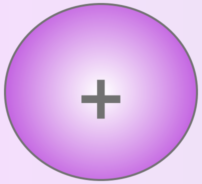
Nuclear Chemistry

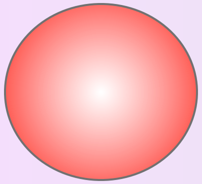
Atoms are composed of

PROTONS



positively charged mass = 1.6726×10^{-27} kg

NEUTRONS

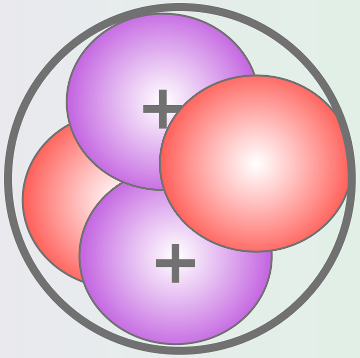


neutral mass = 1.6750×10^{-27} kg

ELECTRONS

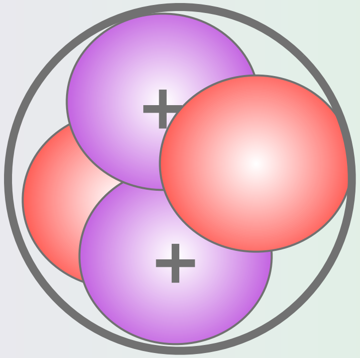
negatively charged mass = 9.1096×10^{-31} kg

the Nucleus



made up of protons and neutrons

Nuclear Force



the neutrons within the nucleus act as sort of glue countering the electrostatic repulsion between the protons

Radioactivity

when an unstable nuclei increases its stability by altering its number of neutrons and protons

Types of Nuclear Decay

Alpha emission ($^{4}_{2}\alpha$)

Beta emission ($^{0}_{-1}\beta$)

Positron emission ($^{0}_{+1}\beta$)

Electron capture ($^{0}_{-1}e$)

Gamma emission ($^{0}_{0}\gamma$)

Alpha emission ($^{4}_{2}\alpha$)

the nucleus emits a helium nuclei (2 protons and 2 neutrons

$$^{4}_{2}\alpha = {}^{4}_{2}\mathrm{He}$$

$$^{210}_{84}\mathrm{Po} \longrightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$$

Beta emission (${}^{0}_{-1}\beta$)

the nucleus changes a neutron into a proton by emitting an electron

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

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

Positron emission (${}^{0}_{+1}\beta$)

the nucleus changes a proton into a neutron by emitting a positron

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

$${}^{8}_{5}B \longrightarrow {}^{0}_{+1}\beta + {}^{8}_{4}Be$$

Electron capture $\left({}^{0}_{-1}e\right)$

the nucleus captures an electron and changes a proton into a neutron

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

$${}^{0}_{-1}\beta + {}^{11}_{6}C \longrightarrow {}^{11}_{5}B$$

Gamma emission ($^{0}_{0}\gamma$)

electromagnetic radiation emitted during nuclear decay

balance the following nuclear equations

$$^{210}_{84}\text{Po} \longrightarrow {}^{206}_{82}\text{Pb} + \text{X}$$

$$^{137}_{55}\text{Cs} \longrightarrow {}^{137}_{56}\text{Ba} + \text{X}$$

$$^{20}_{11}\text{Na} \longrightarrow {}^{20}_{10}\text{Ba} + \text{X}$$

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$$^{20}_{11}\mathrm{Na} \longrightarrow {}^{20}_{10}\mathrm{Ne} + \mathrm{X}$$

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$$^{20}_{11}\mathrm{Na} \longrightarrow {}^{20}_{10}\mathrm{Ne} + {}^{0}_{+1}\beta$$

Nuclear Stability

the principle factor in determining whether a nucleus is stable is the neutron-to-proton ratio

for elements of low atomic number the value is close to one

as the mass number increases, the neutron-to-proton ratios become greater than one

Nuclear Stability

nuclei that contain 2, 8, 20, 50, 82, and 126 protons are generally more stable (magic numbers)

nuclei with even numbers of both protons and neutrons are generally more stable than odd numbers

Nuclear Stability

If an isotope’s mass number is greater than its atomic weight, *beta emission* is expected

If an isotope’s mass number is less than its atomic weight, *positron emission* or *electron capture* is expected

All elements having an atomic number greater than 83 are radioactive. *Alpha particles* are emitted by most of these isotopes.

a decay series

when a radioactive nucleus disintegrates, the products formed may also be unstable and under go further disintegration’s until a stable product is formed

$$^{238}_{92}\text{U} \longrightarrow {}^{206}_{82}\text{Pb}$$

involves 14 steps

$${}^{238}_{92}\mathrm{U} \longrightarrow {}^{206}_{82}\mathrm{Pb}$$

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

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

$${}^{234}_{91}\mathrm{Pa} \longrightarrow {}^{234}_{92}\mathrm{U} + {}^{0}_{-1}\beta$$

$${}^{234}_{92}\mathrm{U} \longrightarrow {}^{230}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

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

$${}^{226}_{88}\mathrm{Ra} \longrightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$

$${}^{222}_{86}\mathrm{Rn} \longrightarrow {}^{218}_{84}\mathrm{Po} + {}^{4}_{2}\mathrm{He}$$

$${}^{222}_{86}\mathrm{Rn} \longrightarrow {}^{218}_{84}\mathrm{Po} + {}^{4}_{2}\mathrm{He}$$

$${}^{218}_{84}\mathrm{Po} \longrightarrow {}^{214}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$$

$${}^{214}_{82}\mathrm{Pb} \longrightarrow {}^{214}_{83}\mathrm{Bi} + {}^{0}_{-1}\beta$$

$${}^{214}_{83}\mathrm{Bi} \longrightarrow {}^{214}_{84}\mathrm{Po} + {}^{0}_{-1}\beta$$

$${}^{214}_{84}\mathrm{Po} \longrightarrow {}^{210}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$$

$${}^{210}_{82}\mathrm{Pb} \longrightarrow {}^{210}_{83}\mathrm{Bi} + {}^{0}_{-1}\beta$$

$${}^{210}_{83}\mathrm{Bi} \longrightarrow {}^{210}_{84}\mathrm{Po} + {}^{0}_{-1}\beta$$

$${}^{210}_{84}\mathrm{Po} \longrightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$$

Kinetics of Radioactive Decay

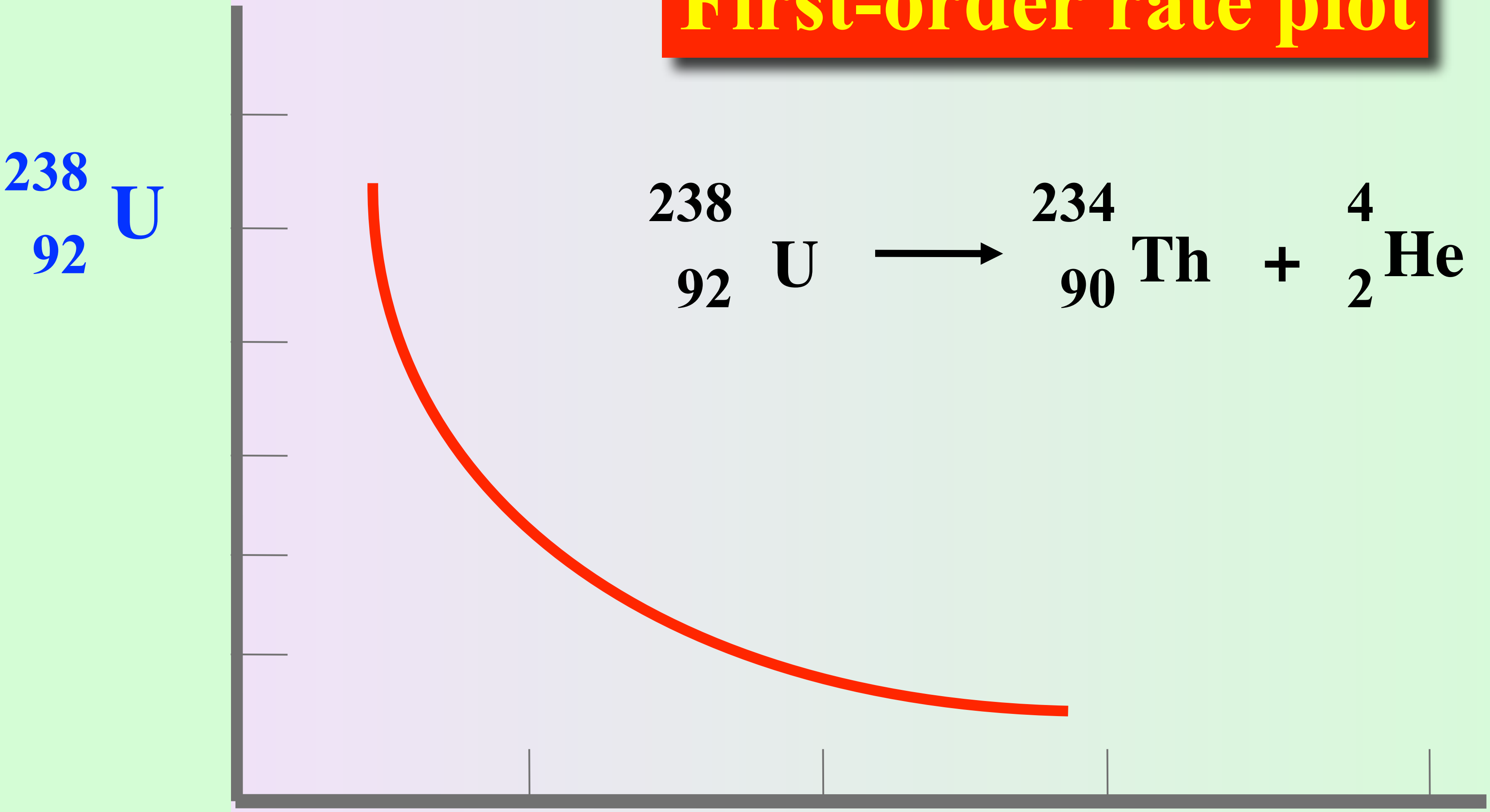
all radioactive decays obey first-order kinetics

Rate of decay at time t = $k\,N$

k = rate constant

N = the number of radioactive nuclei present at time t

First-order rate plot



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

The plot shows the decay of uranium-238 to thorium-234

First-Order rate law Integrated

the integrated form of the rate law is:

$$\ln \frac{N_0}{N_t} = kt$$

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

Integrated rate law

is an equation for a straight line

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

$$y = mx + b$$

Plot $\ln N_t$ versus t

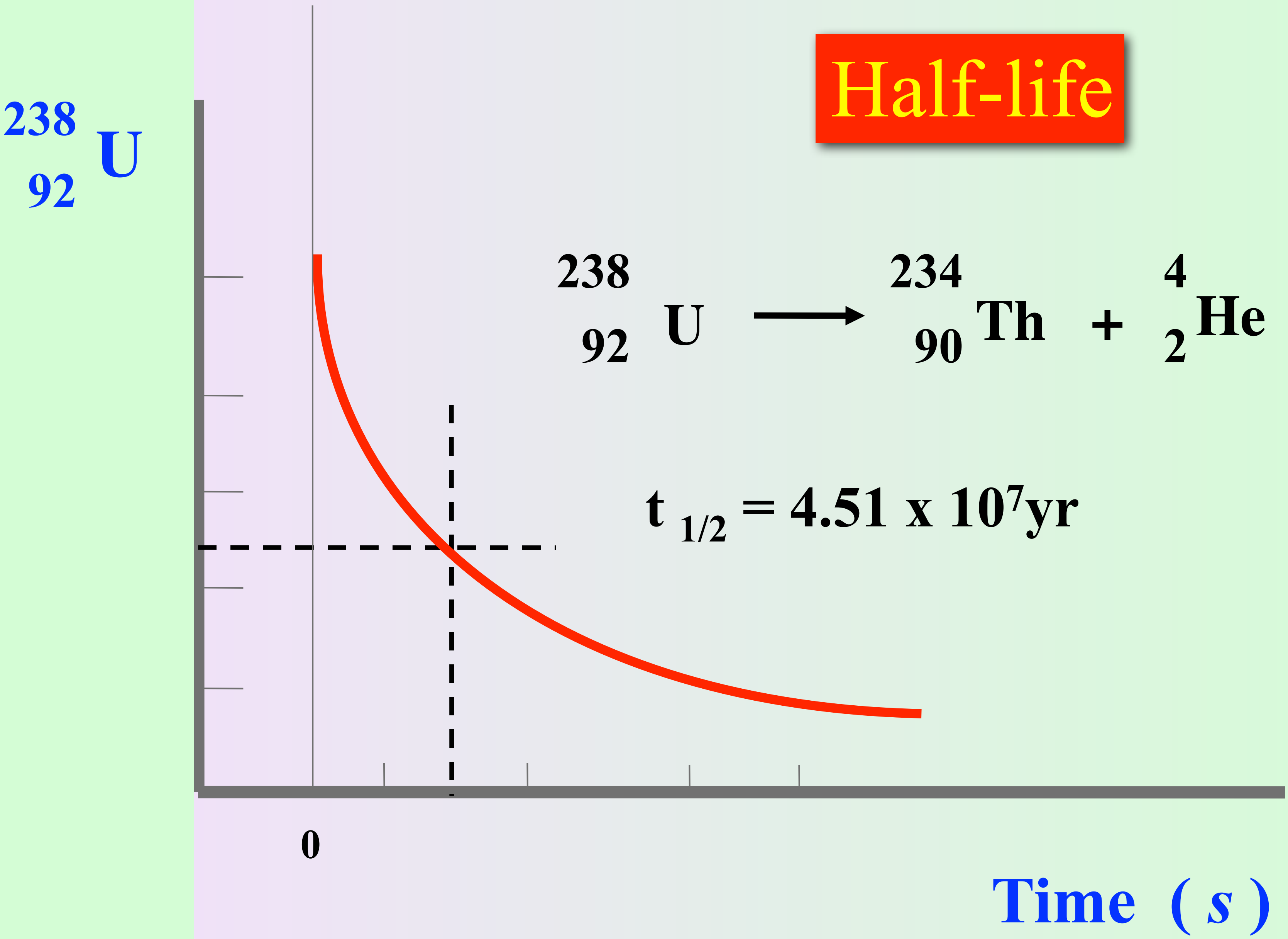
Slope = -k

y intercept is $\ln N_0$

Half-life

the time for the concentration of a reactant to decrease to one-half of its initial concentration

Half-life



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

$t_{1/2} = 4.51 \times 10^7 yr$

Radiocarbon Dating

Willard Libby (Nobel Prize, 1960)

Carbon-14

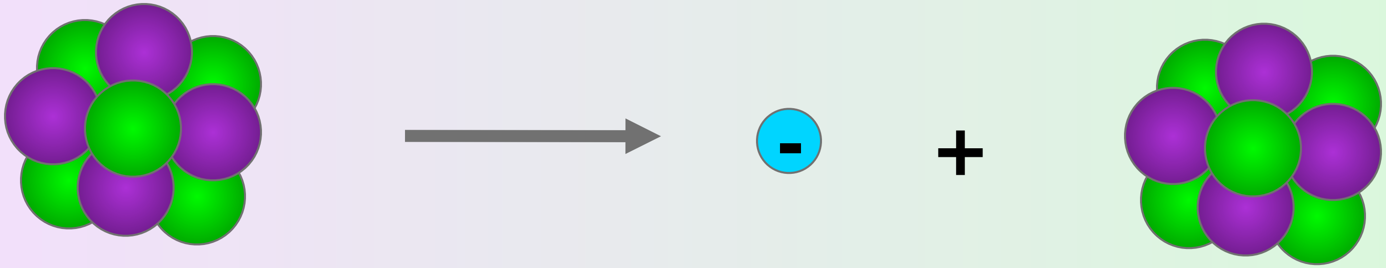
Natural abundance: 1 part in 10^{12}

β – emitter

Half-life = 5730 years

used to date archeological artifacts younger than 30,000 years

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



Example

The C-14 decay rate of wood obtained from a live tree is 0.260 disintegration per second per gram of sample A sample of wood from an archaeological site has C-14 decay rate of 0.186 disintegration per second per gram. How old is the sample?

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$t_{1/2}$ for ^{14}C is known to be 5730 years

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

Therefore, $k = (0.693/5730\ \text{yr}) = 1.21 \times 10^{-4}\ \text{yr}^{-1}$

$$\ln \frac{[A]_0}{[A]} = kt \qquad \ln \frac{260}{186} = (1.21 \times 10^{-4}\ \text{yr}^{-1})\, t$$

$t = 2770$ years

Some representative half-lives

Tc-99	6 hours
Mo-99	67 hours
Sr-90	28.8 years
C-14	5730 years
K-40	1,300,000 years
U-238	45, 000,000 years