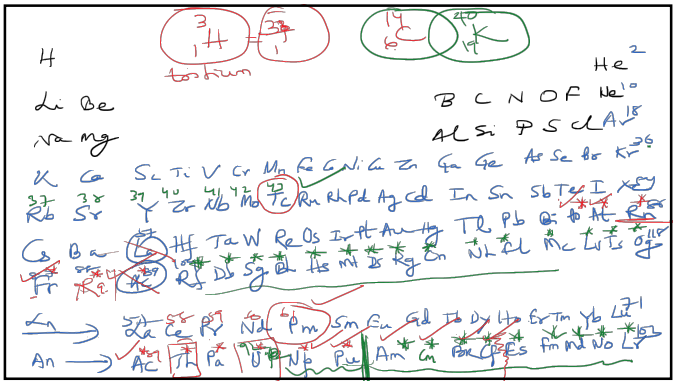
Radioactive Elements (Natural and Synthetic)



NORM

- **Naturally Occuring Radioactive Materials(NORM)**:
- Tc-99, Pm-147, H-3, C-14, K-40, Pb-210,(Bi-209) Po-210, At-218, Rn-222, Fr-223, Ra-226, Ac-227, Th-232, Pa-234 U-238, Np-237, Pu-239 etc.
- These as well as all the synthetic radioactive elements decay spontaneously by emitting three types of particles from their nuclei followed by emission of radioactive radiations(photon)in some cases; called gamma(γ) rays.

- Alpha(α) particles: He^{++} (^4_2He)
- Beta(β) particles: $\beta^-\left(^0_{-1}\beta\right)$(same as an electron)
- Positron Particle: β^+ $\left(^0_{+1}\beta\right)$(anti-particle of electron)
- Gamma(γ) radiation($^0_0\gamma$): Electromagnetic radiation

Fun Facts

- A 70 kg person emits 4400 β particles from K-40 and 3000 β particles from carbon-14 per SECOND.
- So each of us a is RADIOACTIVE (Ha… Ha…..)
- Banana and other eatables contains K-40(0.012%)
- Atm. CO_2 contain trace qt. of C-14.
- Greater than acceptable human limits is dangerous.

Half Life Period $\left(t_{1/2}/t_{0.5}\right)$

- The time needed for a radionuclide to reduce to half of its initial amount. This period is independent of the initial amounts.

$^{238}_{92}U = 4.5 \times 10^9 years;\ ^{228}_{88}Ra = 5.8\ years;\ ^{226}_{88}Ra = 1599\ years;$

$^{234}_{90}Th = 24\ days,\ ^{232}_{90}Th = 1.4 \times 10^{10}\ years$

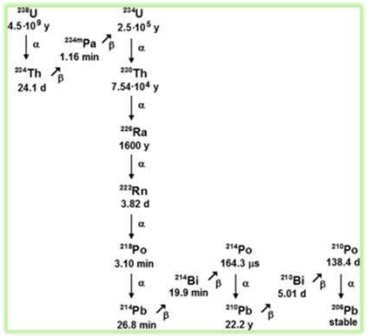
$^{234}_{91}Pa = 1.17\ min;\quad ^{216}_{84}Po = 0.15\ sec.$

$^{294}_{118}Og = 0.9\ ms$

Natural Radioactive Series

- 1. Uranium Series: (4n+2) : U-238 ($t_{0.5}$=4.5 X 10^9 years)
- 2. Thorium Series(4n) : Th-232 ($t_{0.5}$=1.4 X 10^{10} years)
- 3. Actinium Series(4n+3): Ac-227 ($t_{0.5}$=21.8 years) (Actually Pu-239: extinct, U-235($t_{0.5}$=7.04X10^8 years)
- 4. Neptunium series(4n+1): Np-237($t_{0.5}$=2.2X10^6 years) (Actually Pu-241)

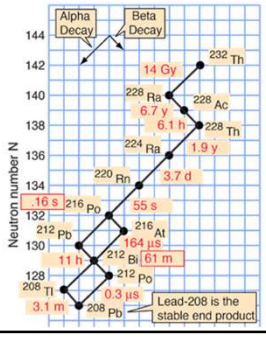
Uranium(4n+2) Series:



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

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

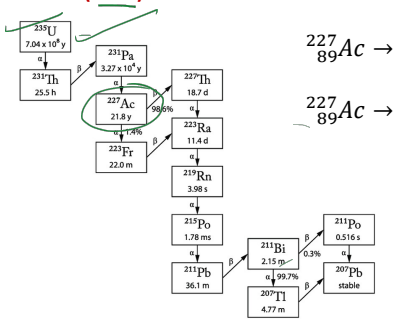
Thorium(4n) Series:



$$^{232}_{90}Th \rightarrow {}^{228}_{88}Ra + {}^{4}_{2}He$$

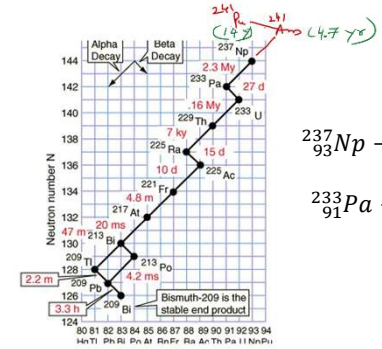
$$^{228}_{88}Ra \rightarrow {}^{228}_{89}Ac + {}^{0}_{-1}\beta$$

Actinium(4n+3) Series:



$$^{227}_{89}Ac \rightarrow {}^{227}_{90}Th + {}^{0}_{-1}\beta$$

$$^{227}_{89}Ac \rightarrow {}^{223}_{87}Fr + {}^{4}_{2}He$$



$$^{237}_{93}Np \rightarrow {}^{233}_{91}Pa + {}^{4}_{2}He$$

$$^{233}_{91}Pa \rightarrow {}^{233}_{92}U + {}^{0}_{-1}\beta$$

Positron Emission and K-Capture

- Lighter radioisotopes having smaller mass numbers than the natural stable isotope, either decay by positron emission or by Electron(K) capture.
- Lighter radioisotopes which have greater mass number than the natural, often decay by beta emisstion.

Beta and Positron Emission:

- ${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta + \bar{\nu}_e$ ($\beta = {}^{0}_{-1}\beta$) $t_{0.5}$ = 5730 y
- ${}^{11}_{6}C \rightarrow {}^{11}_{5}B + {}^{0}_{+1}\beta + \nu_e$ $t_{0.5}$ = 20 min
- ${}^{27}_{12}Mg \rightarrow {}^{27}_{13}Al + {}^{0}_{-1}\beta + \bar{\nu}_e$
- ${}^{23}_{12}Mg \rightarrow {}^{23}_{11}Na + {}^{0}_{+1}\beta + \nu_e$

K-Capture

- ${}^{125}_{53}I + {}^{0}_{-1}e \rightarrow {}^{125}_{52}Te + {}^{0}_{0}\nu_e$
- ${}^{26}_{13}Al + {}^{0}_{-1}e \rightarrow {}^{26}_{12}Mg + {}^{0}_{0}\nu_e$

Nuclear Transmutation/Transformation

- All radioactive processes involve Nuclear Transformation.
- But the artificial nuclear reaction leading to transformation is expressed by

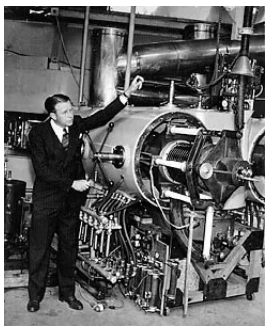
  T[P,x]R reaction.

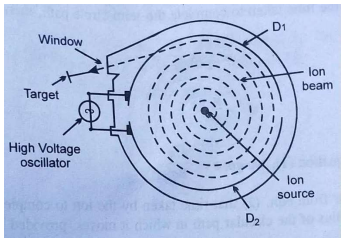
  Often R is not given, it is determined.
- Where P= projectile particle;
- x=emitted particle
- T=Target nuclide (whose Mass number is known)
- R= Residual nucleus(product nuclide)

- The target nuclide(T) is kept at rest. Another nucleus or subatomic particle is allowed to accelerate in a Particle Accelerator such as CYCLOTRONE to act a projectile(P) to hit on the target nucleus(T) which is at rest.
- Projectile(P) can be a subatomic particle like Proton (H^+), or particles like deuteron(D^+), α-(He^{++}) or any other heavier particles like Ca-48 etc.

Why is a Cyclotrone(Particle Accelerator)

- A cyclotron accelerates charged particles outwards from the centre of a flat cylindrical vacuum chamber along a spiral path. Static Magnetic field and rapidly varying electric fields are applied for the particle beam to accelerate and gain high speed.
- Ernest Lawrence (1930), University of California, Berkeley,USA invented the particle accelerator and got the Nobel awal in 1939 for this.
- They are now used for nuclear medicines, particle therapy and basic research.
- Synchrotron and Super-Sychrotron have replaced Cyclotrone in high grade research such as Hadron colliders.





$^{9}_{4}Be[\alpha,n]$ reaction

$$^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ^{1}_{0}n$$

$^{75}_{33}As[\alpha,n]$ reaction:

$$^{75}_{33}As + ^{4}_{2}He \rightarrow ^{78}_{35}Br^{*} + ^{1}_{0}n$$

$^{78}_{35}Br \rightarrow ^{78}_{34}Se + ^{0}_{+1}\beta$

$^{27}_{13}Al[d,\alpha]$ reaction:

$$^{27}_{13}Al + ^{2}_{1}H \rightarrow ^{25}_{12}Mg + ^{4}_{2}He$$

$^{27}_{13}Al[n,p]$ reaction:

- $^{27}_{13}Al + ^{1}_{0}n \rightarrow ^{27}_{12}Mg^{*} + ^{1}_{1}H$

How Technetium(Tc) was synthesized

- Tc-99 is produced continuously as a fission(spontaneous) product from the fission of Uranium or Plutonium in nuclear reactors which is recovered from spent fuel rods or by firing Deuteron on Mo-99.

$$^{238}_{92}\mathrm{U} \xrightarrow{\mathrm{sf}} {}^{137}_{53}\mathrm{I} + {}^{99}_{39}\mathrm{Y} + 2\,{}^{1}_{0}\mathrm{n}$$

$$^{99}_{39}\mathrm{Y} \xrightarrow[1.47\ \mathrm{s}]{\beta^-} {}^{99}_{40}\mathrm{Zr} \xrightarrow[2.1\ \mathrm{s}]{\beta^-} {}^{99}_{41}\mathrm{Nb} \xrightarrow[15.0\ \mathrm{s}]{\beta^-} {}^{99}_{42}\mathrm{Mo} \xrightarrow[65.94\ \mathrm{h}]{\beta^-} {}^{99}_{43}\mathrm{Tc} \xrightarrow[211{,}100\ \mathrm{y}]{\beta^-} {}^{99}_{44}\mathrm{Ru}$$

$$^{99}_{42}Mo + ^{2}_{1}D \rightarrow ^{99}_{43}Tc + 2\,^{1}_{0}n$$

How Promethium(Pm)-147 was synthesized ?

- From the Induced fission of U-235 with thermal neutrons. One pair of fission products was Pm-147. So it was synthesized in the nuclear reactors.
- It was also produced by firing neturon to Nd-146.
- $^{235}_{92}U + ^{1}_{0}n \rightarrow [^{236}_{92}U] \rightarrow ^{147}_{61}Pm + ^{87}_{31}Ga + 2\,^{1}_{0}n$
- $^{146}_{60}Nd + ^{1}_{0}n \rightarrow [^{147}_{60}Nd] \rightarrow ^{147}_{61}Pm + ^{0}_{-1}\beta$

How Astatine and Polonium are synthesized ?

- $^{209}_{83}Bi + ^{4}_{2}He \rightarrow ^{211}_{85}At + 2\,^{1}_{0}n$ ($t_{0.5}$=7.21h)
- $^{209}_{83}Bi + ^{4}_{2}He \rightarrow ^{210}_{85}At + 3\,^{1}_{0}n$ ($t_{0.5}$=8.1h)
- $^{209}_{83}Bi + ^{4}_{2}He \rightarrow ^{209}_{85}At + 4\,^{1}_{0}n$ ($t_{0.5}$= 5.41 h)
- $^{209}_{83}Bi + ^{2}_{1}D \rightarrow ^{209}_{84}Po + 2\,^{1}_{0}n$ ($t_{0.5}$= 124 yrs)
- $^{209}_{83}Bi + ^{1}_{1}H \rightarrow ^{208}_{84}Po + 2\,^{1}_{0}n$ ($t_{0.5}$= 2.898 yrs)
- $^{209}_{83}Bi \xrightarrow{(n,\gamma)} {}^{210}_{83}Bi \xrightarrow{-\,{}^{0}_{-1}\beta} {}^{210}_{84}Po$ ($t_{0.5}$= 138.34 d)
- (Note that Natural At-216, At-217 and At-218 occur in nature in trace quantity in the Uranium and Thorium ores as decay products.)

How Francium is synthesized ?

- $^{197}_{79}Au + {}^{18}_{8}O \rightarrow {}^{209}_{84}Fr + 6{}^{1}_{0}n$
- $^{197}_{79}Au + {}^{18}_{8}O \rightarrow {}^{211}_{84}Fr + 4{}^{1}_{0}n$
- (Franium has two natural isotopes Fr-221 ($t_{0.5}$=4.8 min) & Fr-223($t_{0.5}$=22.0 min)
- **Radium**-226($t_{0.5}$ of 1600 years), Ra-225($t_{0.5}$=15d), Ra-228($t_{0.5}$=6.7 y) and Ra-223($t_{0.5}$=11.4 d) are the decay products from Uranium-238, Neptunium-237, Thorium-232 and Actinium-227 series respectively. So its synthesis, though possible, not usually done.

Synthesis of Transuranic Elements

- $^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}U \xrightarrow{-{}^{0}_{-1}e} {}^{239}_{93}Np \xrightarrow{-{}^{0}_{-1}e} {}^{239}_{94}Pu$
- $^{239}_{94}Pu + {}^{4}_{2}He \rightarrow {}^{242}_{96}Cm + {}^{1}_{0}n$
- $^{239}_{94}Pu + 2{}^{1}_{0}n \rightarrow {}^{241}_{95}Am + {}^{0}_{-1}e$
- $^{240}_{95}Am + {}^{4}_{2}He \rightarrow {}^{243}_{97}Bk + {}^{1}_{0}n$
- $^{246}_{96}Cm + {}^{12}_{6}C \rightarrow {}^{254}_{102}No + 4{}^{1}_{0}n$

Synthesis of Heavy Transuranic elements

- $^{239}_{94}Pu \xrightarrow{4(n,\gamma)} {}^{243}_{94}Pu \xrightarrow{-\beta^-} {}^{243}_{95}Am \xrightarrow{(n,\gamma)} {}^{244}_{95}Am \xrightarrow{-\beta^{-1}} {}^{244}_{96}Cm$

  $\xrightarrow{5(n,\gamma)} {}^{249}_{96}Cm \xrightarrow{-\beta^{-1}} {}^{249}_{97}Bk \xrightarrow{-\beta^{-1}} {}^{250}_{98}Cf$

- $^{252}_{98}Cf \xrightarrow{(n,\gamma)} {}^{253}_{98}Cf \xrightarrow{-{}^{0}_{-1}\beta} {}^{253}_{99}Es \xrightarrow{(n,\gamma)} {}^{254}_{99}Es \xrightarrow{-{}^{0}_{-1}\beta} {}^{254}_{100}Fm$
- $^{238}_{92}U + {}^{16}_{8}O \rightarrow {}^{250}_{100}Fm + 4{}^{1}_{0}n$

- $^{253}_{99}Es + {}^{4}_{2}He \rightarrow {}^{256}_{101}Md + {}^{1}_{0}n$
- $^{244}_{96}Cm + {}^{12}_{6}C \rightarrow {}^{252}_{102}No + 4{}^{1}_{0}n$
- $^{238}_{92}U + {}^{22}_{10}Ne \rightarrow {}^{254}_{102}No + 6{}^{1}_{0}n$
- $^{252}_{98}Cf + {}^{11}_{5}B \rightarrow {}^{258}_{103}Lr + 5{}^{1}_{0}n$
- $^{243}_{95}Am + {}^{18}_{8}O \rightarrow {}^{256}_{103}Lr + 5{}^{1}_{0}n$

Synthesis of Superheavy Elements

- $^{249}_{98}Cf + {}^{12}_{6}C \rightarrow {}^{257}_{104}Rf + 4{}^{1}_{0}n$
- $^{243}_{95}Am + {}^{22}_{10}Ne \rightarrow {}^{261}_{105}Db + 4{}^{1}_{0}n$
- $^{249}_{98}Cf + {}^{18}_{8}O \rightarrow {}^{263}_{106}Sg + 4{}^{1}_{0}n$
- $^{209}_{83}Bi + {}^{54}_{24}Cr \rightarrow {}^{261}_{107}Bh + 2{}^{1}_{0}n$

- $^{209}_{83}Bi + {}^{55}_{25}Mn \rightarrow {}^{263}_{108}Hs + {}^{1}_{0}n$
- $^{209}_{83}Bi + {}^{58}_{26}Fe \rightarrow {}^{266}_{109}Mt + {}^{1}_{0}n$
- $^{208}_{82}Pb + {}^{62}_{28}Ni \rightarrow {}^{269}_{110}Ds + {}^{1}_{0}n$
- $^{209}_{83}Bi + {}^{64}_{28}Ni \rightarrow {}^{272}_{111}Rg + {}^{1}_{0}n$
- $^{208}_{82}Pb + {}^{70}_{30}Zn \rightarrow {}^{277}_{112}Cn + {}^{1}_{0}n$

- $^{209}_{83}Bi + ^{70}_{30}Zn \rightarrow ^{278}_{113}Nh + ^{1}_{0}n$
- $^{244}_{94}Pu + ^{48}_{20}Ca \rightarrow ^{290}_{114}Fl + 2^{1}_{0}n$
- $^{243}_{95}Am + ^{48}_{20}Ca \rightarrow ^{288}_{115}Mc + 3^{1}_{0}n$
- $^{248}_{96}Cm + ^{48}_{20}Ca \rightarrow ^{293}_{116}Lv + 3^{1}_{0}n$
- $^{249}_{97}Bk + ^{48}_{20}Ca \rightarrow ^{294}_{117}Ts + 3^{1}_{0}n$
- $^{249}_{98}Cf + ^{48}_{20}Ca \rightarrow ^{294}_{118}Og + 3^{1}_{0}n$

Transuranic Synthetic Elements with high half-live Periods

- Np-237($t_{0.5}$=21.X10^6 yrs),
- Pu-239($t_{0.5}$=2.44X10^4 yrs),
- Am-241 ($t_{0.5}$=458 yrs),
- Cm-245($t_{0.5}$=17.6 yrs),
- Bk-247($t_{0.5}$=1380 yrs) ,
- Cf-249($t_{0.5}$=351 yrs)

Other Synthetic Elements having smaller Half Life Periods

- Og-294 : 5 atoms produced ($t_{0.5}$ = 0.9 ms)
- Ts-294: few mg produced ($t_{0.5}$=112 ms)
- Lv-293 : 3 atoms produced($t_{0.5}$=80 ms)
- Mc-288: 100 atoms produced($t_{0.5}$=0.65 s)
- Fl-290 : 1 atom produced at a time($t_{0.5}$=19s)
- Nh-286: 1 atom produced at a time($t_{0.5}$= 10 s)
- Cn-285: few atoms produced ($t_{0.5}$=30s)
- Rg-282 : few μg synthesized($t_{0.5}$=130 s)
- Ds-282: few mg synthesized($t_{0.5}$=130s)
- Mt-278: few mg synthesized($t_{0.5}$=4.5 s)

- Hs-277: few mg produced ($t_{0.5}$=130 s)
- Bh-270: few mg produced ($t_{0.5}$=2.3 min)
- Sg-267: few mg produced ($t_{0.5}$=9.8 min)
- Db-268: few mg produced ($t_{0.5}$=16 h)
- Rf-267: few mg produced ($t_{0.5}$=48 mins)
- Lr-266: few mg produced($t_{0.5}$=11 h)
- No-259: few mg produced($t_{0.5}$=58 min)
- Md-258: few g produced($t_{0.5}$=51.59 days)
- Fm-257: few g produced($t_{0.5}$=100.5 days)
- Es-255: few g produced($t_{0.5}$=39.8 days)