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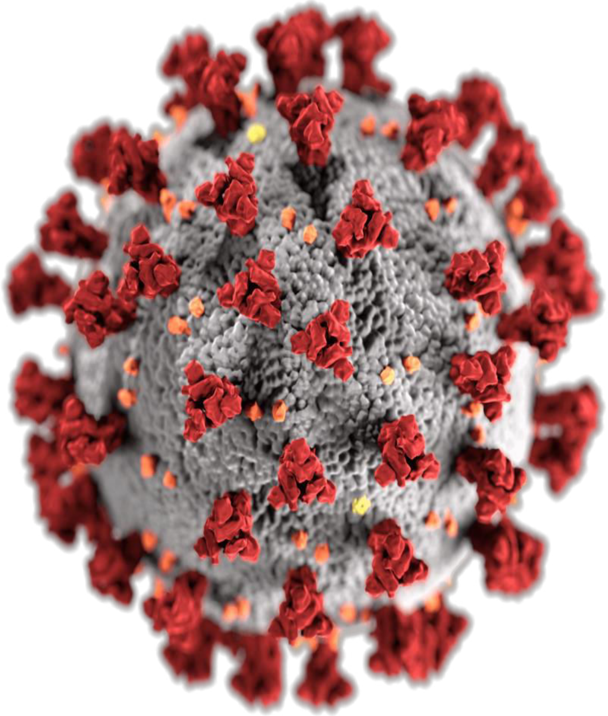
Welcome to my Class

Physics Ph 1205

05:00 PM
March 23, 2021

COVID-19 Precautions



- Don’t be afraid
- Be aware of the pandemic
- Use appropriate outfits if you compelled to go out
- Try to maintain proper diet
- Do not forget to exercise (at least one hour) regularly
- Try to follow the guidelines of WHO and Bangladesh Government
- Try to stay at home

Half Life Period

Half life period of a radioactive element may be defined as the time during which a given amount of that element is reduced by disintegration to half its initial amount.

It is written as $t_{1/2}$ or T. Its value may be found by putting $N=N_o/2$ and t = T in eqn. (1)

$$N = N_o e^{-\lambda t} \qquad (1)$$

$$\therefore \quad \frac{N_o}{2} = N_o e^{-\lambda T}$$

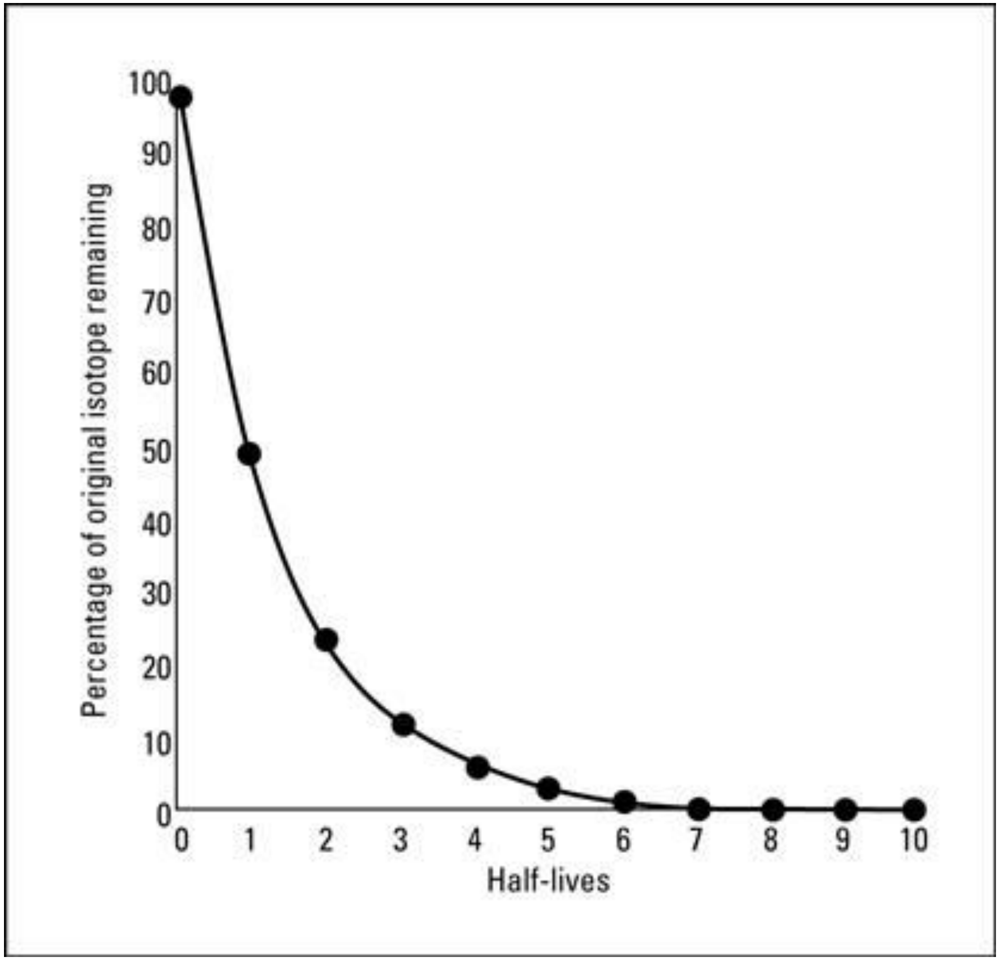
$$or \quad \frac{1}{2} = e^{-\lambda T}$$

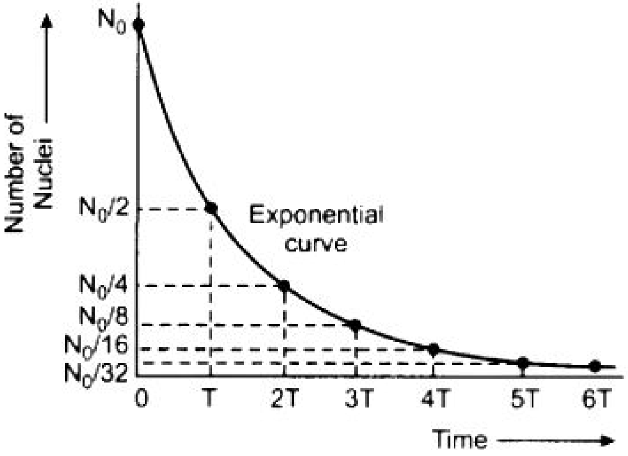
$$or \quad e^{\lambda T} = 2$$

$$\therefore \quad \lambda T \log_e e = \log_e 2$$

$$\therefore \quad T = \frac{0.693}{\lambda}$$

As seen T is inversely proportional to the radioactive constant and hence is a characteristic constant which can be employed to differentiate radioelements.





Average Life

Since atoms of a radioactive element are constantly disintegrating one after another, the life of every atom is different.

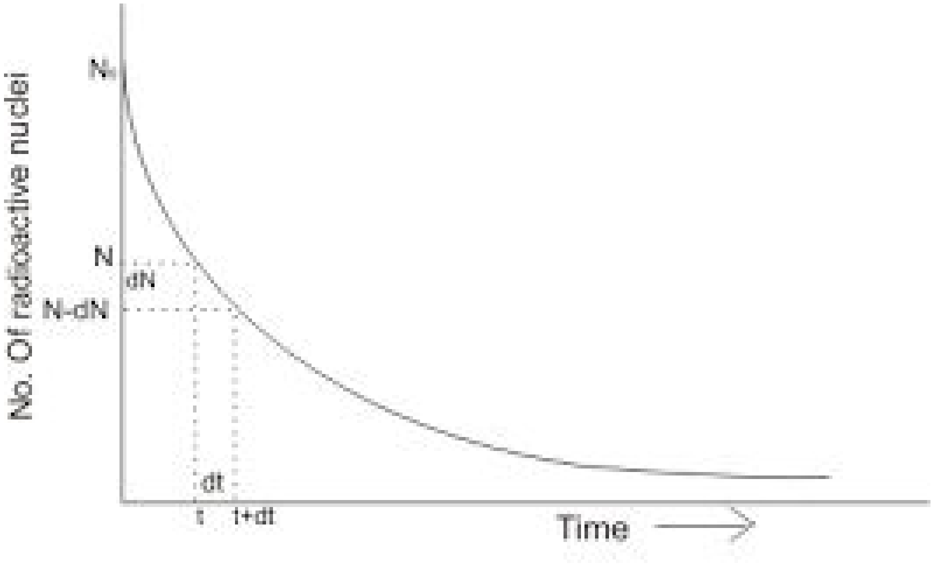


Figure 2. This curve shows how number of nuclei dN decays in time dt

The atoms which disintegrate earlier have very short life whereas others which disintegrate at the end have a long life. Hence, the average or mean life of a radioactive atom is given as

$$l = \frac{Sum\ of\ lives\ of\ all\ atoms}{Total\ number\ of\ atoms}$$

From the decay curve, it is seen that –dN atoms disintegrate between time t and (t + dt) so that these atoms have a life of t seconds.

∴ Total life of –dN atoms = -dN.t

Since the possible life of any of the given number N_o of atoms varies 0 to ∞, total life of all the N_o atoms is given by

$$\int_0^\infty -t.\,dN$$

$$\therefore\ average\,life,\qquad l = \frac{1}{N_o}\int_0^\infty -t.\,dN$$

$$Now,\qquad N = N_o e^{-\lambda t}$$

$$Hence, -dN = \lambda N_o e^{-\lambda t} dt$$

Substituting this value of –dN in the above equation, we get

$$l = \frac{1}{N_o}\int_0^\infty \lambda N_o t e^{-\lambda t} dt$$

$$= \lambda \int_0^\infty t e^{-\lambda t} dt$$

Using double integration, we get

$$l = \lambda \left[\frac{e^{-\lambda t}}{-\lambda} . t - \int_0^\infty \frac{e^{-\lambda t}}{-\lambda} dt\right]_0^\infty$$

$$= \lambda \left[\frac{e^{-\lambda t}}{-\lambda} . t - \frac{e^{-\lambda t}}{\lambda^2} \right]_0^\infty$$

$$= -\frac{1}{\lambda} \left[(\lambda t + 1) e^{-\lambda t} \right]_0^\infty$$

$$= \frac{1}{\lambda}$$

$$or \quad l = \frac{1}{\lambda}$$

Obviously, average life or life expectancy of an individual radioactive atom is equal to the reciprocal of the decay constant.

Incidentally, it may be noted that

$$T = \frac{0.693}{\lambda} = 0.693l$$

i.e. half life period = 69.3% of average life

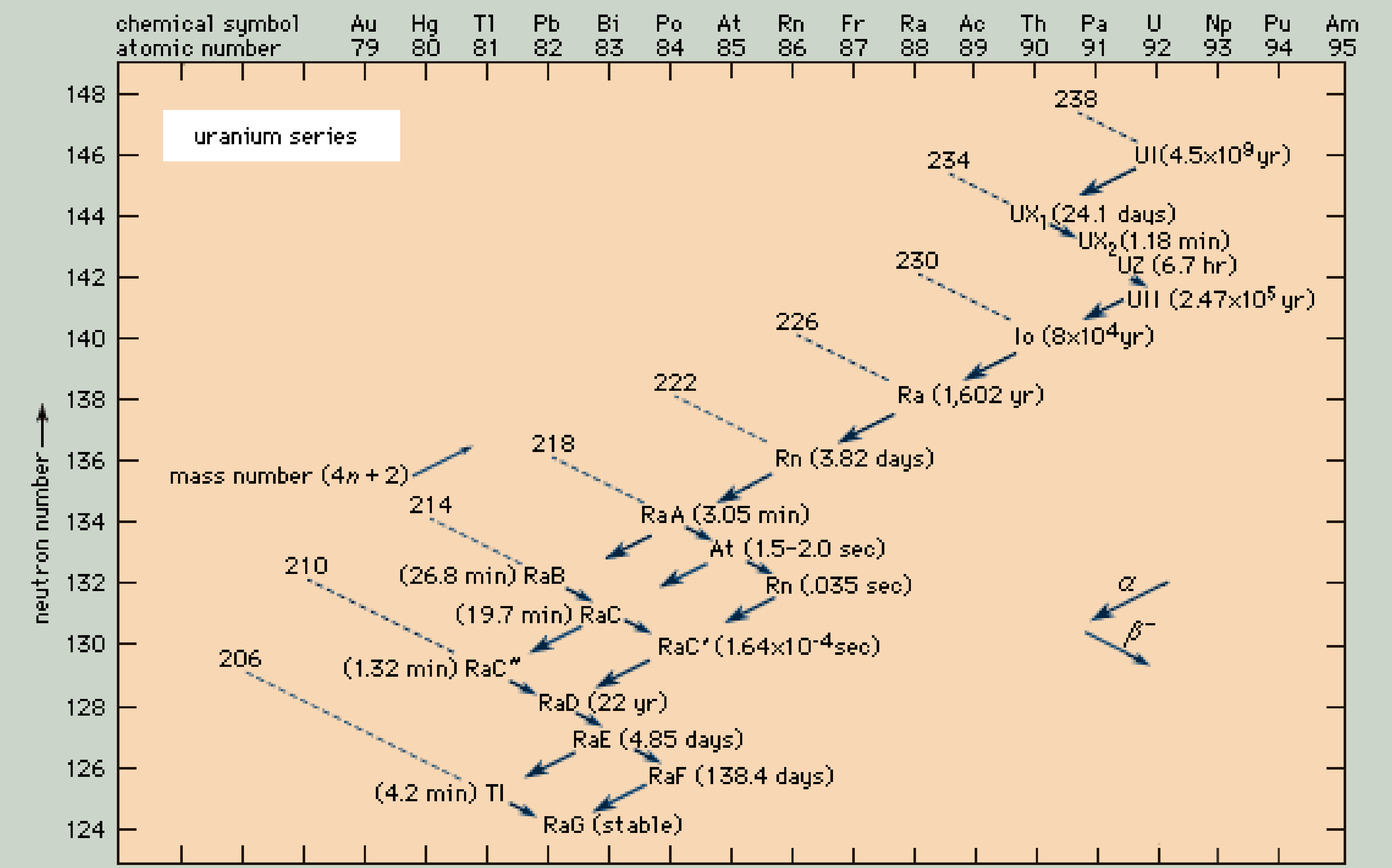
Units of Radioactivity

The activity of a radioactive substance is measured in terms of disintegrations/seconds (or dN/dt).

The unit for measuring activity is Curie (Ci). One curie is defined as that quantity of a radioactive material which gives 3.7×10^{10} disintegrations per second.

A new absolute unit of activity or radioactive disintegration rate has been recently suggested. Its name is rutherford (rd). One rutherford is defined as that quantity of a radioactive substance which gives 10^6 disintegrations per second.

Radioactive Series



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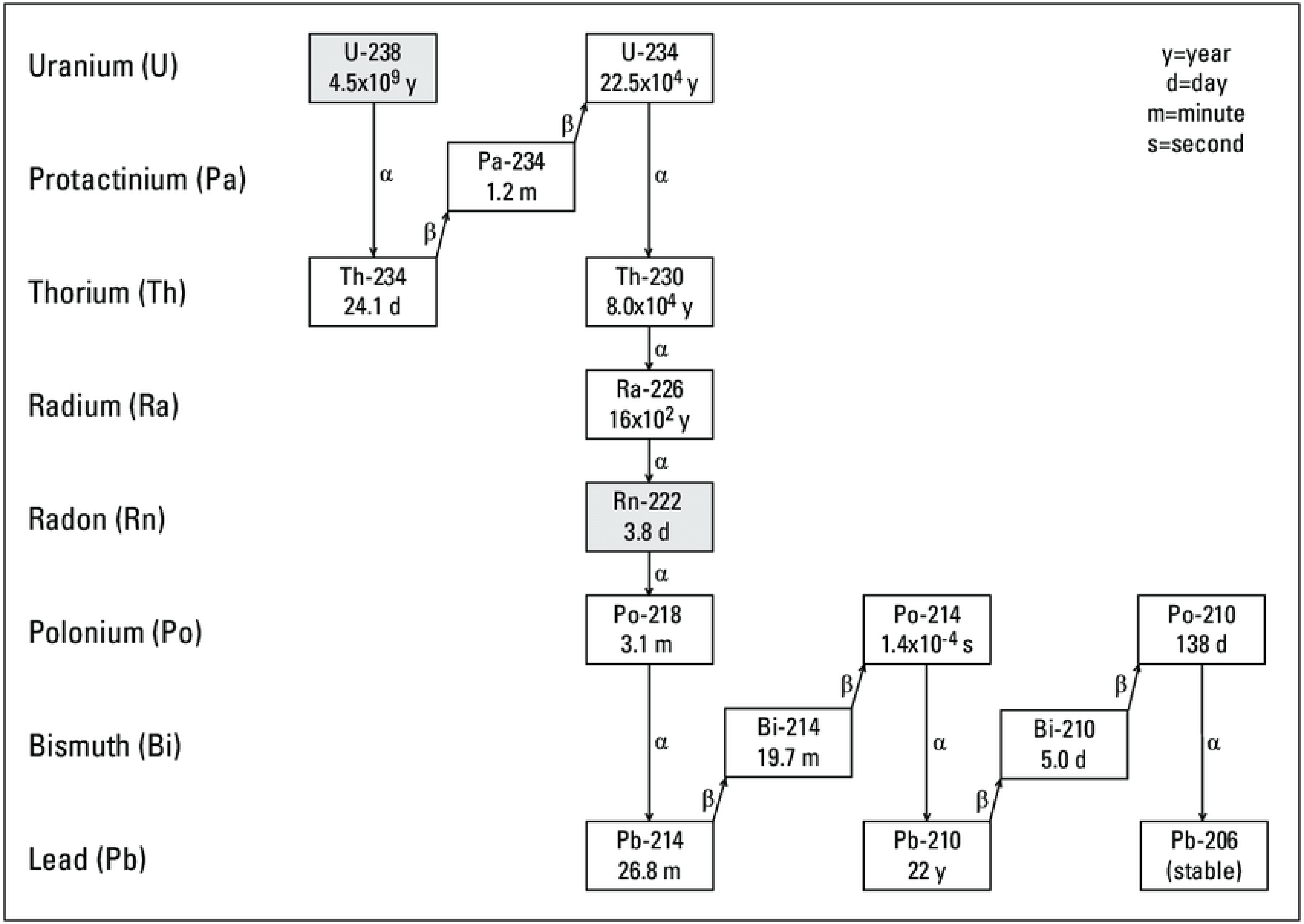
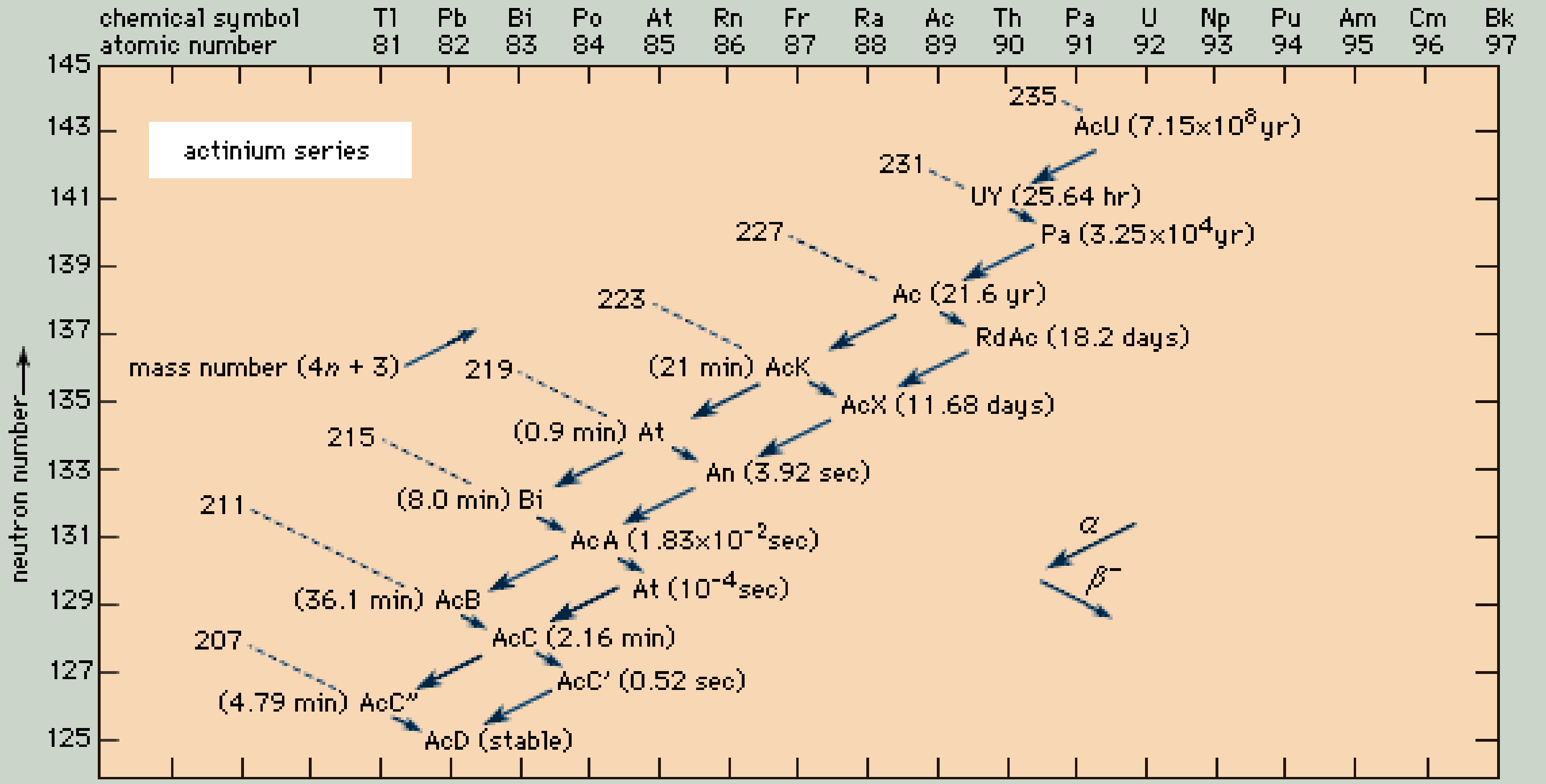
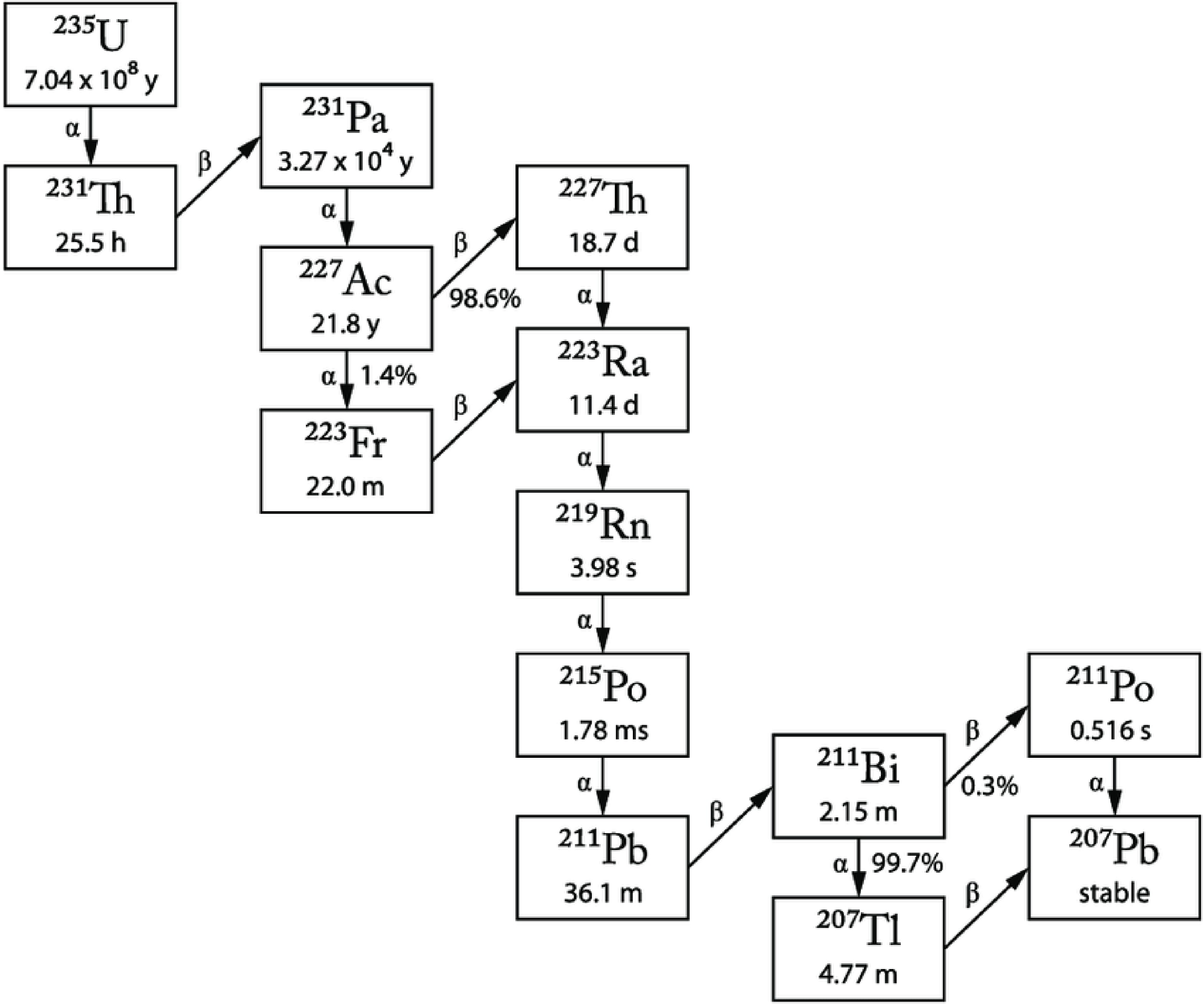
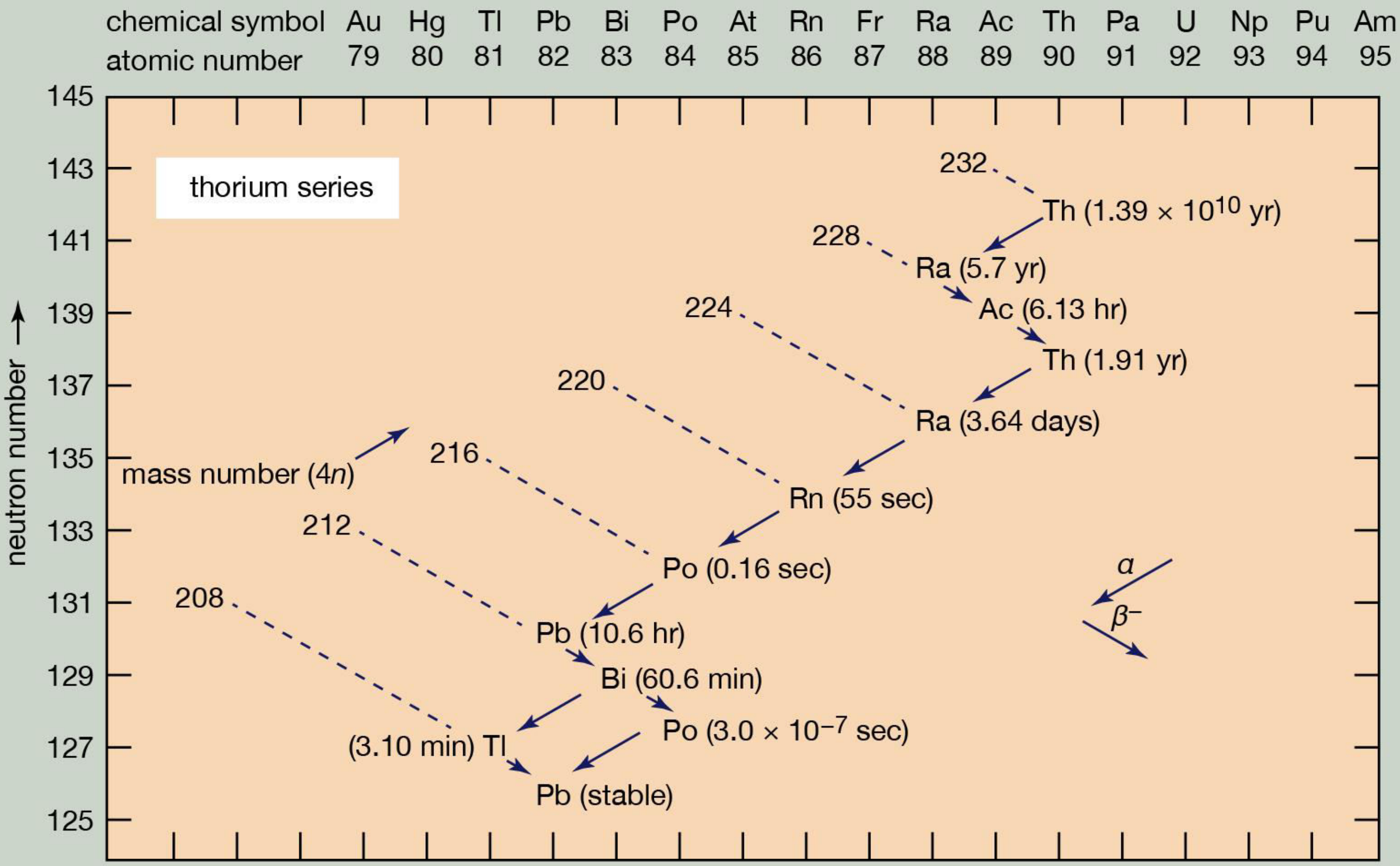
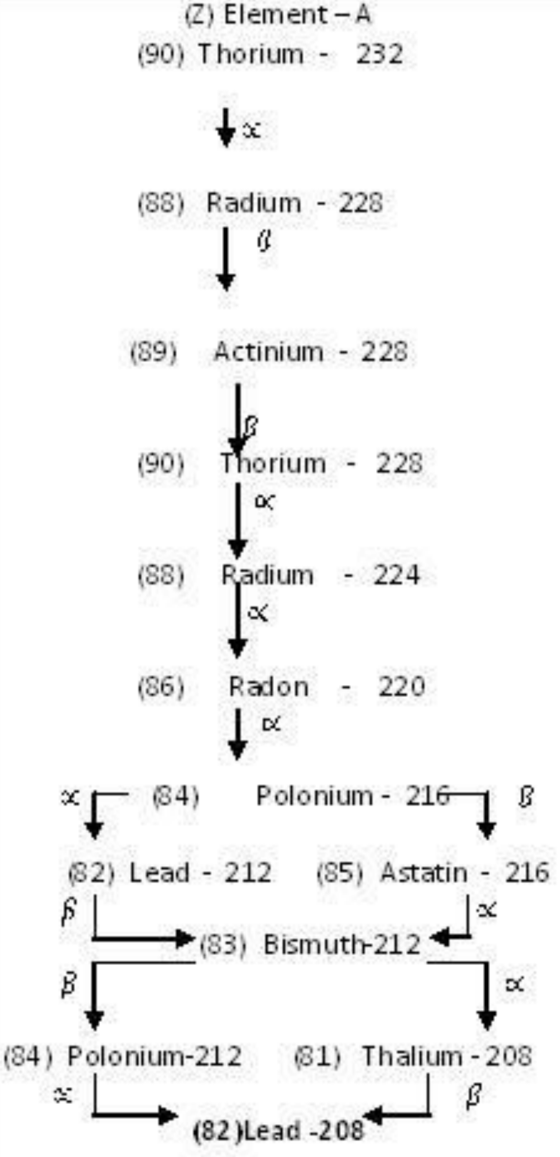

Uranium (U)
Protactinium (Pa)
Thorium (Th)
Radium (Ra)
Radon (Rn)
Polonium (Po)
Bismuth (Bi)
Lead (Pb)
U-238 4.5x10^9 y
α
Th-234 24.1 d
β
Pa-234 1.2 m
β
U-234 22.5x10^4 y
α
Th-230 8.0x10^4 y
α
Ra-226 16x10^2 y
α
Rn-222 3.8 d
α
Po-218 3.1 m
α
Pb-214 26.8 m
β
Bi-214 19.7 m
β
Po-214 1.4x10^-4 s
α
Pb-210 22 y
β
Bi-210 5.0 d
β
Po-210 138 d
α
Pb-206 (stable)
y=year
d=day
m=minute
s=second

chemical symbol
atomic number
Tl 81
Pb 82
Bi 83
Po 84
At 85
Rn 86
Fr 87
Ra 88
Ac 89
Th 90
Pa 91
U 92
Np 93
Pu 94
Am 95
Cm 96
Bk 97
145
143
141
139
137
135
133
131
129
127
125
neutron number
actinium series
mass number (4n + 3)
235
AcU (7.15x10^{8}yr)
231
UY (25.64 hr)
Pa (3.25x10^{4}yr)
227
Ac (21.6 yr)
223
RdAc (18.2 days)
(21 min) AcK
219
AcX (11.68 days)
(0.9 min) At
215
An (3.92 sec)
(8.0 min) Bi
211
AcA (1.83x10^{-2}sec)
At (10^{-4}sec)
(36.1 min) AcB
207
AcC (2.16 min)
AcC′ (0.52 sec)
(4.79 min) AcC″
AcD (stable)
α
β⁻



235U
7.04 x 10^8 y
α
231Th
25.5 h
β
231Pa
3.27 x 10^4 y
α
227Ac
21.8 y
β
98.6%
227Th
18.7 d
α
1.4%
223Fr
22.0 m
β
223Ra
11.4 d
α
219Rn
3.98 s
α
215Po
1.78 ms
α
211Pb
36.1 m
β
211Bi
2.15 m
β
0.3%
211Po
0.516 s
α
α
99.7%
207Tl
4.77 m
β
207Pb
stable


chemical symbol Au Hg Tl Pb Bi Po At Rn Fr Ra Ac Th Pa U Np Pu Am
atomic number 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95
neutron number →
145
143
141
139
137
135
133
131
129
127
125
thorium series
232
Th (1.39×10^{10} yr)
228
Ra (5.7 yr)
Ac (6.13 hr)
224
Th (1.91 yr)
220
Ra (3.64 days)
mass number (4*n*)
216
Rn (55 sec)
212
Po (0.16 sec)
208
Pb (10.6 hr)
Bi (60.6 min)
Po (3.0×10^{-7} sec)
(3.10 min) Tl
Pb (stable)
α
β^-


(Z) Element – A

(90) Thorium - 232

$\downarrow \alpha$

(88) Radium - 228

$\downarrow \beta$

(89) Actinium - 228

$\downarrow \beta$

(90) Thorium - 228

$\downarrow \alpha$

(88) Radium - 224

$\downarrow \alpha$

(86) Radon - 220

$\downarrow \alpha$

α (84) Polonium - 216 β

(82) Lead - 212 (85) Astatin - 216

β α

(83) Bismuth-212

β α

(84) Polonium-212 (81) Thalium - 208

α β

(82)Lead -208

Half life , $t_{½}$

1.39 x 10^{10} years

6.7 years

1.90 years

3.64 days

55.6 sec.

0.16 sec.

At - 216
10.6 hrs.

Pb - 212

54 sec

60.6 min.

Tl - 208,
3 x 10 sec .

Po - 212

3.1 min .

Stabe

Application of Radioactivity

Many radiation sources such as cobalt-60 (a ϒ-ray emitter) have been used for industrial radiography. i.e. for investigating the interiors of metallic castings for detecting any flaws or defects.

Radioactive nuclides emitting α or β-particles have been used for the production of electric power by thermo-electric conversion

Radionuclides have been used as compact sources of heat energy because of which they fined many space related applications.

Radionuclides of promethium-147, polonium-210 and plutonium-238 have been used to heat the propellant gas (hydrogen) in low thrust rockets.

Nuclear radiations like ϒ-rays have been utilized for preservation of food. The irradiation of food stuff mainly meat, poultry, fish and fruits is achieved by exposure to ϒ-rays from cobalt-60 or caesium-147.

Gamma radiations from cobalt-60 are used in hospitals for sterilization of materials like dressings, hyperdemic syringes and surgical sutures.

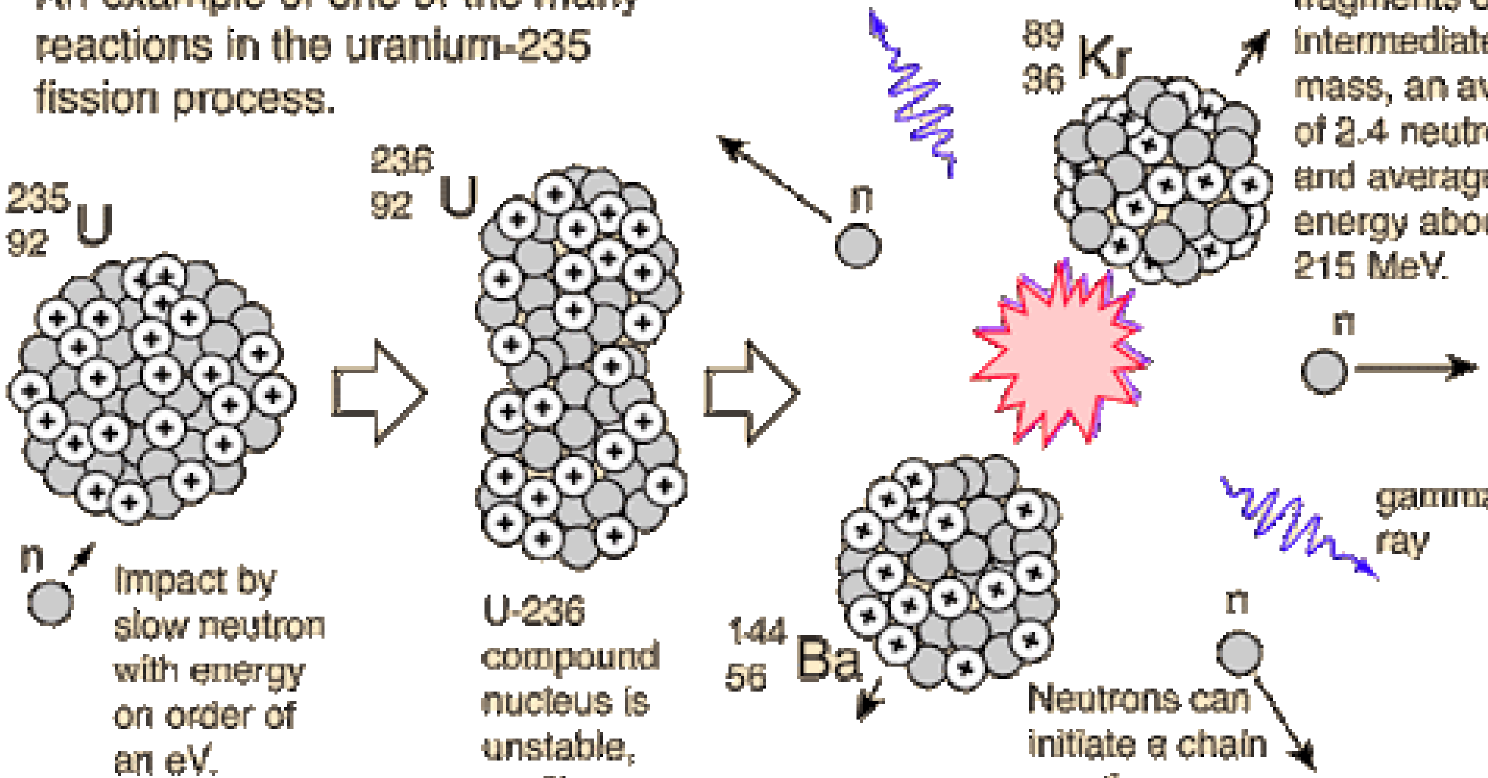
The ionization produced by β-particles has been widely used for the elimination of static electricity which constitutes a serious fire and explosion hazard in the paper, textile, rubber and plastic industries.

Discovery of Fission

Fermi attempts in 1934 to produce transurani elements by bombarding uranium

German radio-chemists Otto Hahn and two associates Meitner and Strassmann discovered fission in 1939.

An example of one of the many reactions in the uranium-235 fission process.



Impact by slow neutron with energy on order of an eV.

U-236 compound nucleus is unstable, oscillates.

Fission yields fragments of intermediate mass, an average of 2.4 neutrons, and average energy about 215 MeV.

Neutrons can initiate a chain reaction.

Mass Distribution of Fission Products

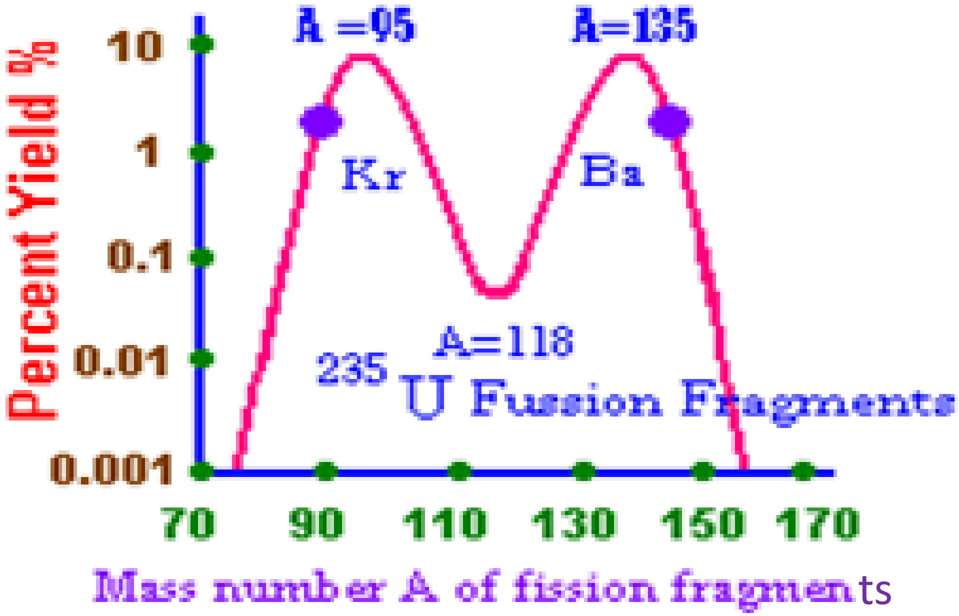
About 97% of the U^{235} nuclei undergoing fission give fragments which fall into two groups.

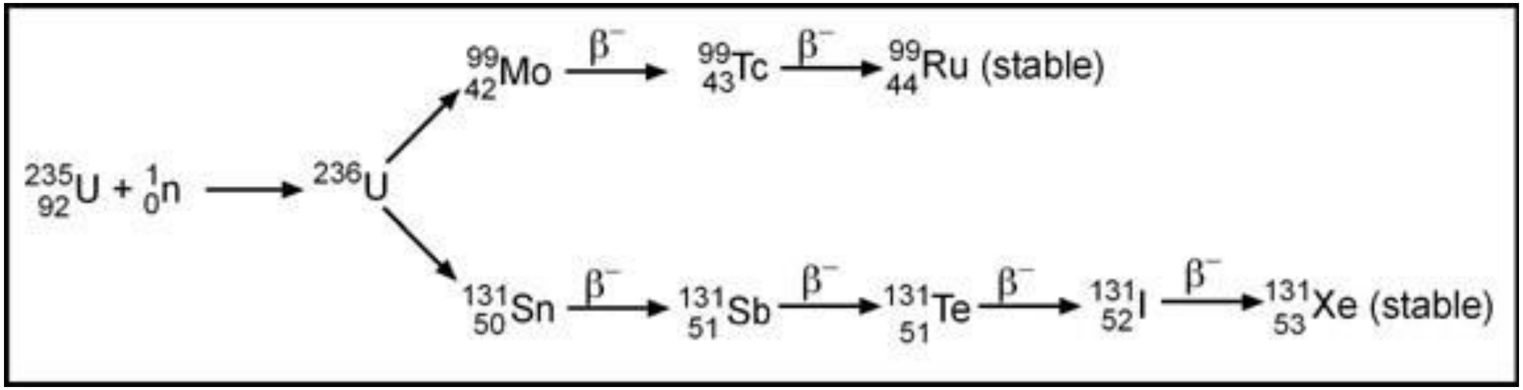
Light group with mass number 85 to 104 and

Heavy group with mass number 130 to 149 and

Fission fragments have too many neutrons in their nuclei for stability. Consequently most of them decay by electron emission.

Each fragment starts a short radioactive series involving many emissions of β-particles. These series are called fission decay series.


A =95
A=135
Percent Yield %
10
1
0.1
0.01
0.001
Kr
Ba
A=118
235 U Fussion Fragments
70
90
110
130
150
170
Mass number A of fission fragments

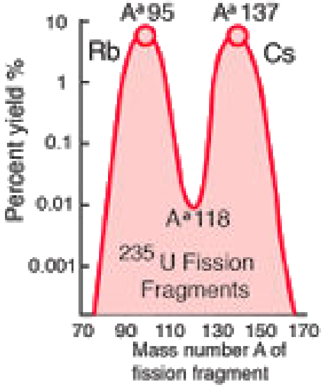

235 92 U + 1 0 n
236 U
99 42 Mo
β⁻
99 43 Tc
β⁻
99 44 Ru (stable)
131 50 Sn
β⁻
131 51 Sb
β⁻
131 51 Te
β⁻
131 52 I
β⁻
131 53 Xe (stable)

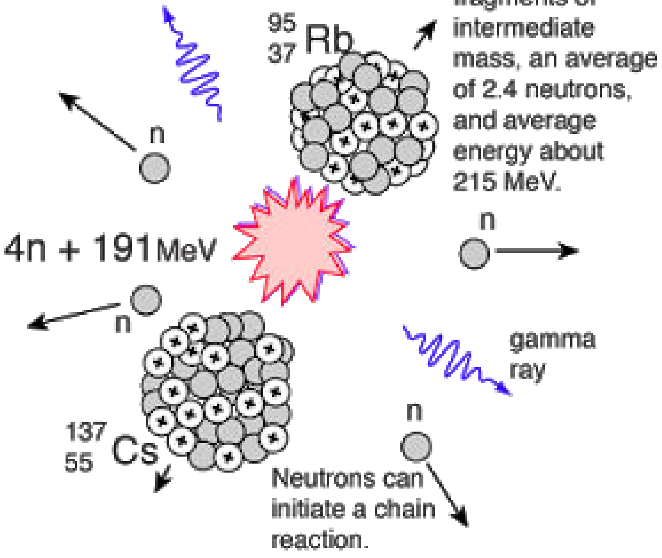
Fission Energy

Energy yield calculation for a typical fission of uranium-235

$$n + {}^{235}_{92}\mathrm{U} \rightarrow {}^{236}_{92}\mathrm{U}$$

$${}^{236}_{92}\mathrm{U} \rightarrow {}^{137}_{55}\mathrm{Cs} + {}^{95}_{37}\mathrm{Rb} + 4n + 191\,\mathrm{MeV}$$





Fission yields fragments of intermediate mass, an average of 2.4 neutrons, and average energy about 215 MeV.

Neutrons can initiate a chain reaction.

Energy balance:

${}^{235}_{92}\mathrm{U}$ 218.8969 GeV rest mass energy

${}^{137}_{55}\mathrm{Cs}$ 127.5011 GeV

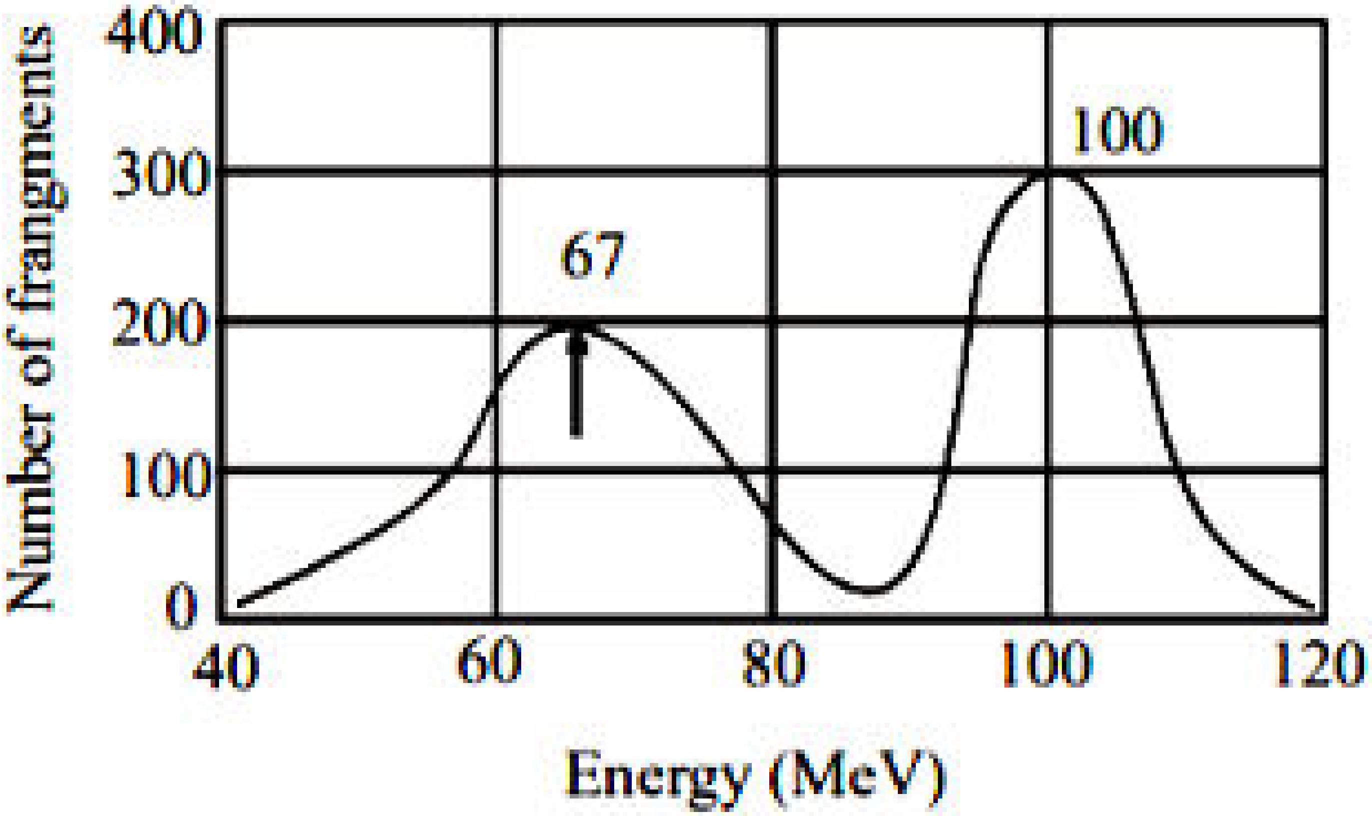
${}^{95}_{37}\mathrm{Rb}$ 88.3859 GeV

3n 3 x 0.93956 GeV

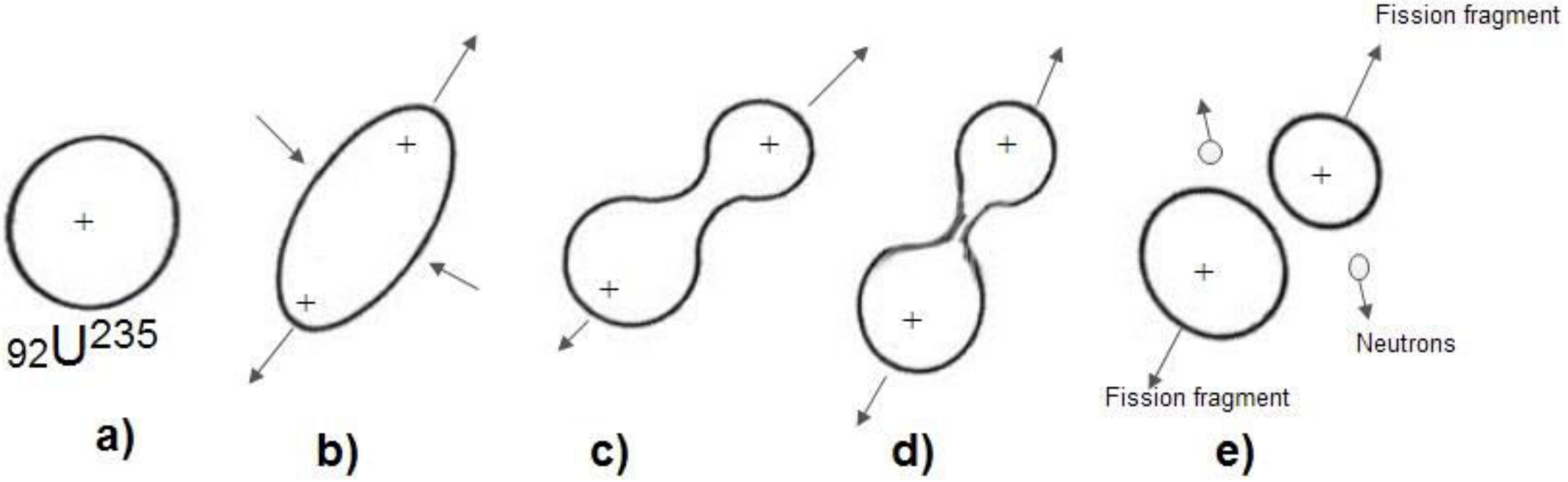
Net conversion of mass energy 0.1911 GeV = 191.1 MeV

Energy yield = $E = \Delta mc^2$

Energy Distribution of Fission Products



Theory of Fission Process



Nuclear Fusion

It is the process of combining or fusing two lighter nuclei into a stable and heavier nuclide.

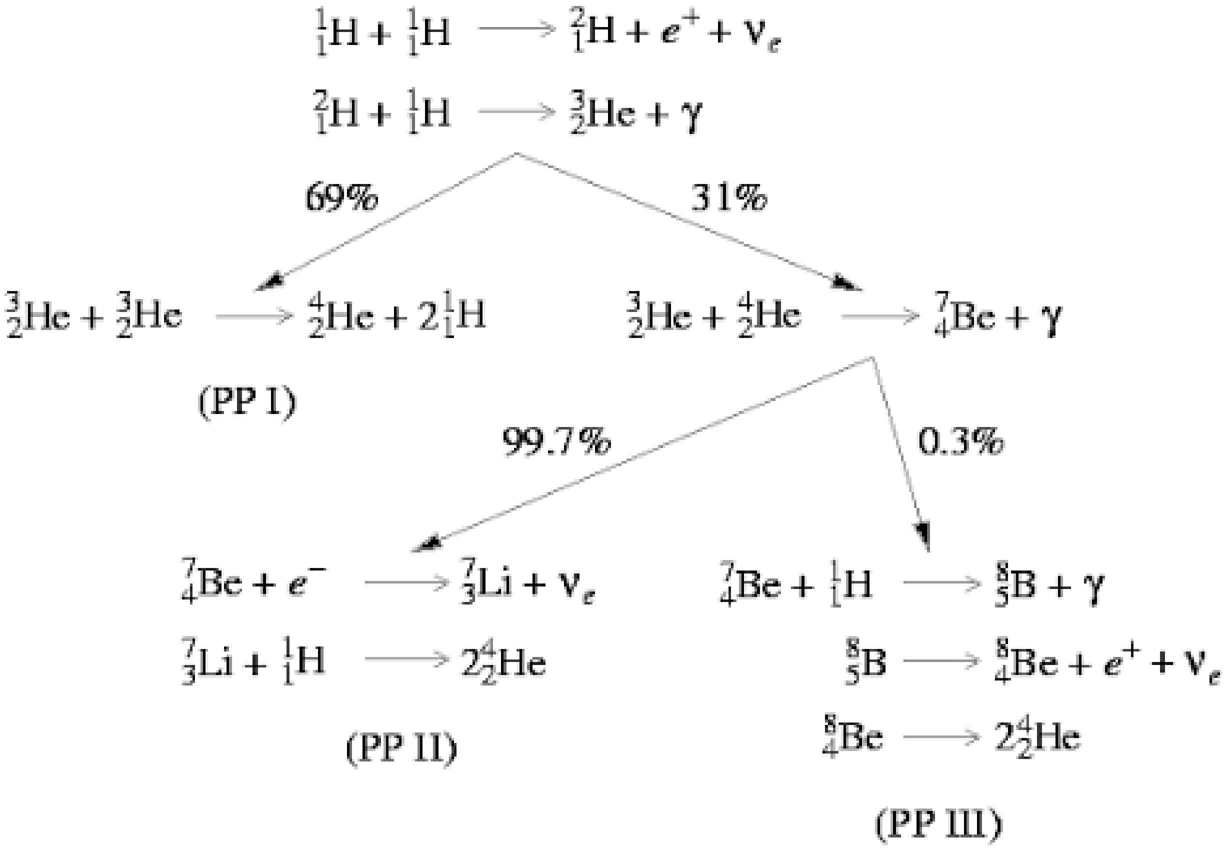
In this case also large amount of energy is released because mass of the product nucleus is less than the masses of the two nuclei which are fused.

Stellar Thermonuclear Reactions

Following two sets of thermonuclear reactions have been proposed as sources of energy in the Sun and other stars of the main sequence:

Proton-proton (p-p) chain and carbon-nitrogen (C-N) cycle.

Proton-Proton chain



$${}^{1}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{2}_{1}\mathrm{H} + e^{+} + \nu_{e}$$

$${}^{2}_{1}\mathrm{H} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + \gamma$$

69%

31%

$${}^{3}_{2}\mathrm{He} + {}^{3}_{2}\mathrm{He} \longrightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{1}_{1}\mathrm{H}$$

(PP I)

$${}^{3}_{2}\mathrm{He} + {}^{4}_{2}\mathrm{He} \longrightarrow {}^{7}_{4}\mathrm{Be} + \gamma$$

99.7%

0.3%

$${}^{7}_{4}\mathrm{Be} + e^{-} \longrightarrow {}^{7}_{3}\mathrm{Li} + \nu_{e}$$

$${}^{7}_{3}\mathrm{Li} + {}^{1}_{1}\mathrm{H} \longrightarrow 2\,{}^{4}_{2}\mathrm{He}$$

(PP II)

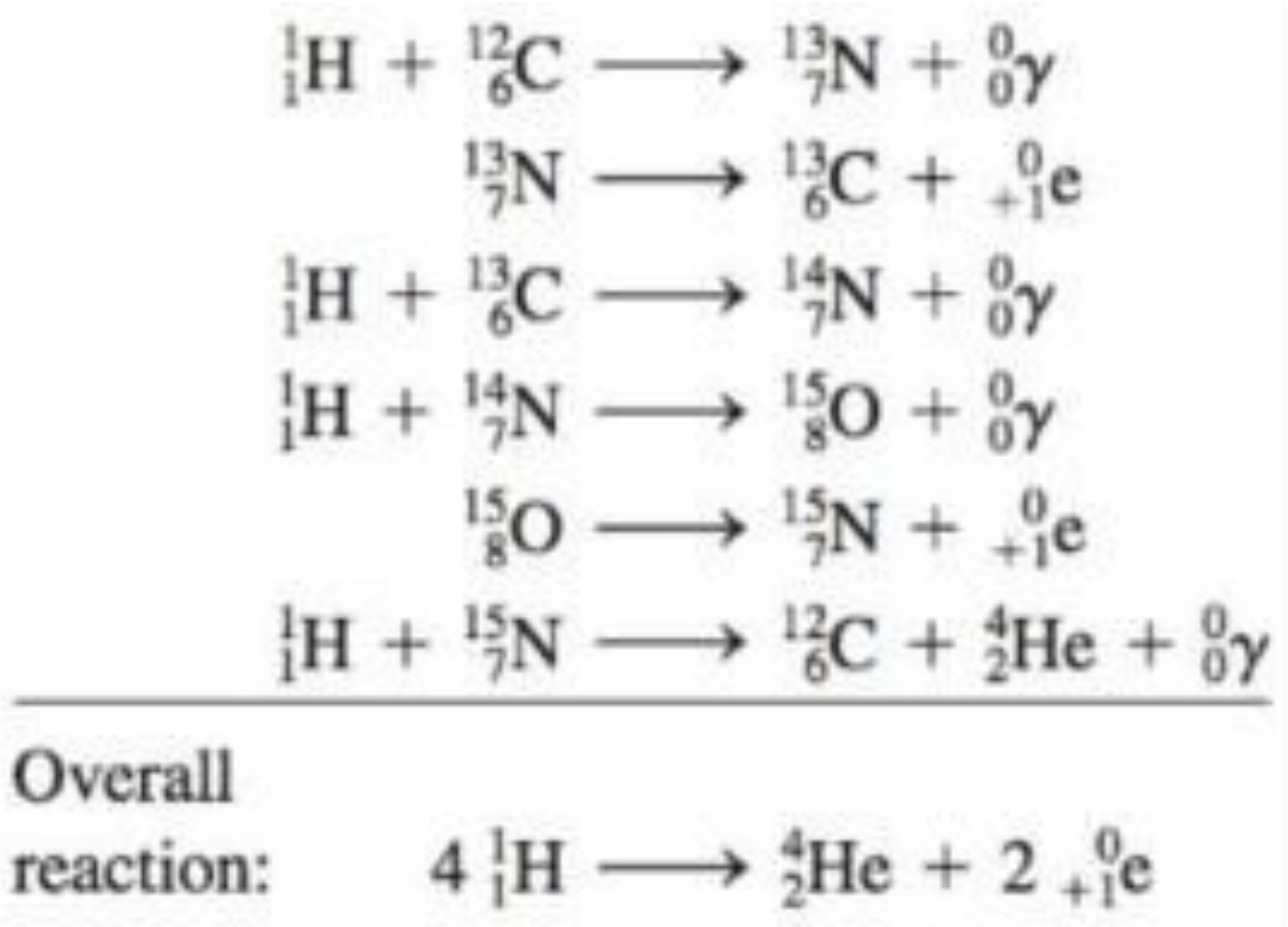
$${}^{7}_{4}\mathrm{Be} + {}^{1}_{1}\mathrm{H} \longrightarrow {}^{8}_{5}\mathrm{B} + \gamma$$

$${}^{8}_{5}\mathrm{B} \longrightarrow {}^{8}_{4}\mathrm{Be} + e^{+} + \nu_{e}$$

$${}^{8}_{4}\mathrm{Be} \longrightarrow 2\,{}^{4}_{2}\mathrm{He}$$

(PP III)

Carbon-Nitrogen Cycle



$$
\begin{aligned}
{}^{1}_{1}\mathrm{H} + {}^{12}_{6}\mathrm{C} &\longrightarrow {}^{13}_{7}\mathrm{N} + {}^{0}_{0}\gamma \\
{}^{13}_{7}\mathrm{N} &\longrightarrow {}^{13}_{6}\mathrm{C} + {}^{0}_{+1}\mathrm{e} \\
{}^{1}_{1}\mathrm{H} + {}^{13}_{6}\mathrm{C} &\longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{0}\gamma \\
{}^{1}_{1}\mathrm{H} + {}^{14}_{7}\mathrm{N} &\longrightarrow {}^{15}_{8}\mathrm{O} + {}^{0}_{0}\gamma \\
{}^{15}_{8}\mathrm{O} &\longrightarrow {}^{15}_{7}\mathrm{N} + {}^{0}_{+1}\mathrm{e} \\
{}^{1}_{1}\mathrm{H} + {}^{15}_{7}\mathrm{N} &\longrightarrow {}^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He} + {}^{0}_{0}\gamma
\end{aligned}
$$

Overall reaction: $4\,{}^{1}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{0}_{+1}\mathrm{e}$

Controlled Thermonuclear Reactions

The fact that nuclear fusion reactions release large amounts of energy, as in the stars has attracted much attention and continuous search is being made for finding practical means for controlled release of such energy.

It has however been found that reactions of the C-N cycle and proton-proton chain occur too slowly to be of any practical use.

Other thermonuclear reactions which occur much more rapidly and depend on abundant hydrogen isotopes like deuteron (${}_1H^2$) and tritium (${}_1H^3$) and hence seem more practical proposition, are as under:

$${}_1H^2 + {}_1H^2 = {}_2He^3 + {}_0n^1 + 3.3 \text{ MeV}$$

$${}_1H^2 + 1H^2 = {}_1H^3 + {}_1H^1 + 4 \text{ MeV}$$

$${}_1H^2 + {}_1H^3 = {}_2He^4 + {}_0n^1 + 17.6 \text{ MeV}$$

Condition for Controlled Fusion

In order to provide useful energy, the fusion process must be self-sustaining.

Once the temperature of deuterium (or a mixture of D^2 and T^3) has been raised to the point at which fusion occurs at an appreciable rate, the energy released must be sufficient, at least, as critical ignition temperature and may be defined as that temperature above which the rate of energy production by fusion exceeds the rate of energy loss.

Its value is about 5 keV (i.e. 50 million °K) for a D-T reaction and 40 keV (i.e. 400 million °K) for a D-D reaction.


I Thank you