Nuclear Chemistry

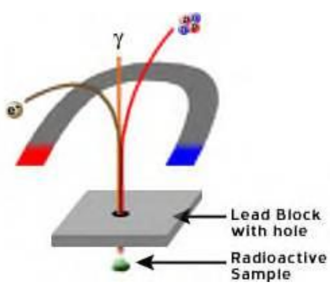
Reading:	Ch 19, sections 1 – 12	Homework:	Chapter 19: 31*, 33*, 35, 45, 47*, 49*, 53, 55, 59*, 61, 63, 65, 67, 69*, 71*

* = 'important' homework question

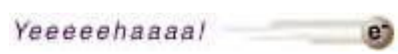
Radioactivity

Discussion: What kinds of nuclear radiation are there? What are the origins of each type of radiation?

Types of radiation (see appendix)*



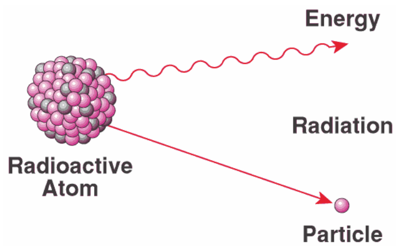
Alpha particles are helium nuclei (2 p, 2 n): 

Beta particles are speedy electrons: 

Gamma radiation is a high-energy photon: 

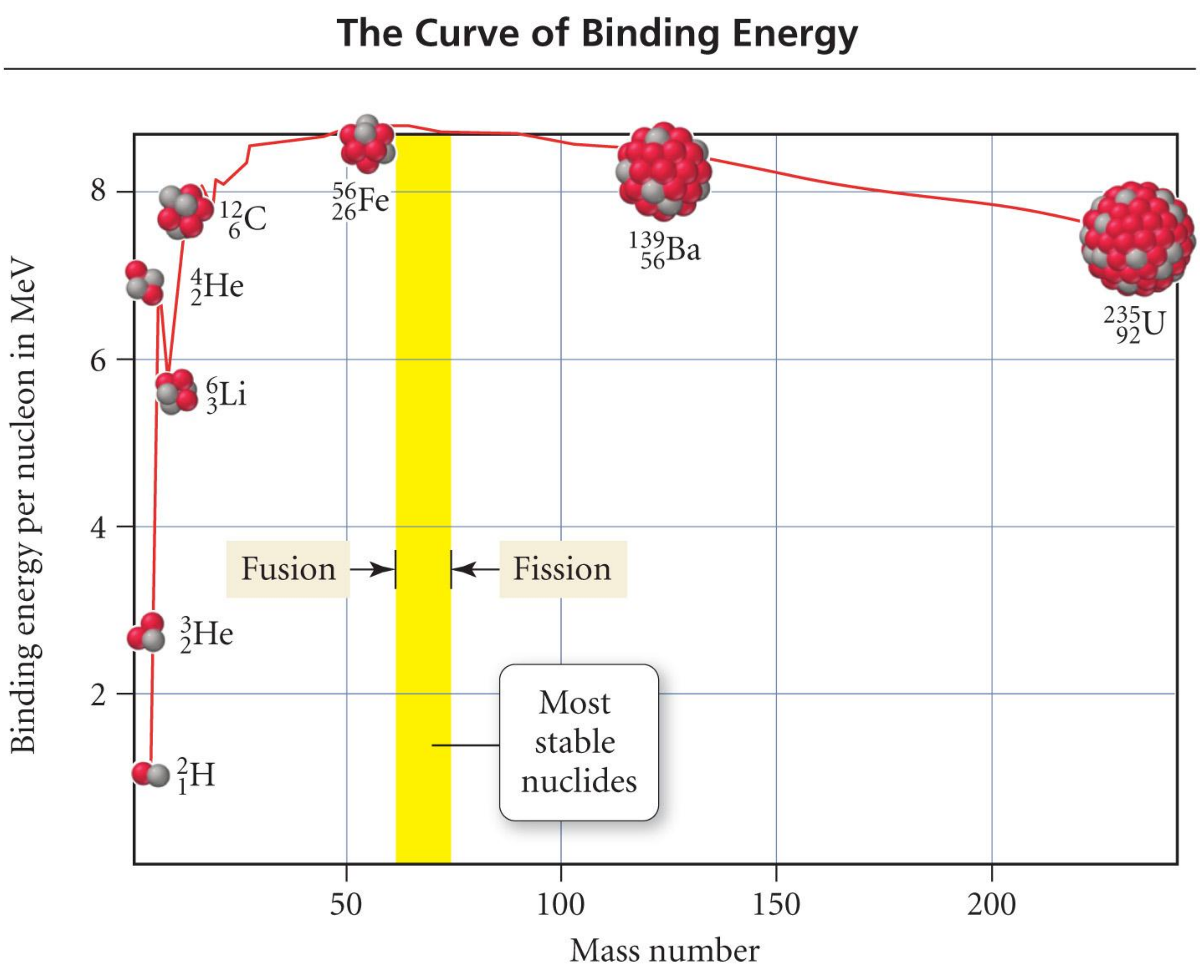
Name	Symbol	Charge	Penetration Limit
alpha (α) particles	${}^{4}_{2}He$ or ${}^{4}_{2}\alpha$	+2	skin, thin metal foil
beta (β) particles	${}^{0}_{-1}\beta$ or ${}^{0}_{-1}e$	-1	thicker foil, plastic
gamma (γ) rays	${}^{0}_{0}\gamma$	0	lead, concrete

Overview



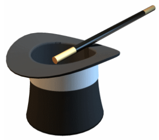
'Heavy' nuclei are unstable; they undergo nuclear decay via either alpha, beta and/or gamma emission to form lighter, more stable nuclei.

Iron has the most stable nucleus (ever wondered why the Earth and many other planets have iron cores?).



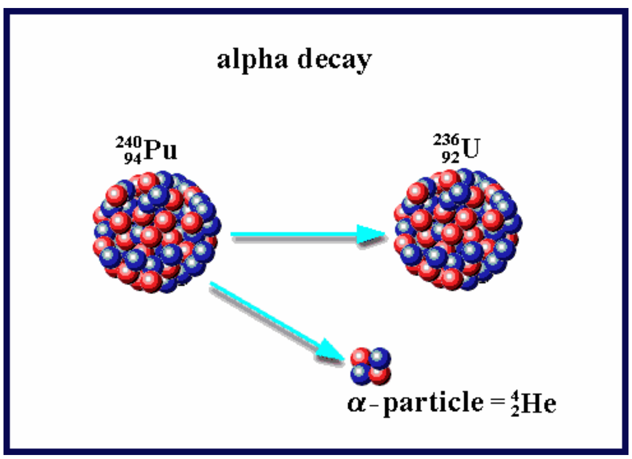
Strong v weak nuclear force - it's magnets with velcro (more later!)

<u>Writing radioactive decay equations</u>

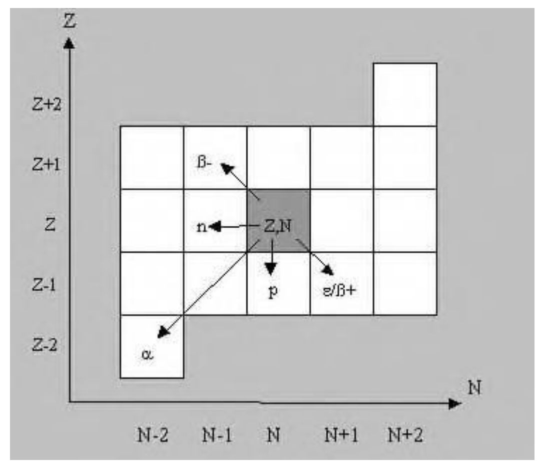


Recall writing complete atomic symbols from CHM 101. Writing nuclear decay equations is just accounting for changes in atomic number (Z) and atomic mass (A) in such symbols

<u>Worked Example</u>: Write reaction for the α-particle decay of Pu-240.



α-particle decay of Pu-240



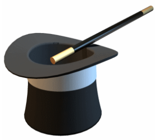
Variation in Z and #N for various types of nuclear decay

<u>Task</u>: Write nuclear decay equations for the following processes:

1. The β decay of I-131

2. The α decay of U-238 (see appendix)

Nuclear Transmutations



Similar math (with regard to balancing mass and atomic numbers) can be used for writing nuclear transmutation equations

Worked example: Write an equation for the capture of a neutron (cosmic ray) by N-14

Task: Write nuclear transmutation equations for the following processes:

1. Fe-58 undergoing neutron capture

2. See Example question 19.2 (a – c), page 870, of your text

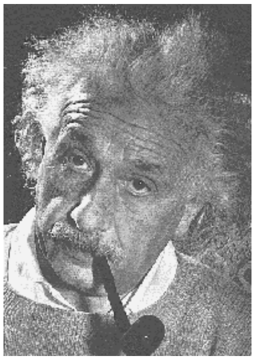
Radioactive Decay

All radioactive decay processes are 1^{st} order in terms of their kinetics. Thus, familiar relationships from the 'Kinetics' topic can be employed directly**. Remember the basic 'half-life trick' for simpler questions**

Worked Example: It takes 5.2 minutes for a 1.000 g sample of Fr-210 to decay to 0.250 g. What is the half-life of Fr-210?

Task: How much time is required for a 5.75 mg of Cr-51 to decay to 1.50 mg if its half-life is 27.8 days?

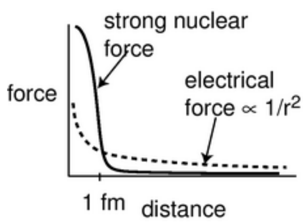
Nuclear Binding Energy



It's a little more complicated than that….

Discussion: What Holds a nucleus together? Shouldn't it fly apart – after all, protons must repel one another, right?

Remember: *Strong v weak nuclear force - it's magnets with velcro!*



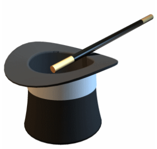
Einstein showed that mass and energy are *convertible*. The relationship is:

$$\mathbf{E = mc^2} \quad \textit{or} \quad \mathbf{\Delta E = \Delta mc^2}$$

The energy, or 'glue', that holds a nucleus' otherwise repulsive nuclear particles together appears as a *mass defect*

Where: mass proton = 1.00728 amu
mass neutron = 1.00866 amu
1 amu = 1.66053873 $\times 10^{-24}$ g
c = 3.0 $\times 10^{8}$ m/s

Mass Defect: the difference in mass between an atomic nucleus and the sum of its individual component particles.

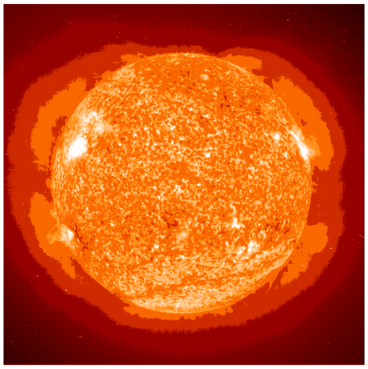


To work out mass defect problems, the mass of the nucleus must be compared to the sum of the masses of its component neutrons and protons.

The mass difference, stated in the form of energy (from $E = mc^2$), is the binding energy of the nucleus.

Worked example: Calculate the binding energy per nucleon for C-12 (nuclear mass = 11.996708 amu)

Task: Calculate the binding energy per nucleon for Cl-37 (nuclear mass = 36.956576 amu)

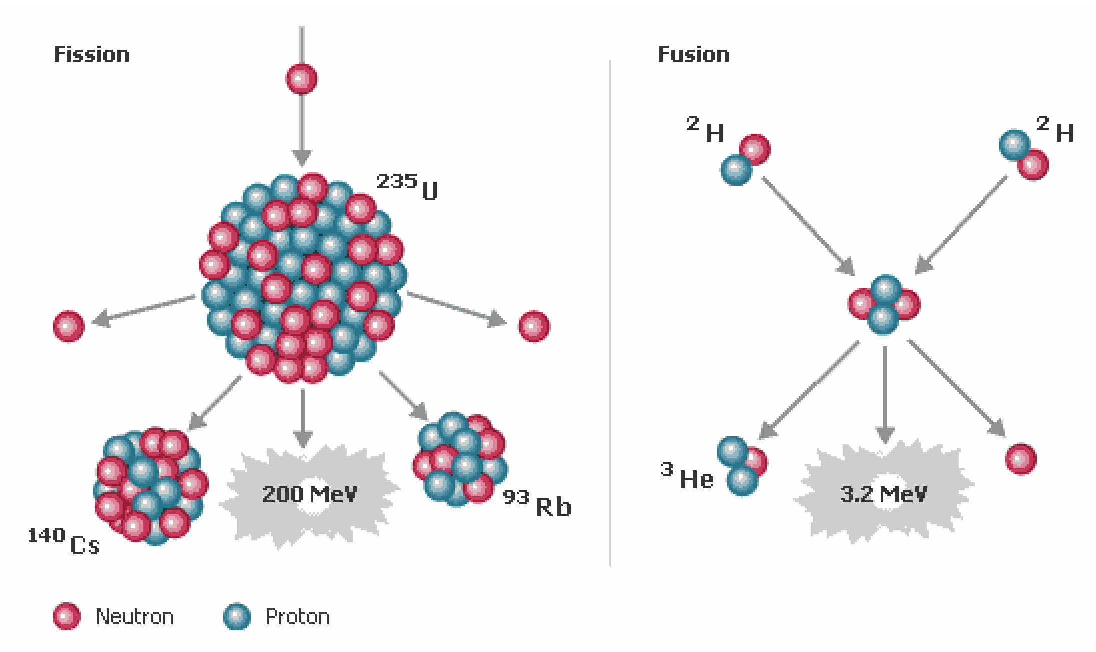


Nuclear Fission and Fusion

Recall the graph of nuclear stability – Fe-56 has the most binding energy per nucleon, so is the most stable of all nuclei. Thus, ALL heavier nuclei may undergo ***fission***, while all lighter nuclei may undergo ***fusion*** to form more stable products. *Hey, universe, there's a lot of iron in your distant future!?*

Vast amounts of energy are liberated during fission (nuclear weapons, U-235) or fusion (the sun, H $\rightarrow$ He) reactions. The origin of this energy is the mass deficit (Δm) between products and reactants in each respective process.

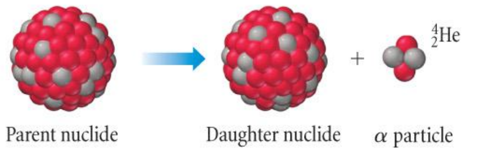
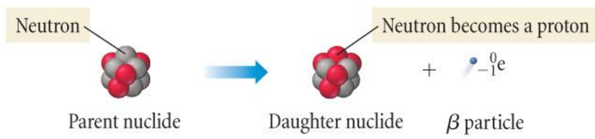
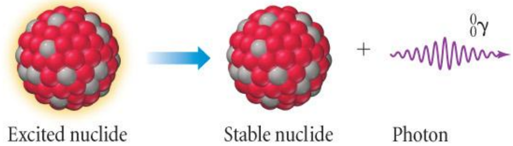
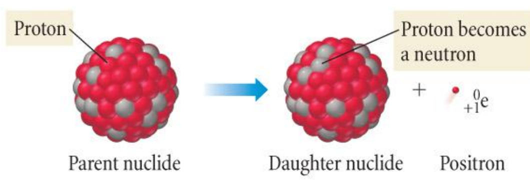
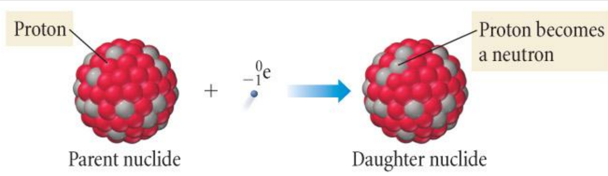
Fission and Fusion processes



Group Wrap Up: Try question 19.7 from your text

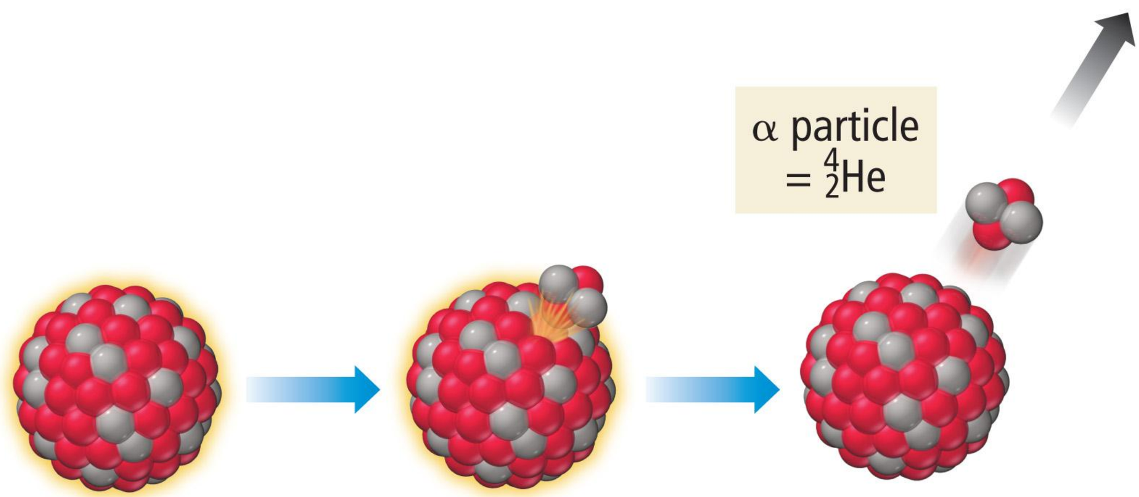
Appendix:

TABLE 19.1 Modes of Radioactive Decay

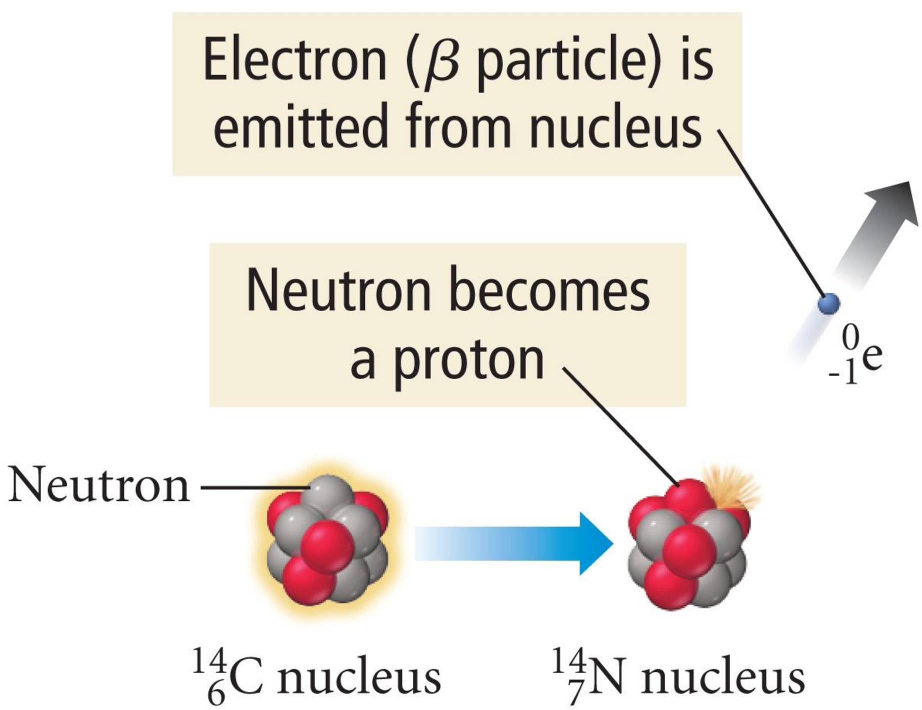
Decay Mode	Process	Change in: A	Z	N/Z*	Example
α		−4	−2	Increase	${}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$
β		0	+1	Decrease	${}^{228}_{88}Ra \longrightarrow {}^{228}_{89}Ac + {}^{0}_{-1}e$
γ		0	0	None	${}^{234}_{90}Th \longrightarrow {}^{234}_{90}Th + {}^{0}_{0}\gamma$
Positron emission		0	−1	Increase	${}^{30}_{15}P \longrightarrow {}^{30}_{14}Si + {}^{0}_{+1}e$
Electron capture		0	−1	Increase	${}^{92}_{44}Ru + {}^{0}_{-1}e \longrightarrow {}^{92}_{43}Tc$

*Neutron-to-proton ratio

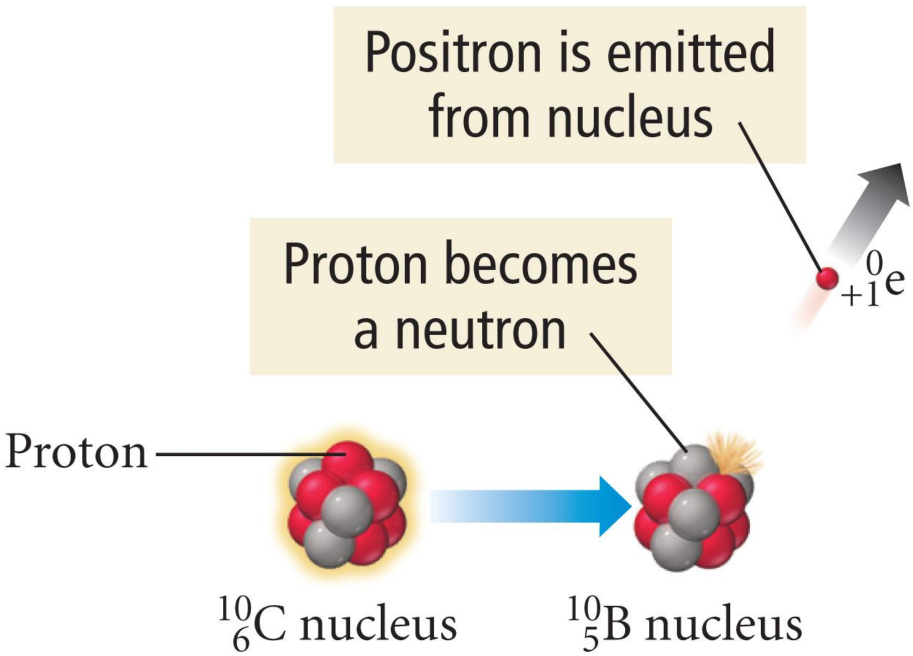
Alpha Decay



Beta Decay



Positron Emission



PET Scan

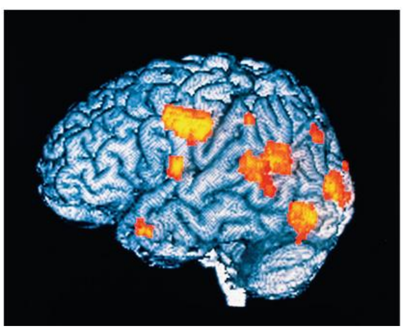


TABLE 19.6 Common Radiotracers

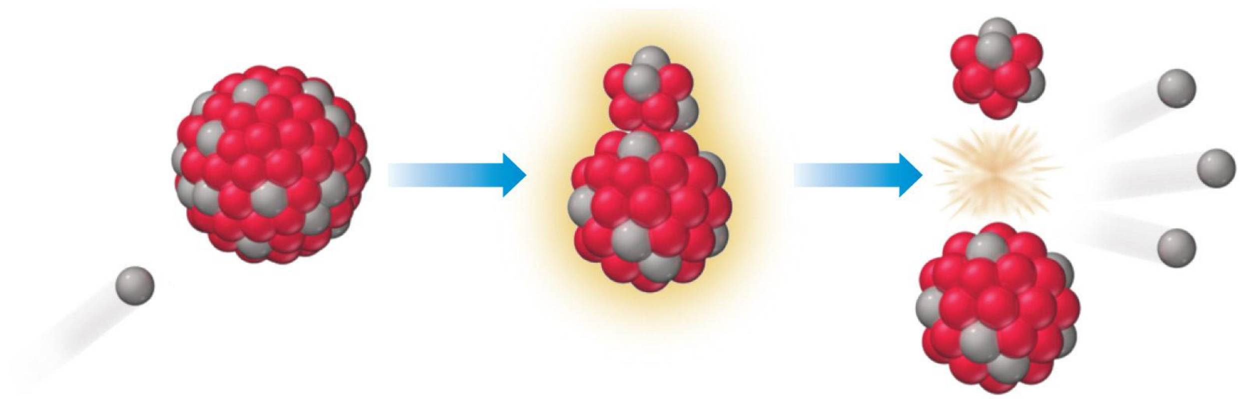
Nuclide	Type of Emission	Half-Life	Part of Body Studied
Technetium-99m	Gamma (primarily)	6.01 hours	Various organs, bones
Iodine-131	Beta	8.0 days	Thyroid
Iron-59	Beta	44.5 days	Blood, spleen
Thallium-201	Electron capture	3.05 days	Heart
Fluorine-18	Positron emission	1.83 hours	PET studies of heart, brain
Phosphorus-32	Beta	14.3 days	Tumors in various organs

Parent nuclide

Daughter nuclide

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

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{140}_{56}\mathrm{Ba} + {}^{93}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n} + \text{energy}$$

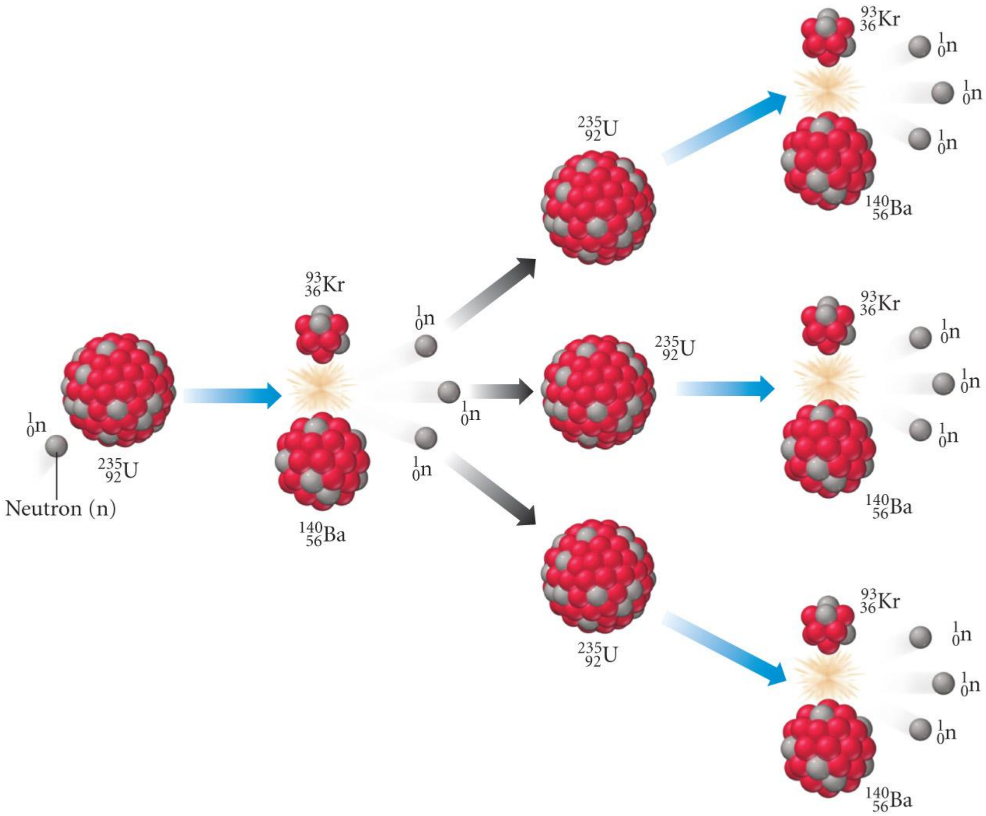


$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{239}_{92}\mathrm{U} \longrightarrow {}^{239}_{93}\mathrm{X} + {}^{0}_{-1}\mathrm{e}$$

Neutron

Newly synthesized element

Fission Chain Reaction



Deuterium-Tritium Fusion Reaction

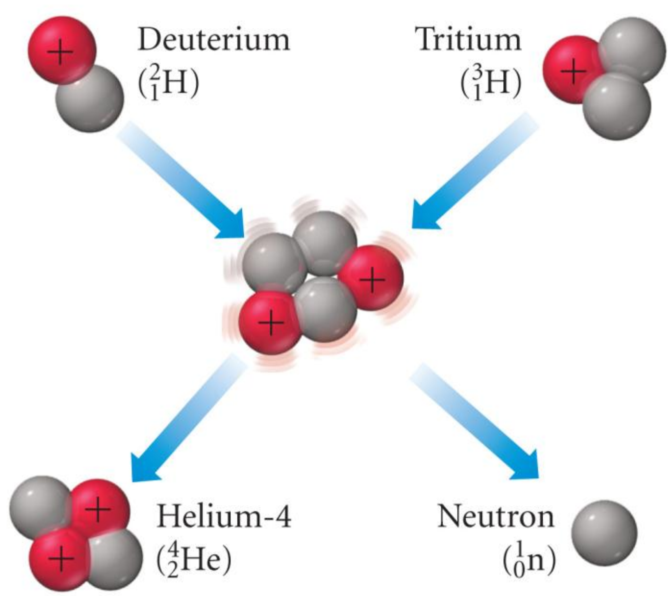


TABLE 19.3 Selected Nuclides and Their Half-Lives

Nuclide	Half-life	Type of Decay
$^{232}_{90}Th$	1.4×10^{10} yr	Alpha
$^{238}_{92}U$	4.5×10^{9} yr	Alpha
$^{14}_{6}C$	5730 yr	Beta
$^{220}_{86}Rn$	55.6 s	Alpha
$^{219}_{90}Th$	1.05×10^{-6} s	Alpha