Nuclear Physics

WKRP - ATOM

Review - Atoms and Isotopes

Know:

atom - fundamental unit

nucleon - general term for particles in the nucleus

→ proton ⇒ +ve charge.

neutron ⇒ neutral

electron ⇒ -ve charge

atom → electrically neutral

p^+ = # e^-

ion → charged

p^+ ≠ # e^-

Name	Mass	Charge
proton	1.67×10^{-27} kg	1.60×10^{-19} C
neutron	1.67×10^{-27} kg	—
electron	9.11×10^{-31} kg	-1.60×10^{-19} C

Isotopes

Atomic nuclei that have the same numbers of protons but different numbers of neutrons are called isotopes.

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

X → chemical symbol

A → atomic mass number or nucleon number (#p + #n)

Z → atomic number (#p)

$A > Z$

ie/ $^{20}_{10}Ne$ || $^{22}_{10}Ne$

⇒ element name — mass number

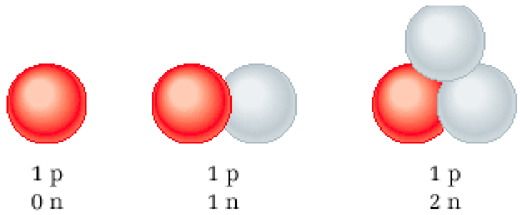
neon-20 neon-22

nuclide - nucleus of an isotope

☆

Hydrogen Isotopes

Figure 20.3 The isotopes of hydrogen are the only isotopes to which physicists have given different names: $^{2}_{1}H$ is called "deuterium" and $^{3}_{1}H$ is called "tritium." For most isotopes, physicists simply use the atomic mass number to describe the isotope: $^{3}_{2}He$ is called "helium-3" and $^{4}_{2}He$ is called "helium-4."



deuterium tritium

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

<u>Radioactive Decay</u>
Alpha, Beta and Gamma

Materials that emit radiation are said to be <u>radioactive</u> and undergo <u>radioactive decay</u>.

The changing of one element into another is called <u>transmutation</u>.

http://serc.carleton.edu/quantskills/methods/quantlit/RadDecay.html

Khan Academy

http://www.youtube.com/watch?v=3koOwozY4oc

1. Alpha decay

→ nucleus emits an alpha particle.

Symbols: α or ${}^{4}_{2}He$

Example:

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

$${}^{238}_{92}U \rightarrow \alpha + {}^{234}_{90}Th$$

parent nucleus — daughter nucleus

Try: Determine the resulting daughter nucleus when each of the following undergoes alpha decay.

① $${}^{234}_{92}U \rightarrow \alpha\ ({}^{4}_{2}He) + {}^{230}_{90}Th$$

② $${}^{226}_{88}Ra \rightarrow \alpha + {}^{222}_{86}Rn$$

radium — radon

③ $${}^{230}_{90}Th \rightarrow \alpha + {}^{226}_{88}Ra$$

2. Beta Decay

→ nucleus emits a beta particle.

1. electron e^-, ${}^{0}_{-1}e$, β^-
2. positron e^+, ${}^{0}_{1}e$, β^+

* electron $n \rightarrow p^+ + e^-$ (proton)
* positron $p^+ \rightarrow n + e^+$

*

Try: Show what happens when C-14 undergoes β^{-1} decay.

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

β^{-1}

e^-

Try:

$${}^{19}_{10}Ne \rightarrow \beta^+ + {}^{19}_{9}F$$

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

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3. Gamma Decay

-> nucleus emits a photon

-> photon is a particle of light.

-> can carry energy to or from electrons

symbol: $^{0}_{0}\gamma$ or γ

Example: $^{238}_{92}U \Rightarrow {}^{0}_{0}\gamma + {}^{238}_{92}U$

↳ carries away energy.

Try Fill in the missing particle or nucleus.

a) $^{45}_{20}Ca \rightarrow$ ______ $+ e^-$

b) $^{58}_{29}Cu \rightarrow$ ______ $+ \gamma$

c) $^{46}_{24}Cr \rightarrow {}^{46}_{23}V +$ ______

d) $^{239}_{94}Pu \rightarrow$ ______ $+ \alpha$

e) $^{239}_{93}Np \rightarrow {}^{239}_{94}Pu +$ ______

Cutnell - Appendix F

Try/ Fill in the missing particle or nucleus.

a) $^{45}_{20}Ca \rightarrow$ $\underline{^{45}_{21}Sc}$ $+ e^-$

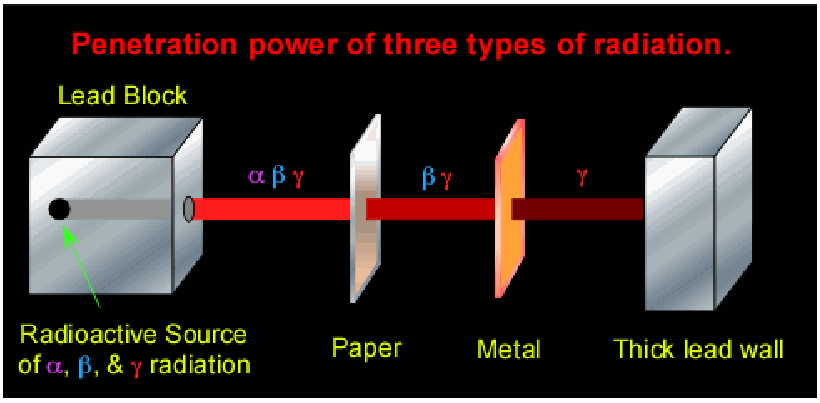
b) $^{58}_{29}Cu \rightarrow$ $\underline{^{58}_{29}Cu}$ $+ \gamma$

c) $^{46}_{24}Cr \rightarrow ^{46}_{23}V +$ $\underline{\beta^+}$

d) $^{239}_{94}Pu \rightarrow$ $\underline{^{235}_{92}U}$ $+ \alpha$

e) $^{239}_{93}Np \rightarrow ^{239}_{94}Pu +$ $\underline{\beta^{-1}}$

Radioactive Decay



α decay $^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He$ An Alpha Decay Reaction

β decay $^{131}_{53}I \longrightarrow ^{131}_{54}Xe + ^{0}_{-1}e$ A Beta Decay Reaction

positron decay $^{11}_{6}C \longrightarrow ^{11}_{5}B + ^{0}_{1}e$ A Positron Decay Reaction

γ decay $^{234}_{90}Th^{*} \longrightarrow ^{234}_{90}Th + \gamma$ A Gamma Decay Reaction

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Decay Series

When a large nucleus decays by the emission of an alpha or beta particle, the daughter nucleus is more stable than the parent; however, the daughter nucleus might still be unstable. As a result, a nucleus can tumble through numerous transmutations before it reaches stability. Figure 20.8 shows one such decay sequence for uranium-238. Notice that the end product is lead-82.

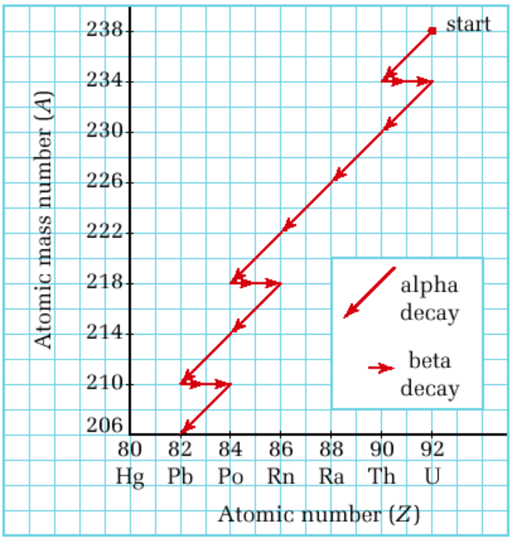

Figure 20.8 This series represents only one of several possible pathways of decay for uranium-238.

Show the transmutations in the decay series of uranium-238.

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Example: Show the steps of the decay series that starts with **U-238**.

1 α
2 β^{-1}
4 α
2 β^-
2 α
2 β^-
1 α

Final daughter nucleus Pb-206

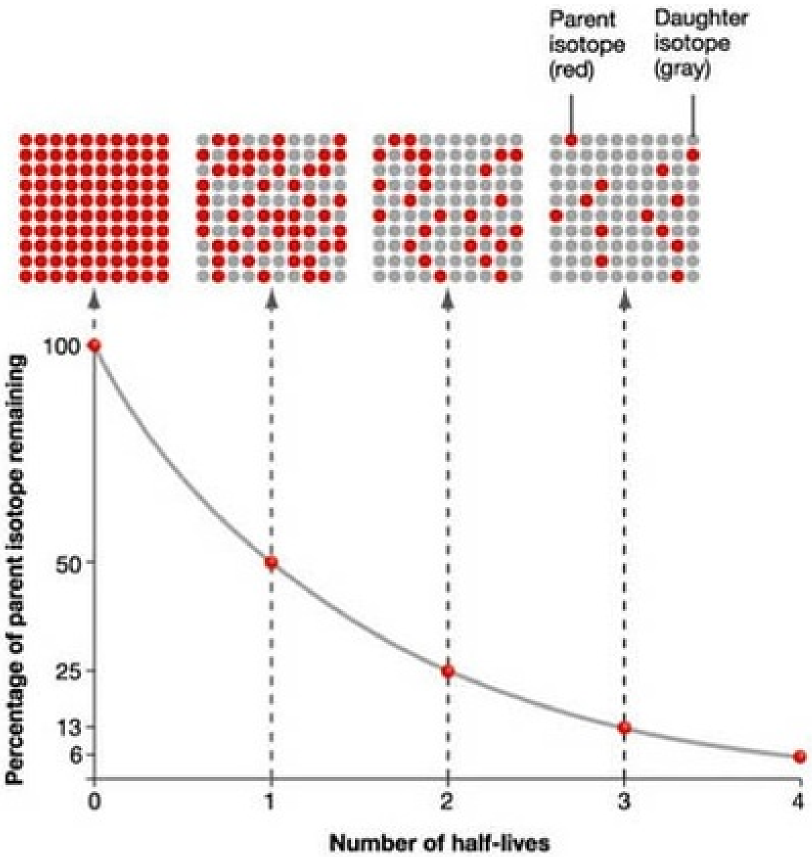
$^{206}_{82}Pb$

Half-Life

The half-life ($T_{1/2}$) of a radioactive substance is the time required for one-half of the nuclei present to disintegrate. The half-life of a given isotope is always the same.

Half-lives vary from about 10^{-22} s to 10^{28} s ($\approx 10^{21}$ years).

Isotope	Emits	Half Life
Uranium-238	Alpha	4500 000 000 years
Thorium-234	Beta, Gamma	24.1 days
Proactinium-234	Beta, gamma	60 seconds
Uranium-234	Alpha, Gamma	245 000 years
Thorium-230	Alpha, Gamma	76 000 years
Radium-226	Alpha, Gamma	1600 years
Radon-222	Alpha	3.8 days
Polonium-218	Alpha	3 minutes
Lead-214	Beta, Gamma	27 minutes
Bismuth-214	Beta, Gamma	20 minutes
Polonium-214	Alpha	160 microseconds
Lead-210	Beta, Gamma	22 years
Bismuth-210	Beta, Gamma	5 days
Polonium-210	Alpha	138 days
Lead-206		Stable


Parent
isotope
(red)
Daughter
isotope
(gray)
100
50
25
13
6
Percentage of parent isotope remaining
0
1
2
3
4
Number of half-lives

Imagine that you had a sample of polonium-218 ($^{218}_{84}Po$). It decays by alpha emission with a half-life of 3.0 min. If you started with 160.0 μg of the pure substance, it would decay as shown in Table 20.3.

Table 20.3 Decay of Polonium-218

Time (min)	Mass of Po-218 remaining (μg)
0	160.0
3.0	80.0
6.0	40.0
9.0	20.0
12.0	10.0
15.0	5.0

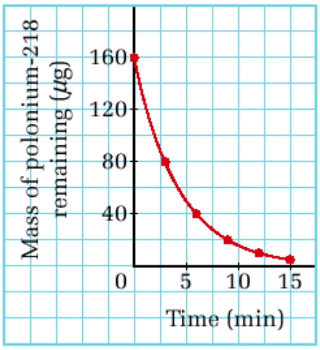


Figure 20.9 A graph of the decay of polonium and all other radioactive isotopes is an exponential curve.

The number of nuclei present at $t = 0$ is $N = N_o$.
The number of nuclei present at $t = T_{1/2}$ is $N = 1/2(N_o)$.
The number of nuclei present at $t = 2T_{1/2}$ is $N = 1/4(N_o)$.

Activity and Decay Constants

The number of decays per second is called the activity of a sample.

$$A = \frac{\Delta N}{\Delta t}$$

The activity of a sample is directly proportional to the number of radioactive nuclei present.

$$A \propto N$$

$$A = \lambda N$$

activity — A; # nuclei present — N; λ — proportionality constant, decay constant (s^{-1})

$Bq = \frac{1 \text{ decay}}{s}$

* SI unit for activity is called the becquerel (Bq) → $\frac{\text{decays}}{s}$

May 13.

The curie is another unit used for activity.

$$1\ Ci = 3.70 \times 10^{10}\ Bq$$

The number N of radioactive nuclei present at time t is given as:

$$N = N_0 e^{-\lambda t}$$

$N \rightarrow$ # nuclei present at time t
$N_0 \rightarrow$ original number of nuclei
$\lambda \rightarrow$ decay constant (s^{-1})
$t \rightarrow$ time (s)

At $t = T_{1/2}$, $N = \frac{1}{2} N_0$.

$$\frac{1}{2} N_0 = N_0 e^{-\lambda T_{1/2}}$$

$$\frac{1}{2} = e^{-\lambda T_{1/2}}$$

$$1 = 2 e^{-\lambda T_{1/2}}$$

$$\frac{1}{e^{-\lambda T_{1/2}}} = 2$$

$$2 = e^{\lambda T_{1/2}}$$

Take the natural log of both sides. $\left(\ln(e^x) = x \right)$

$$\ln 2 = \lambda T_{1/2}$$

$$\lambda = \frac{\ln 2}{T_{1/2}} \quad *$$

$$\lambda = \frac{0.693}{T_{1/2}}$$

Start with

$$N = N_0 e^{-\lambda t}$$

$$A = A_0 e^{-\lambda t}$$

$$m = m_0 e^{-\lambda t}$$

$$N = N_0 e^{-\lambda t}$$

$$\frac{N}{N_0} = \left[e^{-\lambda t}\right]$$

→ fraction of nuclei that remain *