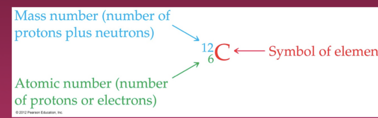
Chapter 24
Sections 1-4

The Nucleus



Remember that the nucleus is composed of the two **nucleons**, protons and neutrons.

The number of protons is the atomic number.

The number of protons and neutrons together is effectively the mass of the atom.

Isotopes

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

There are, for example, three naturally occurring isotopes of uranium:

- Uranium-234
- Uranium-235
- Uranium-238

p = 92   n = 234 − 92

Radioactivity

It is not uncommon for some nuclides of an element to be unstable, or **radioactive**.

We refer to these as **radionuclides**.

There are several ways radionuclides can decay into a different nuclide.

TABLE 21.2 • Particles Found in Nuclear Reactions

Particle	Symbol
Neutron	$^{1}_{0}n$
Proton	$^{1}_{1}H$ or $^{1}_{1}p$
Electron	$^{0}_{-1}e$
Alpha particle	$^{4}_{2}He$ or $^{4}_{2}\alpha$
Beta particle	$^{0}_{-1}e$ or $^{0}_{-1}\beta$
Positron	$^{0}_{1}e$

Types of Radioactive Decay

Alpha Decay

Alpha decay is the loss of an α-particle (a helium nucleus):

$${}^{4}_{2}\text{He}$$

$${}^{238}_{92}\text{U} \longrightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

$${}^{238}_{92}U \xrightarrow{\alpha} {}^{234}_{90}Th + {}^{4}_{2}He$$

Beta Decay

Beta decay is the loss of a β-particle (a high-energy electron):

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

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

$${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

Gamma Emission

Gamma emission is the loss of a γ-ray, which is high-energy radiation that almost always accompanies the loss of a nuclear particle:

$${}^{0}_{0}\gamma$$

α
β
γ

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	${}^{4}_{2}$He nuclei	Electrons	High-energy photons

Positron Emission

Some nuclei decay by emitting a **positron**, a particle that has the same mass as, but an opposite charge to, that of an electron:

$${}^{0}_{1}e$$

$${}^{11}_{6}\text{C} \longrightarrow {}^{11}_{5}\text{B} + {}^{0}_{1}e$$

$${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}e$$

Electron Capture (K-Capture)

Addition of an electron to a proton in the nucleus is known as **electron capture** or **K-capture**.

– The result of this process is that a proton is transformed into a neutron:

$${}^{1}_{1}p + {}^{0}_{-1}e \longrightarrow {}^{1}_{0}n$$

$${}^{81}_{37}Rb + {}^{0}_{-1}e \longrightarrow {}^{81}_{36}Kr$$

Nuclear Decay where the identity of the element changes

TABLE 21.3 • Types of Radioactive Decay

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

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

24.8 Write balanced nuclear equations for the following:

(a) Alpha decay of $^{234}_{92}U$

(b) Electron capture by neptunium-232

(c) Positron emission by $^{12}_{7}N$

a.) $^{234}_{92}U \rightarrow ^{230}_{90}Th + ^{4}_{2}He$

b. $^{232}_{93}Np + ^{0}_{-1}e \rightarrow ^{232}_{92}U$

c.) $^{12}_{7}N \rightarrow ^{12}_{6}C + ^{0}_{1}e$

24.10 Write balanced nuclear equations for the following:

(a) β^- emission by magnesium-27

(b) β^+ emission by $^{23}_{12}Mg$

(c) Electron capture by $^{103}_{46}Pd$

a.) $^{27}_{12}Mg \rightarrow ^{27}_{13}Al + ^{0}_{-1}e$

b.) $^{23}_{12}Mg \rightarrow ^{23}_{11}Na + ^{0}_{1}e$

24.14 Write balanced nuclear equations for the following:

(a) Formation of ^{186}Ir through electron capture

(b) Formation of francium-221 through α decay

(c) Formation of iodine-129 through β^- decay

a) $^{186}_{78}Pt + ^{0}_{-1}e \rightarrow ^{186}_{77}Ir$

b.) $^{225}_{89}Ac \rightarrow ^{221}_{87}Fr + ^{4}_{2}He$

c.) $^{129}_{52}Te \rightarrow ^{129}_{53}I + ^{0}_{-1}e$

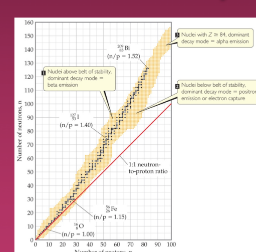
Decay Series

A radioactive nucleus reaches a stable state by a series of steps.

$$^{232}_{90}Th \xrightarrow{\text{series of decays}} ^{208}_{82}Pb$$

Stable Nuclei

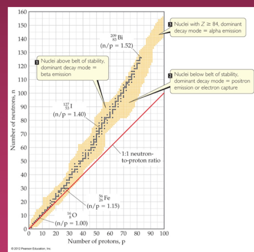
The shaded region in the figure, the so-called **belt of stability**, shows what nuclides would be stable.



Stable Nuclei

Nuclei above this belt have too many neutrons.

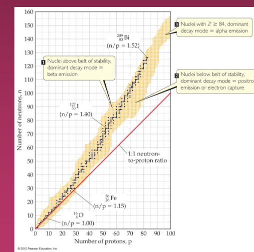
These nuclei tend to decay by emitting beta particles.



Stable Nuclei

Nuclei below the belt have too many protons.

Nuclei tend to become more stable by positron emission or electron capture.



Stable Nuclei

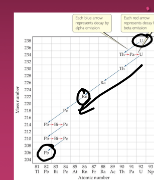
There are no stable nuclei with an atomic number greater than 83.

Nuclei with such large atomic numbers tend to decay by alpha emission.

Radioactive Series

Large radioactive nuclei cannot stabilize by undergoing only one nuclear transformation.

They undergo a series of decays until they form a stable nuclide (often a nuclide of lead).



$^{238}_{92}U \xrightarrow{\alpha} {}^{234}_{90}Th \xrightarrow{\beta} {}^{234}_{91}Pa \xrightarrow{\beta} {}^{234}_{90}U$

$t_{1/2} = 4\times10^9$ yr, 24 day, 6.75 hr, 2×10^5 yr

$\xrightarrow{\alpha} {}^{230}_{90}Th \xrightarrow{\alpha} {}^{226}_{88}Ra \xrightarrow{\alpha} {}^{222}_{86}Rn$

1st Order kinetics

Rate = kN

$\ln N = -kt + \ln N_0$

$t_{1/2} = \frac{\ln 2}{k}$

Rate of Decay

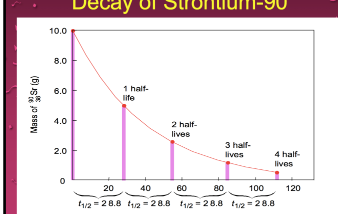
rate = kN #

The rate of decay is proportional to the number of nuclides. This represents a first-order process.

$t_{1/2} = \frac{0.693}{k}$

$\ln N = -kt + \ln N_0$

Decay of Strontium-90



$t_{1/2} = 28.8$ yr

$k = 0.0241\ yr^{-1}$

How long until 99% has decayed

$\ln N = -kt + \ln N_0$

$t = \frac{\ln N - \ln N_0}{-k}$

$t = \frac{(\ln 1 - \ln 100)}{-(0.0241/yr)} = 191$ yr

Problem

It takes 5.2 minutes for a 1.000-g sample of ^{210}Fr to decay to 0.367 g. What is the half-life of ^{210}Fr?

Rate = kN

$\ln N = -kt + \ln N_0$

$t_{1/2} = \frac{0.693}{k}$

$\ln(0.367) = -k(5.2\ min) + \ln(1.00)$

$k = 0.192\ min^{-1}$

$t_{1/2} = 3.61\ min$

24.33 What is the specific activity (in Ci/g) if 1.65 mg of an isotope emits 1.56×10^6 α particles per second?

1 Ci = 3.7 x 10^{10} dis/s

$1.56\times10^6\ dis/s \times \frac{1\ Ci}{3.7\times10^{10}\ dis/s} = 4.22\times10^{-5}\ Ci$

$\frac{4.22\times10^{-5}\ Ci}{1.65\times10^{-3}\ g} = 2.5\times10^{-2}\ Ci/g$

$1.65\ mg \times \frac{1\ g}{1000\ mg} = 1.65\times10^{-3}\ g$

24.35 What is the specific activity (in Bq/g) if 8.58 μg of an isotope emits 7.4×10^4 α particles per minute?

1 Bq = 1 dis/s

$7.4\times10^4\ \frac{dis}{min} \times \frac{1\ min}{60\ s} \times \frac{1\ Bq}{1\ dis/s} = 1233\ Bq$

$\frac{1233\ Bq}{8.58\times10^{-6}\ g} = 1.44\times10^{8}\ Bq/g$

Problem

The cloth shroud from around a mummy is found to have a ^{14}C activity of 9.7 disintegrations per minute per gram of carbon. Living organisms undergo 16.3 disintegrations per minute per gram of carbon. Calculate the age of the shroud. ($t_{1/2}$ for ^{14}C is 5715 years)

$t_{1/2} = \frac{\ln 2}{k}$ $\quad k = 1.21\times10^{-4}\ yr^{-1}$

$\ln N = -kt + \ln N_0$

$\ln(9.7) = -(1.21\times10^{-4}/yr)t + \ln 16.3$

$t = 4278\ yr$

24.39 If 1.00×10^{-12} mol of ^{135}Cs emits 1.39×10^5 β^- particles in 1.00 yr, what is the decay constant?

k

Rate = kN

$\ln N = -kt + \ln N_0$

$t_{1/2} = \frac{\ln 2}{k}$

$Rate = kN = 1.39\times10^5\ \frac{part.}{yr}$

$k = \frac{1.39\times10^5\ part/yr}{N}$

$1.00\times10^{-12}\ mol\ ^{135}Cs \times \frac{6.022\times10^{23}\ ^{135}Cs}{1\ mol\ ^{135}Cs} = 6.02\times10^{11}\ Cs$

$k = \frac{1.39\times10^5/yr}{6.02\times10^{11}} = 2.31\times10^{-7}/yr$

24.41 The isotope $^{212}_{83}Bi$ has a half-life of 1.01 yr. What mass (in mg) of a 2.00-mg sample will remain after 3.75×10^3 h?

1 yr = 8760 hr

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