{98}Cf + {}^{12}_{6}C \rightarrow {}^{257}_{104}Rf + 4\ {}^{1}_{0}n$
	dubnium ($Z = 105$)	${}^{249}_{98}Cf + {}^{15}_{7}N \rightarrow {}^{260}_{105}Db + 4\ {}^{1}_{0}n$
	seaborgium ($Z = 106$)	${}^{249}_{98}Cf + {}^{18}_{8}O \rightarrow {}^{263}_{106}Sg + 4\ {}^{1}_{0}n$

Half-Life

Half-life ($t_{1/2}$): the time it takes for one half of any sample of radioactive material to decay.

It does not matter how big or small a sample is.



Half-Life

Example:

10 mg of $^{131}_{53}I$ ⟶ $t_{1/2}$ of Iodine-131 = 8 days

How much will be left over after 32 days?

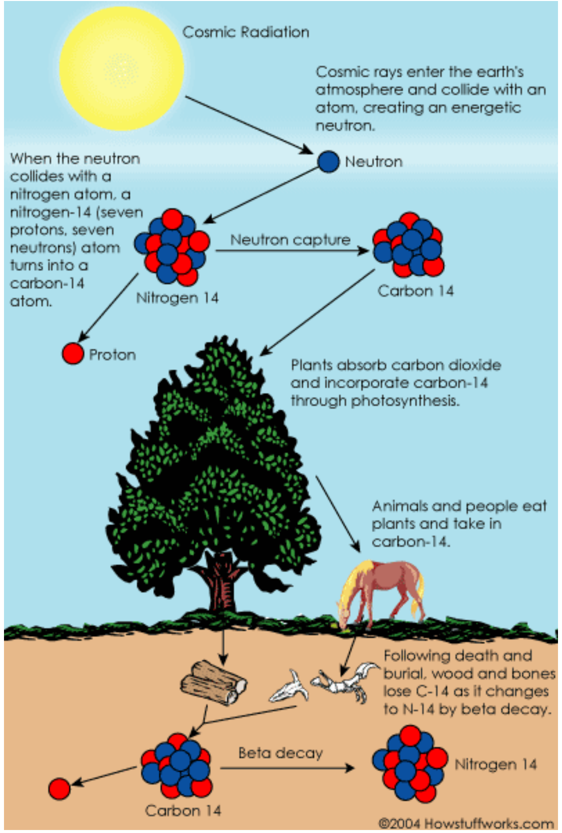
$$10 \text{ mg} \times \underbrace{1/2 \times 1/2 \times 1/2 \times 1/2}_{\text{32 days (4 half-lives)}} = 0.625 \text{ mg}$$

Radiocarbon Dating (Carbon-14 Dating)

Based on the radioactivity of carbon-14.

$$^{14}_{6}\text{C} \rightarrow {}^{0}_{-1}\text{e} + {}^{14}_{7}\text{N}$$

- Used to date wood and artifacts



Radiotracers

- Radioactive nuclides that can be introduced into organisms and traced for diagnostic purposes.

Table 19.4 Some Radioactive Nuclides, Their Half-lives, and Their Medical Applications as Radiotracers*

Nuclide	Half-life	Area of the Body Studied
^{131}I	8.1 days	thyroid
^{59}Fe	45.1 days	red blood cells
^{99}Mo	67 hours	metabolism
^{32}P	14.3 days	eyes, liver, tumors
^{51}Cr	27.8 days	red blood cells
^{87}Sr	2.8 hours	bones
^{99}Tc	6.0 hours	heart, bones, liver, lungs
^{133}Xe	5.3 days	lungs
^{24}Na	14.8 hours	circulatory system

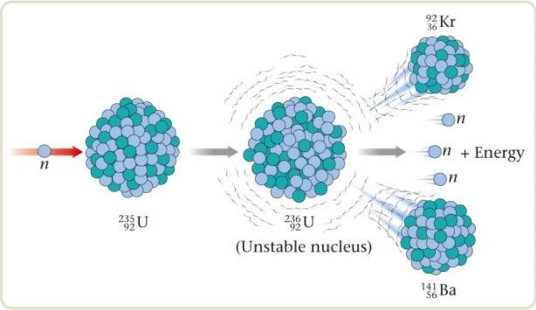
*Z is sometimes not written when listing nuclides.

Nuclear Energy

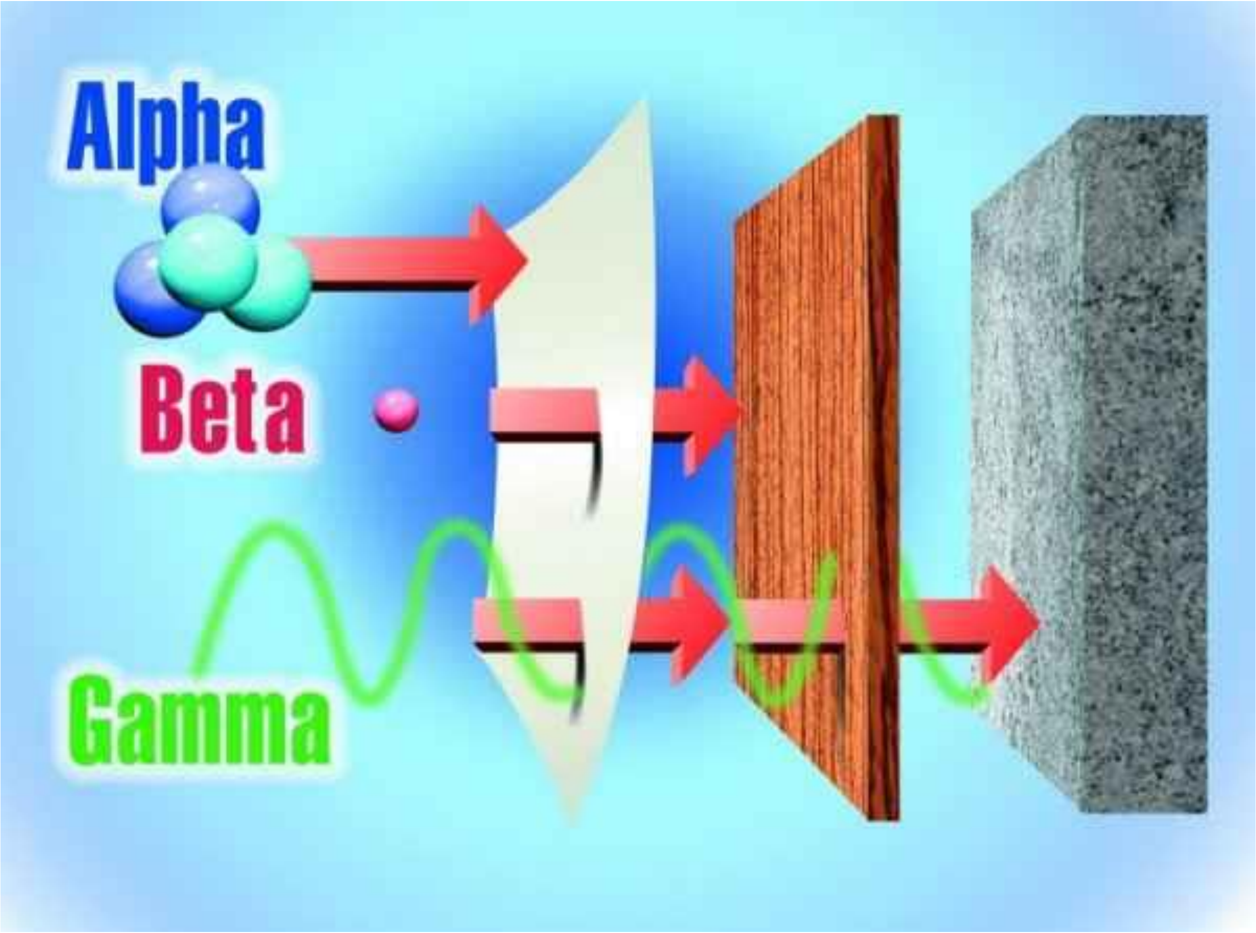
Two types of nuclear processes can produce energy:

- Fusion: Combining two light nuclei to form a heavier nucleus.

- Fission: Splitting a heavy nucleus into two nuclei with smaller mass numbers.



Effect of Radiation



Alpha: most massive and most highly charge → Least penetration power; Lowest energy