Today

Radioactive Decay

First a refresher on nuclear reactions

How does a typical nuclear reaction compare to a chemical reaction in terms of energy change?

the energy per mole for a nuclear reaction is roughly

A. 10 times larger

B. 10^3 times larger

C. 10^6 times larger

D. 10^9 times larger

E. 10^{12} times larger

What is the energy released in this reaction?

$$H(g) + H(g) \longrightarrow H_2(g)$$

~100's kJ mol^{-1}

Average Bond Energies (kJ/mol)

Single Bonds						Multiple Bonds	
H—H	432	N—H	391	I—I	149	C=C	614
H—F	565	N—N	160	I—Cl	208	C≡C	839
H—Cl	427	N—F	272	I—Br	175	O=O	495
H—Br	363	N—Cl	200			C=O*	745
H—I	295	N—Br	243	S—H	347	C≡O	1072
		N—O	201	S—F	327	N=O	607
C—H	413	O—H	467	S—Cl	253	N=N	418
C—C	347	O—O	146	S—Br	218	N≡N	941
C—N	305	O—F	190	S—S	266	C≡N	891
C—O	358	O—Cl	203			C=N	615
C—F	485	O—I	234	Si—Si	340		
C—Cl	339			Si—H	393		
C—Br	276	F—F	154	Si—C	360		
C—I	240	F—Cl	253	Si—O	452		
C—S	259	F—Br	237				
		Cl—Cl	239				
		Cl—Br	218				
		Br—Br	193				

*C=O(CO_2) = 799

What about this reaction?

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{?}_{?}He$$

A. $^{2}_{1}He$

B. $^{2}_{2}He$

C. $^{4}_{2}He$

How much energy is release per helium atom?

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{4}_{2}He$$

mass	2.0141 u	2.0141 u	4.0026 u

$\Delta m = 4.0026 - 2(2.0141)$

$= -0.0256$ u

$1\ u = 1.66 \times 10^{-27}$ kg

$c = 3.0 \times 10^{8}\ m\ s^{-1}$

$\Delta E = mc^2$

$\Delta m = -0.0256 (1.66 \times 10^{-27}\ kg)$

$\Delta E = \Delta m c^2 = -3.8 \times 10^{-12}$ J

$-3.8 \cdot 10^{-12}\ J \times N_a$

$= 1.8 \cdot 10^{8}\ kJ\ mol^{-1}$

$\approx 180 \cdot 10^{6}\ kJ\ mol^{-1}$

Like chemistry we can write a reaction down but it is not necessarily the one that happens

actually

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{1}H + ^{1}_{1}p^{+}$$

What reaction could be spontaneous?

What reaction could be spontaneous?

$\Delta E < 0$

$\Delta m < 0$

Why are we now only talking about energy instead of free energy (ΔG)

A. the energy term is so large it dominates

B. the entropy change is always zero in a nuclear reaction

C. only molecules have entropy

$$\Delta G = \Delta H - T\Delta S$$

HUGE very small

Radioactive Decay

Some nuclei are more stable than others
(they are lower in energy)

Therefore there can be a spontaneous reaction
to change the nucleus to form the more stable atom

this change is accompanied by "nuclear radiation"

What is nuclear radiation?

A. electrons

B. small nuclei

C. high energy electromagnetic radiation

D. A & B

E. all of the above

Three basic types of nuclear radiation

- Radioactivity – the spontaneous emission of radiation by certain elements (Madame Curie).
- Radiation was classified by Rutherford according to its penetrating power
  - alpha rays penetrated the least (a sheet of paper blocked them),
  - beta rays were more penetrating (a book stopped them),
  - and gamma rays were the most penetrating (requiring lead).

Three basic types of nuclear radiation

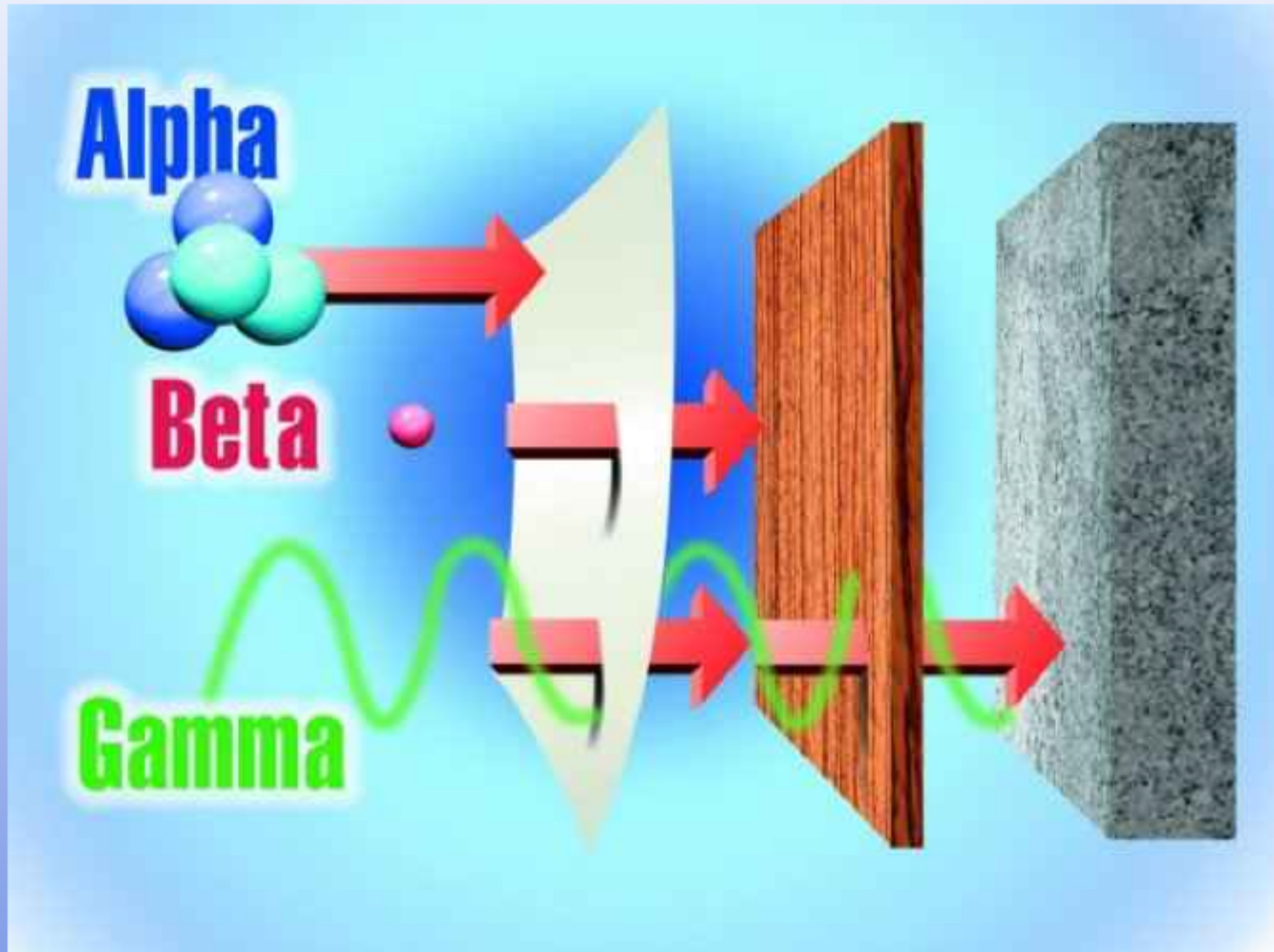
alpha radiation	positive and massive
beta radiation	negative and low mass
gamma radiation	uncharged (no mass)

Three basic types of nuclear radiation

Table 7.2 Types of Nuclear Radiation

Type	Symbol	Consists of	Charge	Change to nucleus that emits it
Alpha	${}^{4}_{2}He$	2 protons 2 neutrons	2+	The mass number decreases by 4, and the atomic number decreases by 2.
Beta	${}^{0}_{-1}e$	an electron	1−	The mass number does not change, and the atomic number increases by 1.
Gamma	${}^{0}_{0}\gamma$	photon of energy	0	No change in either the mass number or in the atomic number.

Effects of all three is very different



Alpha particles

If they get into your body they can be very harmful

bare Helium nucleus
will rip electrons off molecules
ionization of biomolecules = unhealthy you

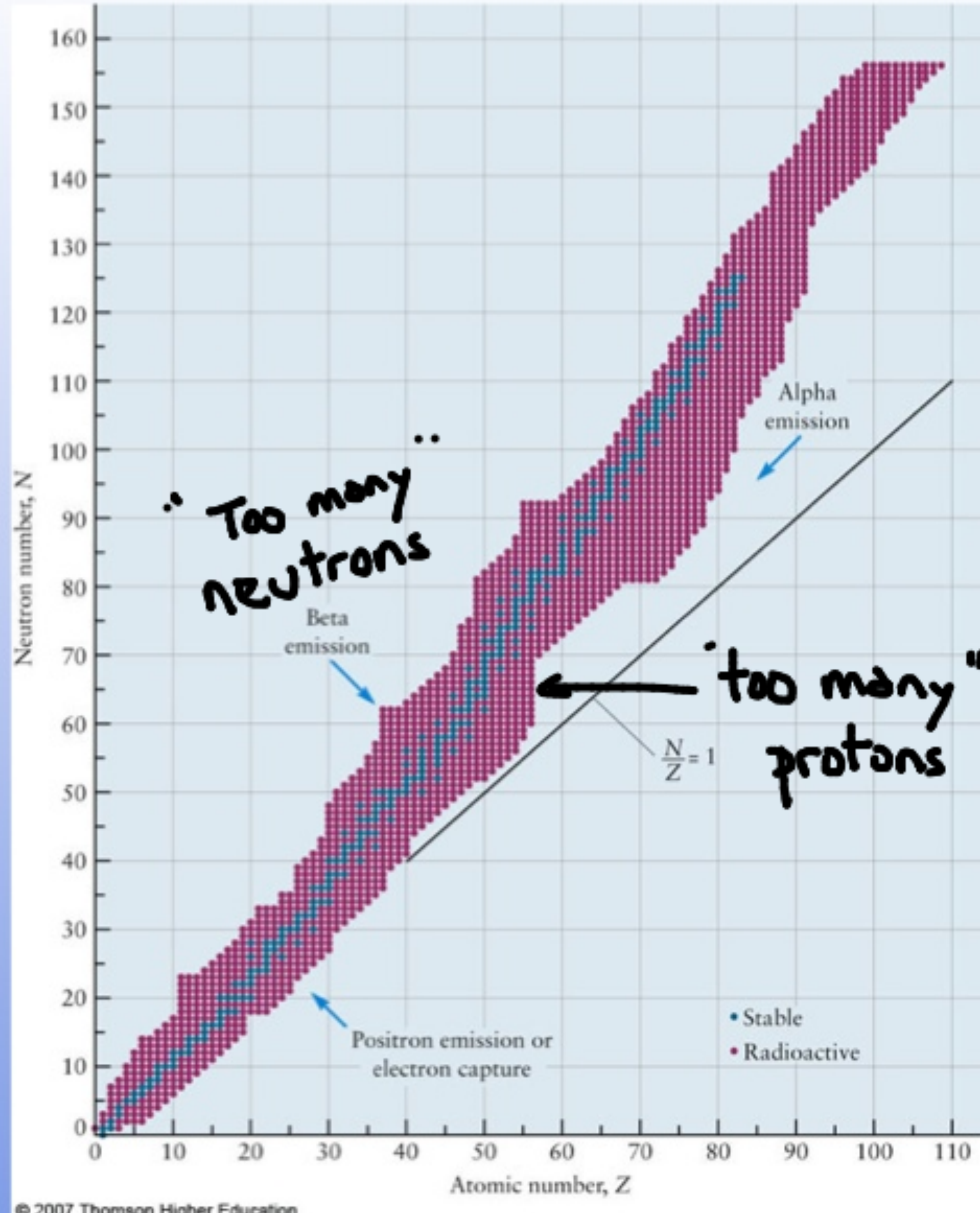
Generally not harmful as they are absorbed by your outer layer of dead skin
(bad news if they get in your lungs!)

http://www.epa.gov/rpdweb00/understand/alpha.html#affecthealth

Gamma rays

This is what will do you in.
Hard to protect against
Highly ionizing.
Like the world's worst sunburn
(except the radiation can penetrate)

http://www.epa.gov/rpdweb00/understand/gamma.html#affecthealth



160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Neutron number, N
0
10
20
30
40
50
60
70
80
90
100
110
Atomic number, Z
Alpha emission
Beta emission
Positron emission or electron capture
N/Z = 1
Stable
Radioactive
"Too many neutrons"
"too many" protons
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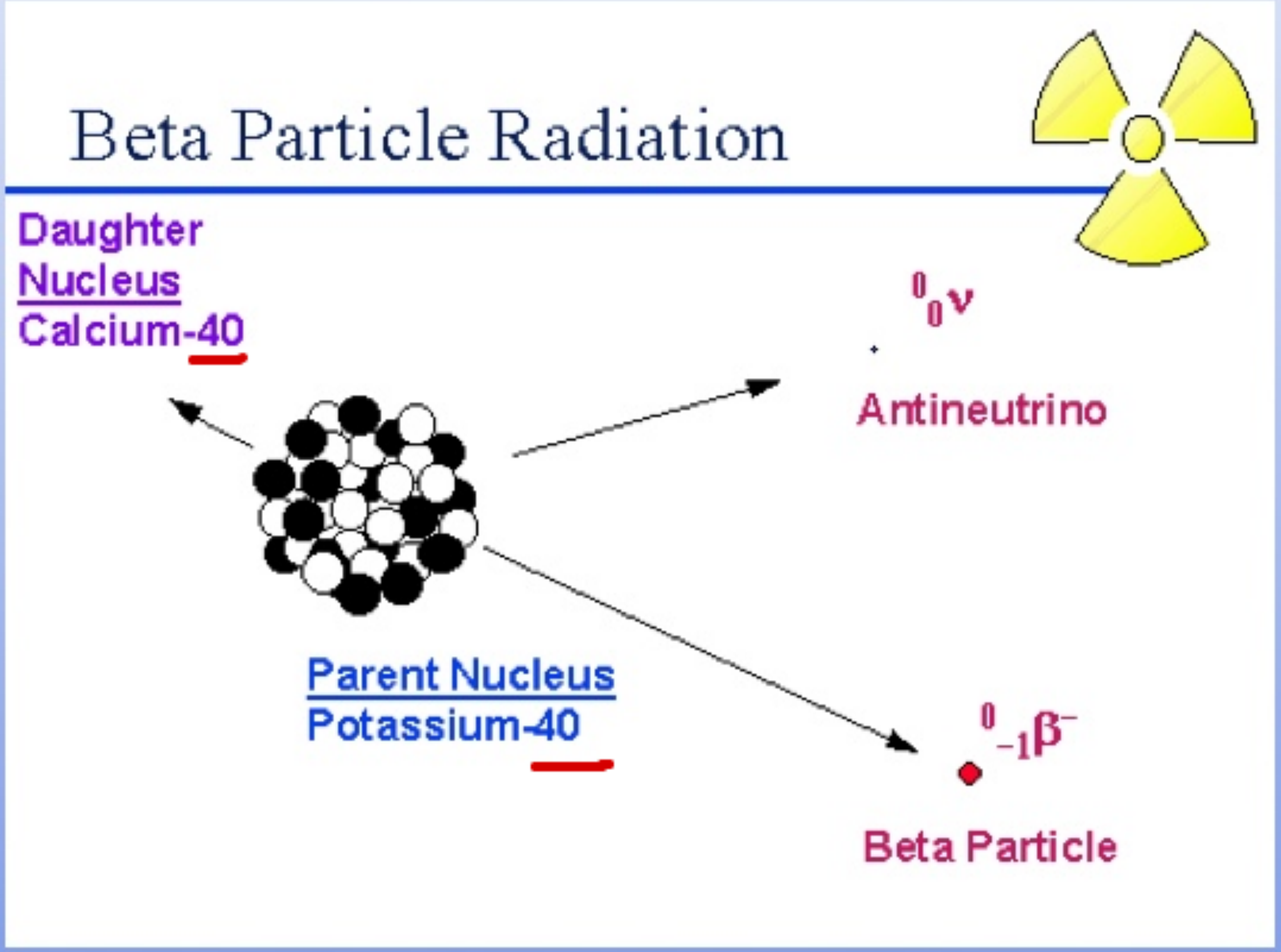
Types of decay

Beta decay



Beta (-) decay

"Too many" neutrons

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

For this to happen spontaneously

$\Delta m < 0$

Beta (+) decay (positron emission)

"Too many" protons

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

or

electron capture

$$^{231}_{92}U + ^{0}_{-1}e^{-} \longrightarrow ^{231}_{91}Pa + \nu$$

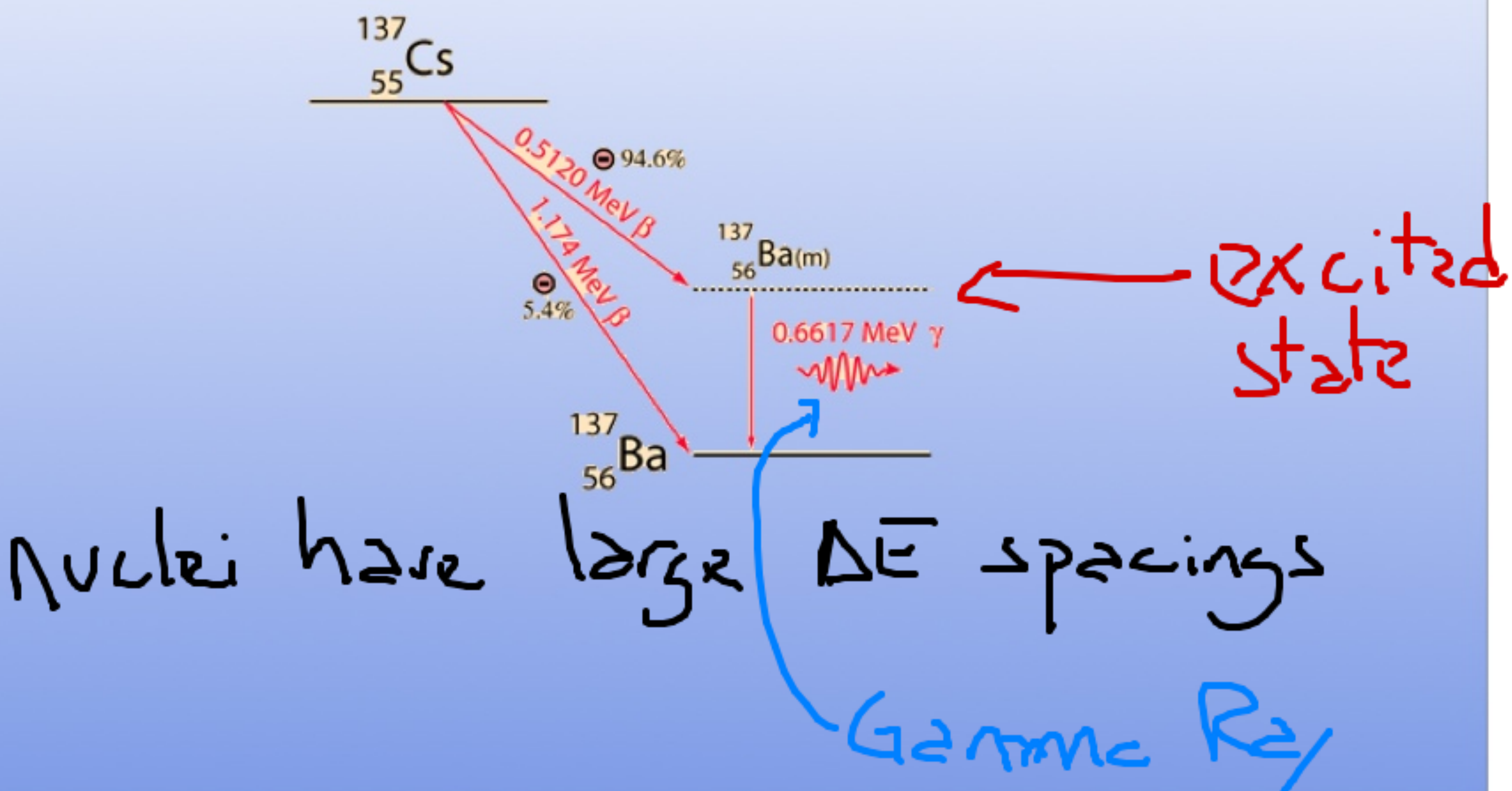
Change $n \rightarrow p$ or $p \rightarrow n$

alpha decay

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

Loss of 2p+2n

Where is all the gamma radiation?



Kinetics of radioactive decay

There is simply a chance of it happening.

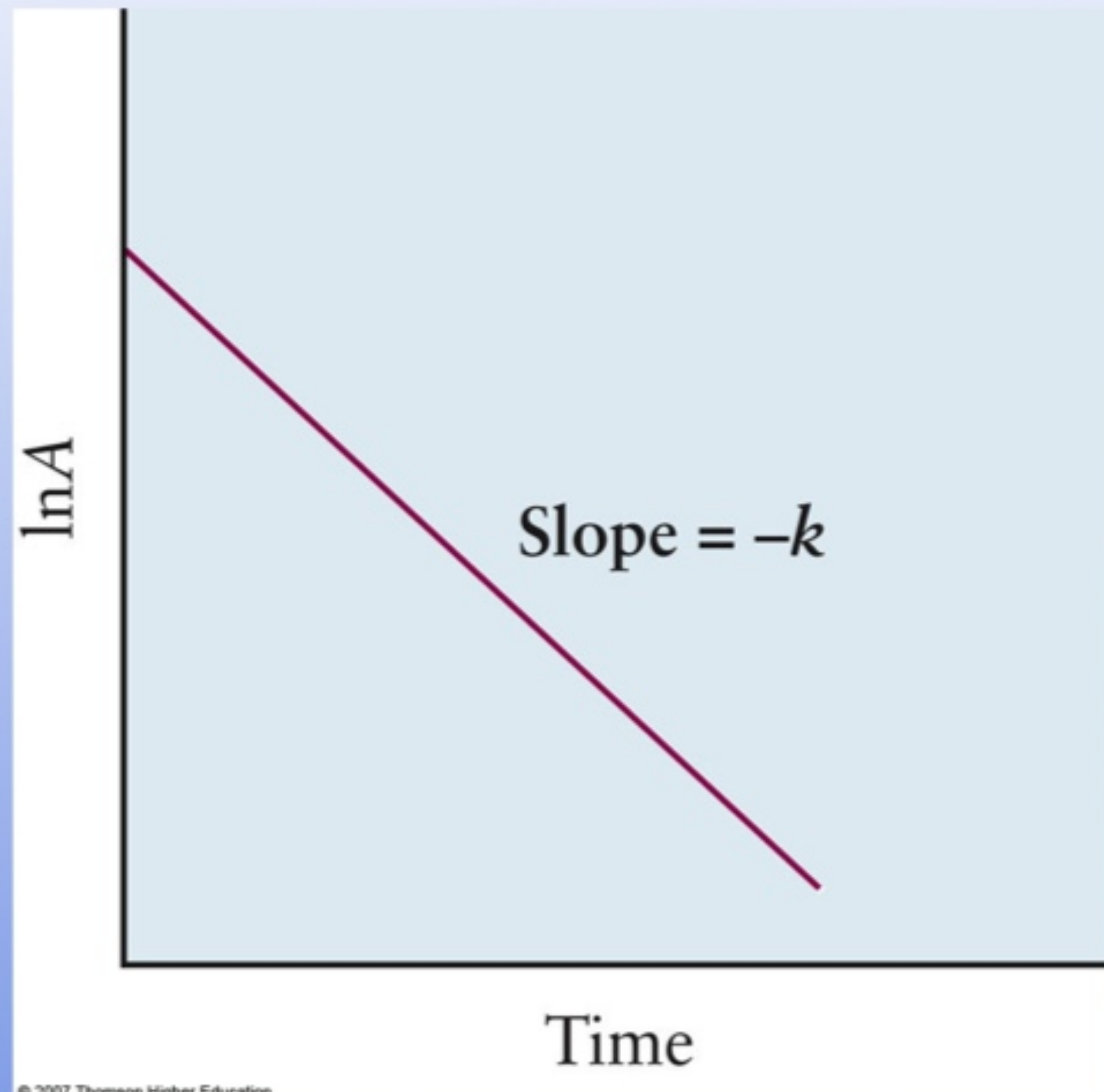
Therefore the number of decays per second depends number of atoms

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

"unimolecular"
First order in C

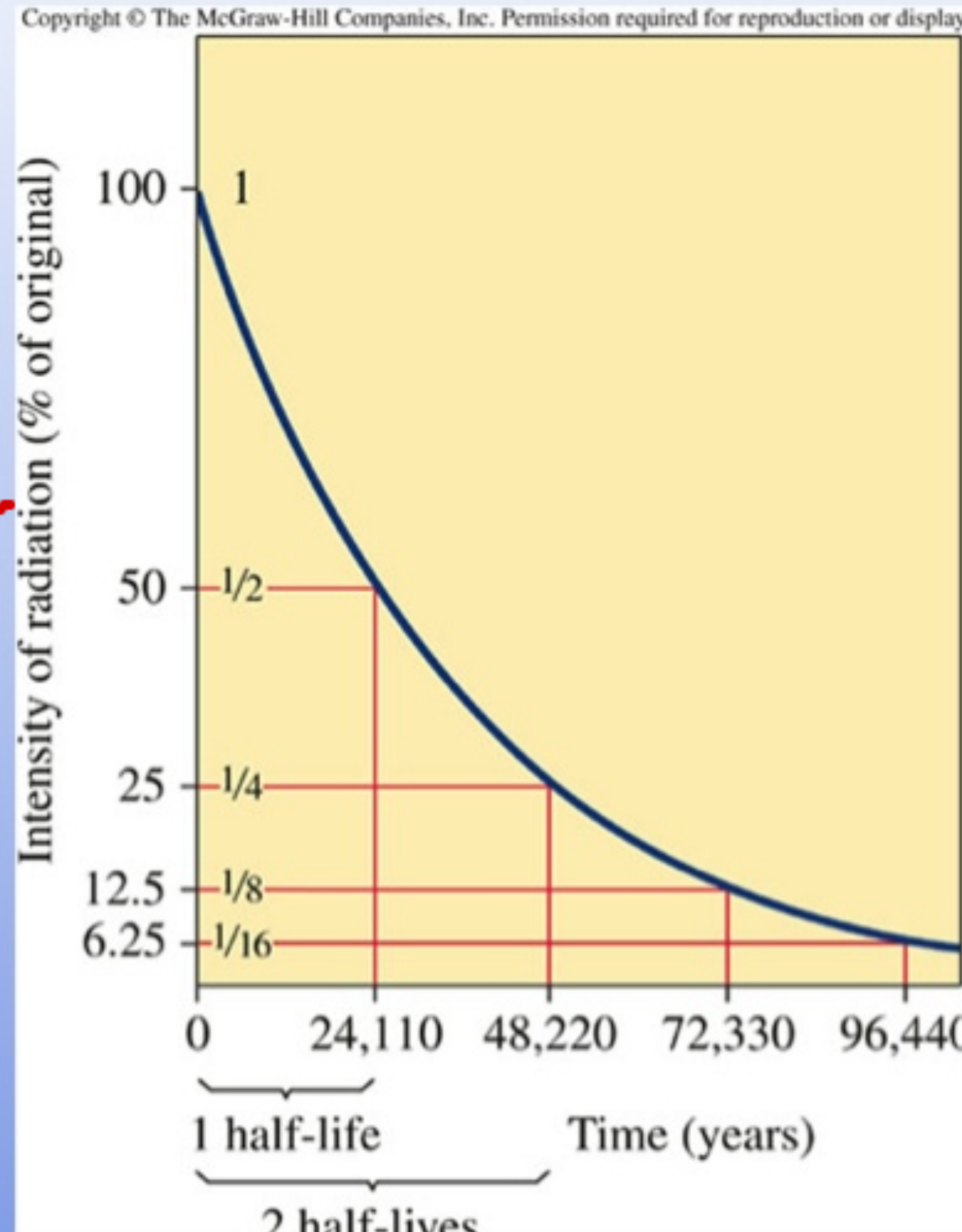
Radioactive decay is first order

ln
of
atoms



Half-life: the time required for the level of radioactivity to fall to one-half of its value. Example of decay of Pu-239.

# of atoms ∝ amount of rad.



The most dangerous radioactive compounds will emit beta and gamma radiation and have half-lives that are

A. very very short — lot of Radiation — SHORT

B. very very long — little Rad. — FOREVER

C. some where in between

D. the half life is irrelevant

DEPENDS

TABLE 19.2	Decay Characteristics of Some Radioactive Nuclei		
Nuclide	**$t_{1/2}$**	**Decay Mode†**	**Daughter**
$^{3}_{1}H$ (tritium)	12.26 years	e^-	$^{3}_{2}He$
$^{8}_{4}Be$	$\sim 1 \times 10^{-16}$ s	α	$^{4}_{2}He$
$^{14}_{6}C$	5730 years	e^-	$^{14}_{7}N$
$^{22}_{11}Na$	2.601 years	e^+	$^{22}_{10}Ne$
$^{24}_{11}Na$	15.02 hours	e^-	$^{24}_{12}Mg$
$^{32}_{15}P$	14.28 days	e^-	$^{32}_{16}S$
$^{35}_{16}S$	87.2 days	e^-	$^{35}_{17}Cl$
$^{36}_{17}Cl$	3.01×10^{5} years	e^-	$^{36}_{18}Ar$
$^{40}_{19}K$	1.28×10^{9} years	e^- (89.3%)	$^{40}_{20}Ca$
		E.C. (10.7%)	$^{40}_{18}Ar$
$^{59}_{26}Fe$	44.6 days	e^-	$^{59}_{27}Co$
$^{60}_{27}Co$	5.27 years	e^-	$^{60}_{28}Ni$
$^{90}_{38}Sr$	29 years	e^-	$^{90}_{39}Y$
$^{109}_{48}Cd$	453 days	E.C.	$^{109}_{47}Ag$
$^{125}_{53}I$	59.7 days	E.C.	$^{125}_{52}Te$
$^{131}_{53}I$	8.041 days	e^-	$^{131}_{54}Xe$
$^{127}_{54}Xe$	36.41 days	E.C.	$^{127}_{53}I$
$^{137}_{57}La$	$\sim 6 \times 10^{4}$ years	E.C.	$^{137}_{56}Ba$
$^{222}_{86}Rn$	3.824 days	α	$^{218}_{84}Po$
$^{226}_{88}Ra$	1600 years	α	$^{222}_{86}Rn$
$^{232}_{90}Th$	1.40×10^{10} years	α	$^{228}_{88}Ra$
$^{235}_{92}U$	7.04×10^{8} years	α	$^{231}_{90}Th$
$^{238}_{92}U$	4.468×10^{9} years	α	$^{234}_{90}Th$
$^{239}_{93}Np$	2.350 days	e^-	$^{239}_{94}Pu$
$^{239}_{94}Pu$	2.411×10^{4} years	α	$^{235}_{92}U$

†E.C. stands for electron capture; e^+ for positron emission; e^- for beta emission; α, for alpha emission.

All nuclear reaction are first order?

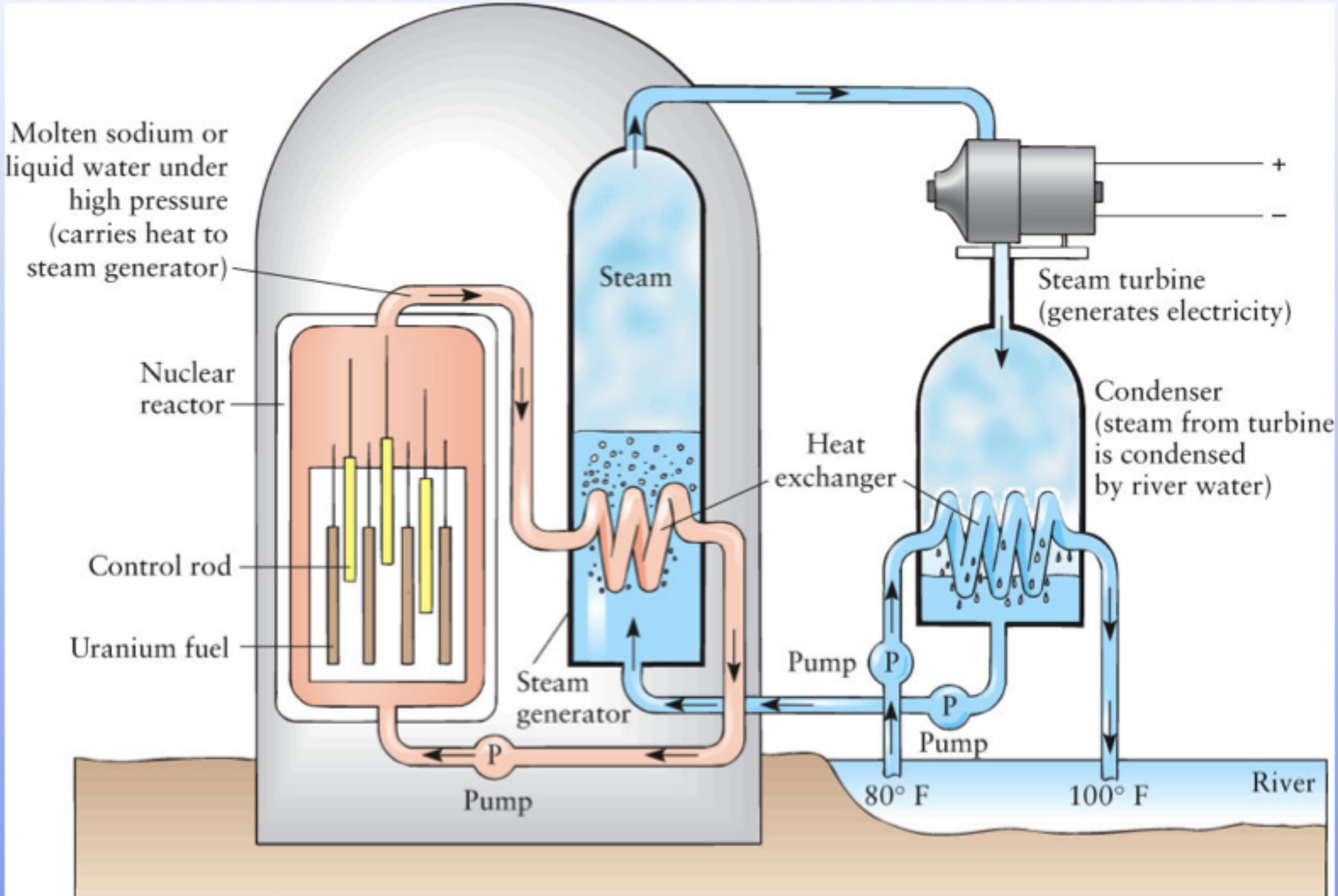
A. true

B. false

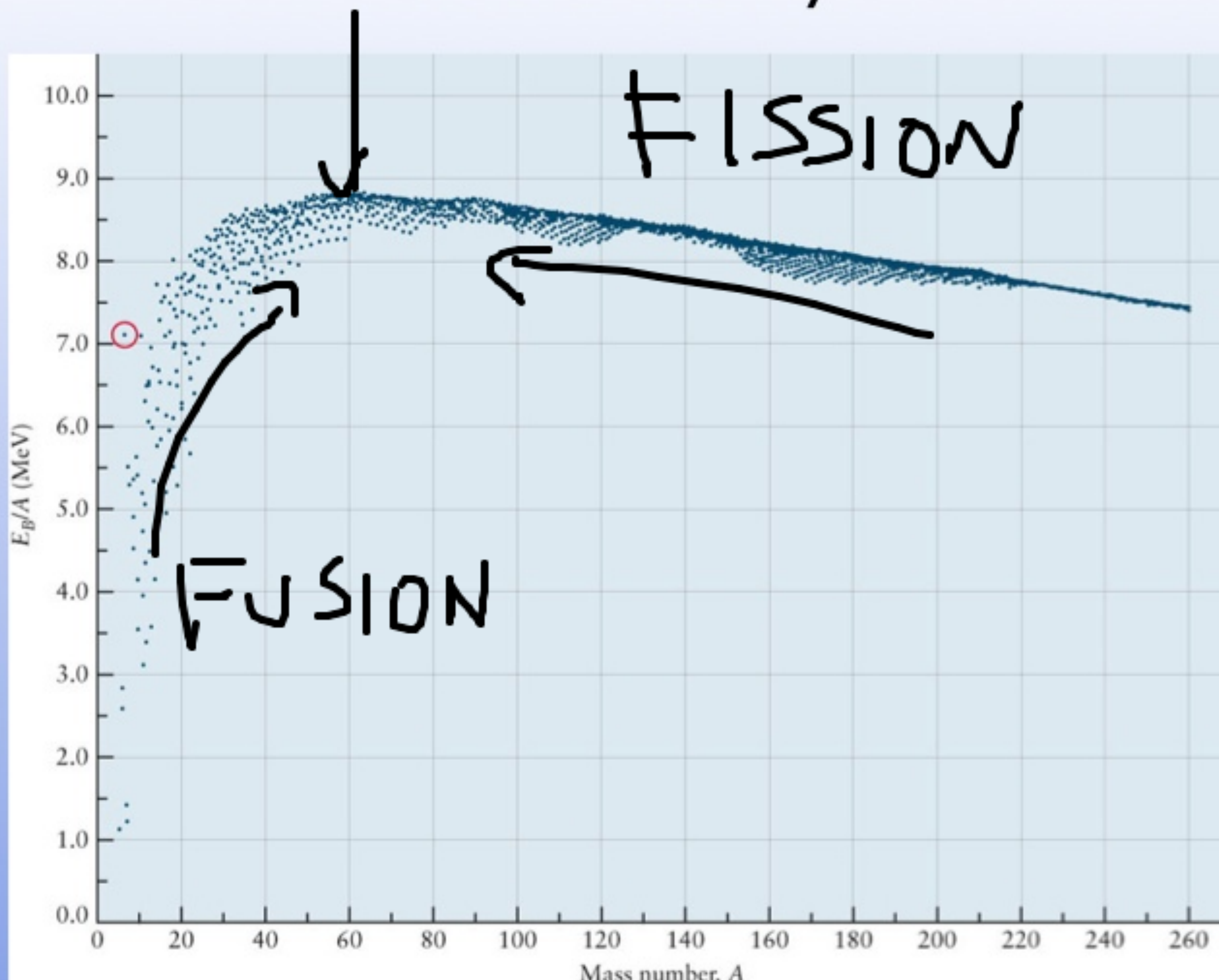
Decay yes!

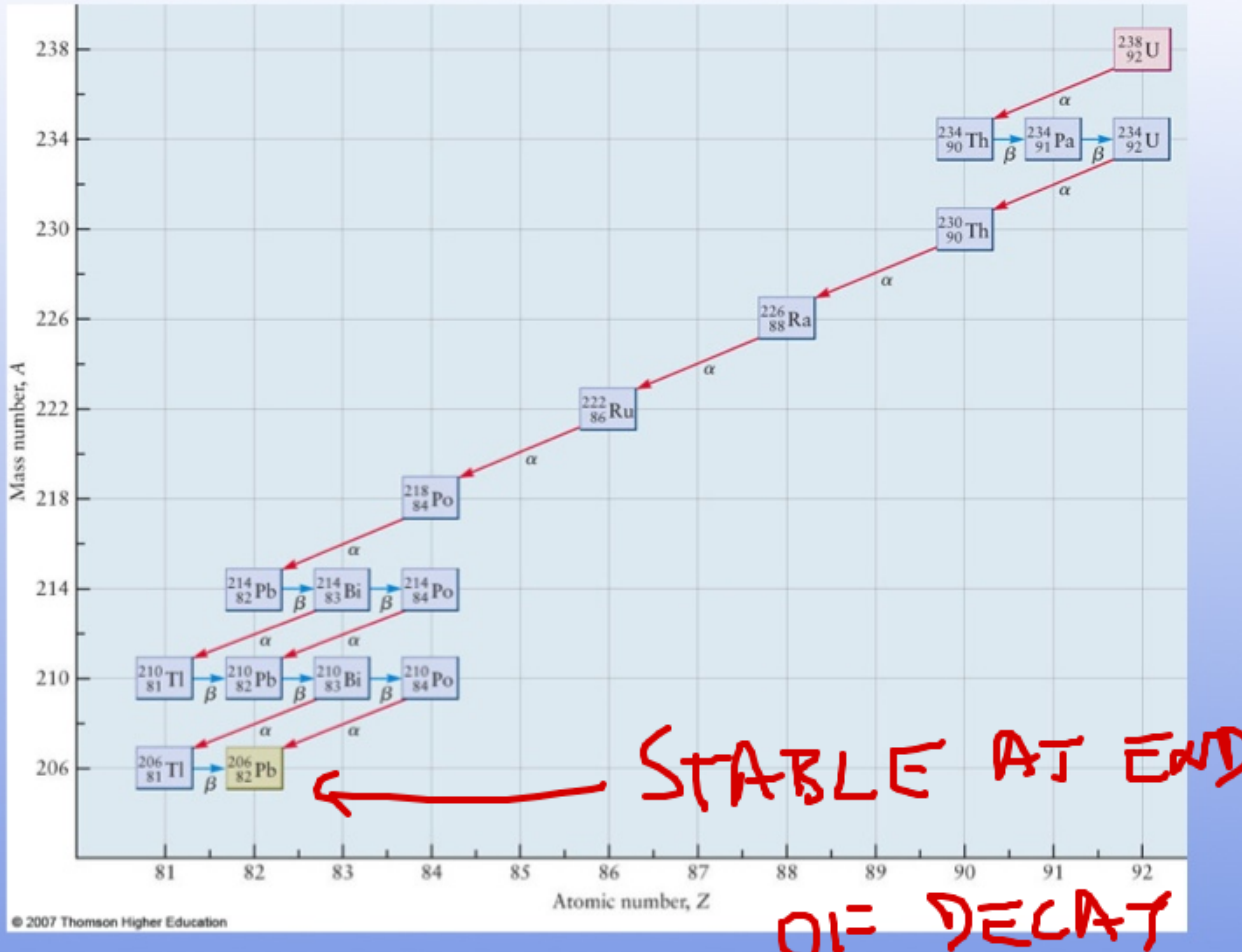
Reaction no

All nuclear reaction are first order?



Where is stability?




Mass number, A
Atomic number, Z
238
234
230
226
222
218
214
210
206
81 82 83 84 85 86 87 88 89 90 91 92
238 92 U
234 90 Th
234 91 Pa
234 92 U
230 90 Th
226 88 Ra
222 86 Ru
218 84 Po
214 82 Pb
214 83 Bi
214 84 Po
210 81 Tl
210 82 Pb
210 83 Bi
210 84 Po
206 81 Tl
206 82 Pb
α
β
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STABLE AT END OF DECAY