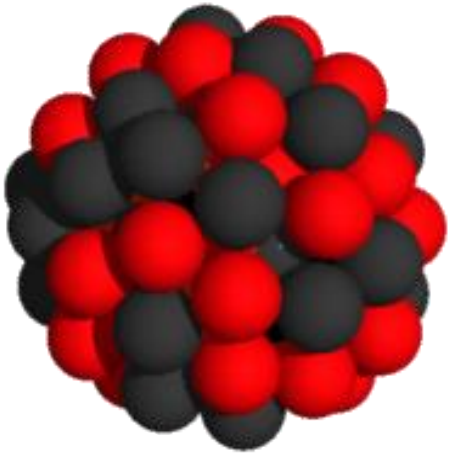


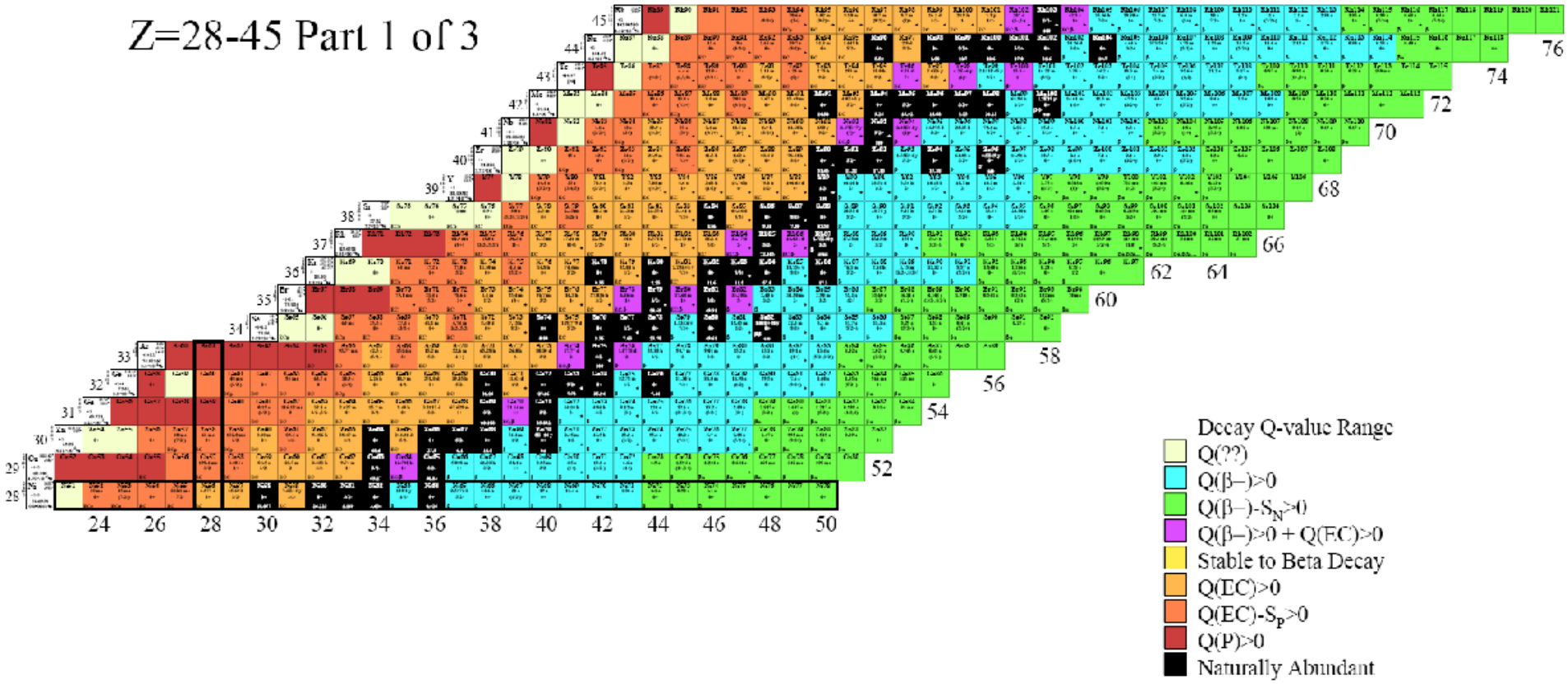
Radioactiviteit

Cursus Stralingsveiligheid CD 2022-2023

M.A. Hofstee
mariet.hofstee@maastrichtuniversity.nl

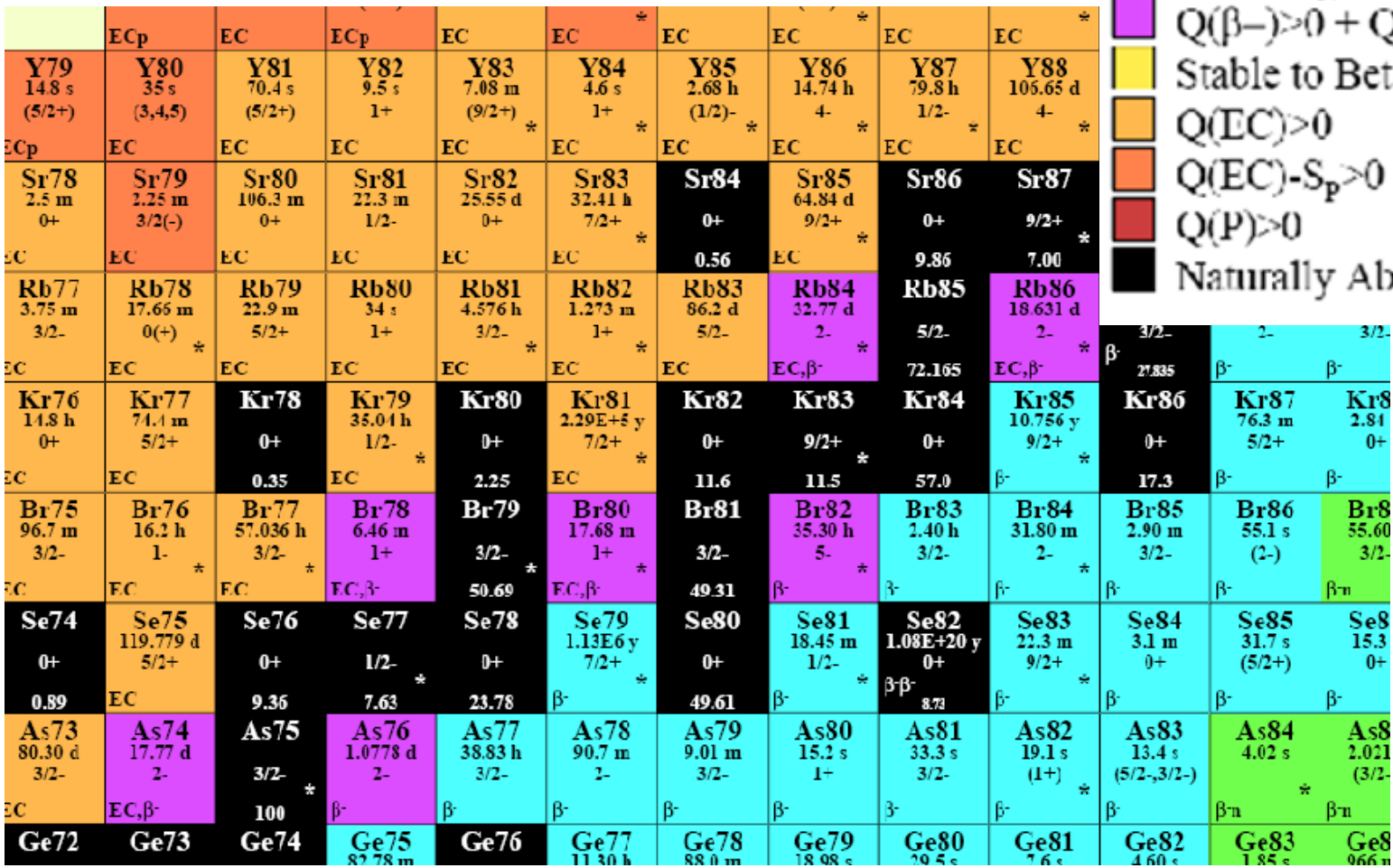
Hoofdstuk 5.1-5.7

Nuclidenkaart



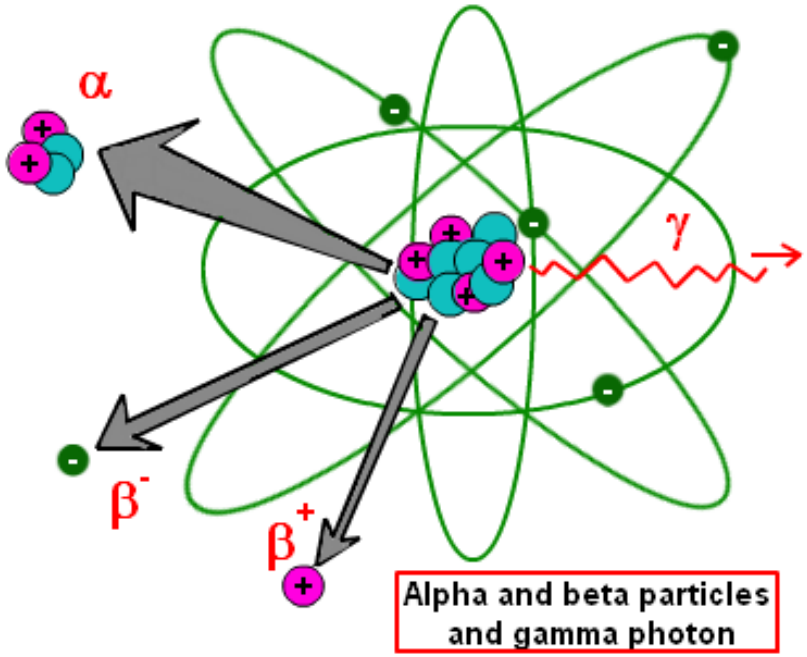
pdf versie: http://nucleardata.nuclear.lu.se/toi/pdf/chart.pdf
interactieve versie https://www.nndc.bnl.gov/nudat3/

Detail


Decay Q-value Range
Q(??)
Q(β–)>0
Q(β–)-S_N>0
Q(β–)>0 + Q(EC)>0
Stable to Beta Decay
Q(EC)>0
Q(EC)-S_p>0
Q(P)>0
Naturally Abundant
ECp
EC
Y79 14.8 s (5/2+) ECp
Y80 35 s (3,4,5) EC
Y81 70.4 s (5/2+) EC
Y82 9.5 s 1+ EC
Y83 7.08 m (9/2+) * EC
Y84 4.6 s 1+ * EC
Y85 2.68 h (1/2)- * EC
Y86 14.74 h 4- * EC
Y87 79.8 h 1/2- * EC
Y88 105.65 d 4- * EC
Sr78 2.5 m 0+ EC
Sr79 2.25 m 3/2(-) EC
Sr80 106.3 m 0+ EC
Sr81 22.3 m 1/2- EC
Sr82 25.55 d 0+ EC
Sr83 32.41 h 7/2+ * EC
Sr84 0+ 0.56
Sr85 64.84 d 9/2+ * EC
Sr86 0+ 9.86
Sr87 9/2+ * 7.00
Rb77 3.75 m 3/2- EC
Rb78 17.66 m 0(+) * EC
Rb79 22.9 m 5/2+ EC
Rb80 34 s 1+ EC
Rb81 4.576 h 3/2- * EC
Rb82 1.273 m 1+ * EC
Rb83 86.2 d 5/2- EC
Rb84 32.77 d 2- * EC,β-
Rb85 5/2- 72.165
Rb86 18.631 d 2- * EC,β-
Kr76 14.8 h 0+ EC
Kr77 74.4 m 5/2+ EC
Kr78 0+ 0.35
Kr79 35.04 h 1/2- * EC
Kr80 0+ 2.25
Kr81 2.29E+5 y 7/2+ * EC
Kr82 0+ 11.6
Kr83 9/2+ * 11.5
Kr84 0+ 57.0
Kr85 10.756 y 9/2+ * β-
Kr86 0+ 17.3
Kr87 76.3 m 5/2+ β-
Br75 96.7 m 3/2- EC
Br76 16.2 h 1- * EC
Br77 57.036 h 3/2- * EC
Br78 6.46 m 1+ EC,β-
Br79 3/2- * 50.69
Br80 17.68 m 1+ * EC,β-
Br81 3/2- 49.31
Br82 35.30 h 5- * β-
Br83 2.40 h 3/2- β-
Br84 31.80 m 2- * β-
Br85 2.90 m 3/2- β-
Br86 55.1 s (2-) β-
Se74 0+ 0.89
Se75 119.779 d 5/2+ EC
Se76 0+ 9.36
Se77 1/2- * 7.63
Se78 0+ 23.78
Se79 1.13E6 y 7/2+ * β-
Se80 0+ 49.61
Se81 18.45 m 1/2- * β-
Se82 1.08E+20 y 0+ ββ- 8.73
Se83 22.3 m 9/2+ * β-
Se84 3.1 m 0+ β-
Se85 31.7 s (5/2+) β-
As73 80.30 d 3/2- EC
As74 17.77 d 2- EC,β-
As75 3/2- * 100
As76 1.0778 d 2- β-
As77 38.83 h 3/2- β-
As78 90.7 m 2- β-
As79 9.01 m 3/2- β-
As80 15.2 s 1- β-
As81 33.3 s 3/2- β-
As82 19.1 s (1+) * β-
As83 13.4 s (5/2-,3/2-) β-
As84 4.02 s * β-n
Ge72
Ge73
Ge74
Ge75
Ge76
Ge77
Ge78
Ge79
Ge80
Ge81
Ge82
Ge83

Wat is Radioactiviteit

- Verandering van de atoomkern
  - energieverlies (aangeslagen toestand)
    - uitzending van gammas
  - transmutatie
    - uitzending van betas
      - A veranderd niet,
      - Z -> Z +/- 1
    - uitzending van alphas
      - A -> A-4,
      - Z -> Z-2



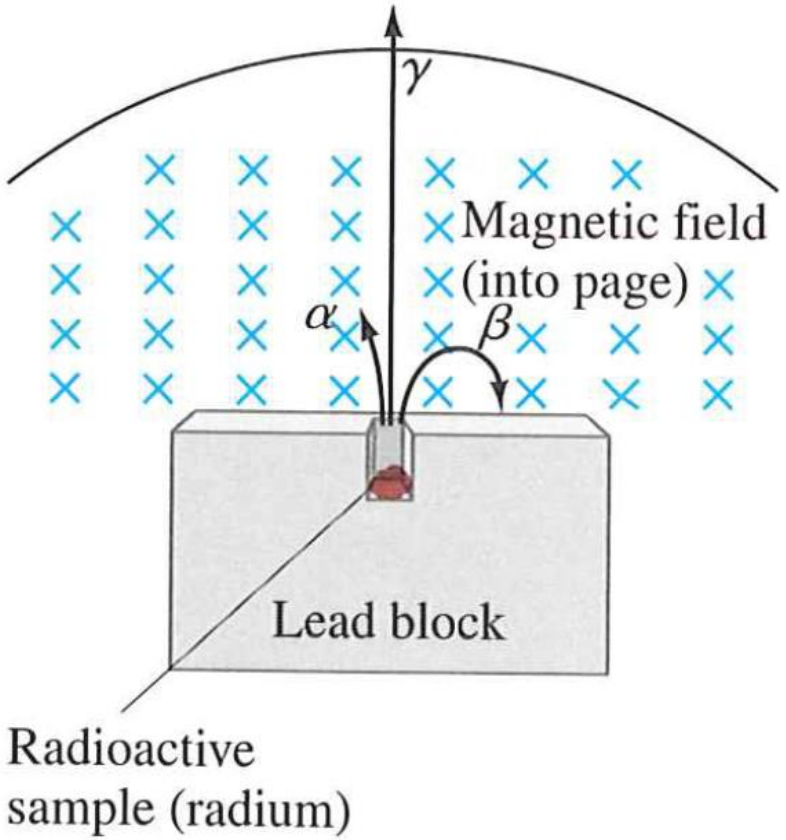
α: $^{A}_{Z}N \rightarrow {}^{A-4}_{Z-2}N' + {}^{4}_{2}He$

β^-: $^{A}_{Z}N \rightarrow {}^{A}_{Z+1}N' + e^- + \bar{\nu}$

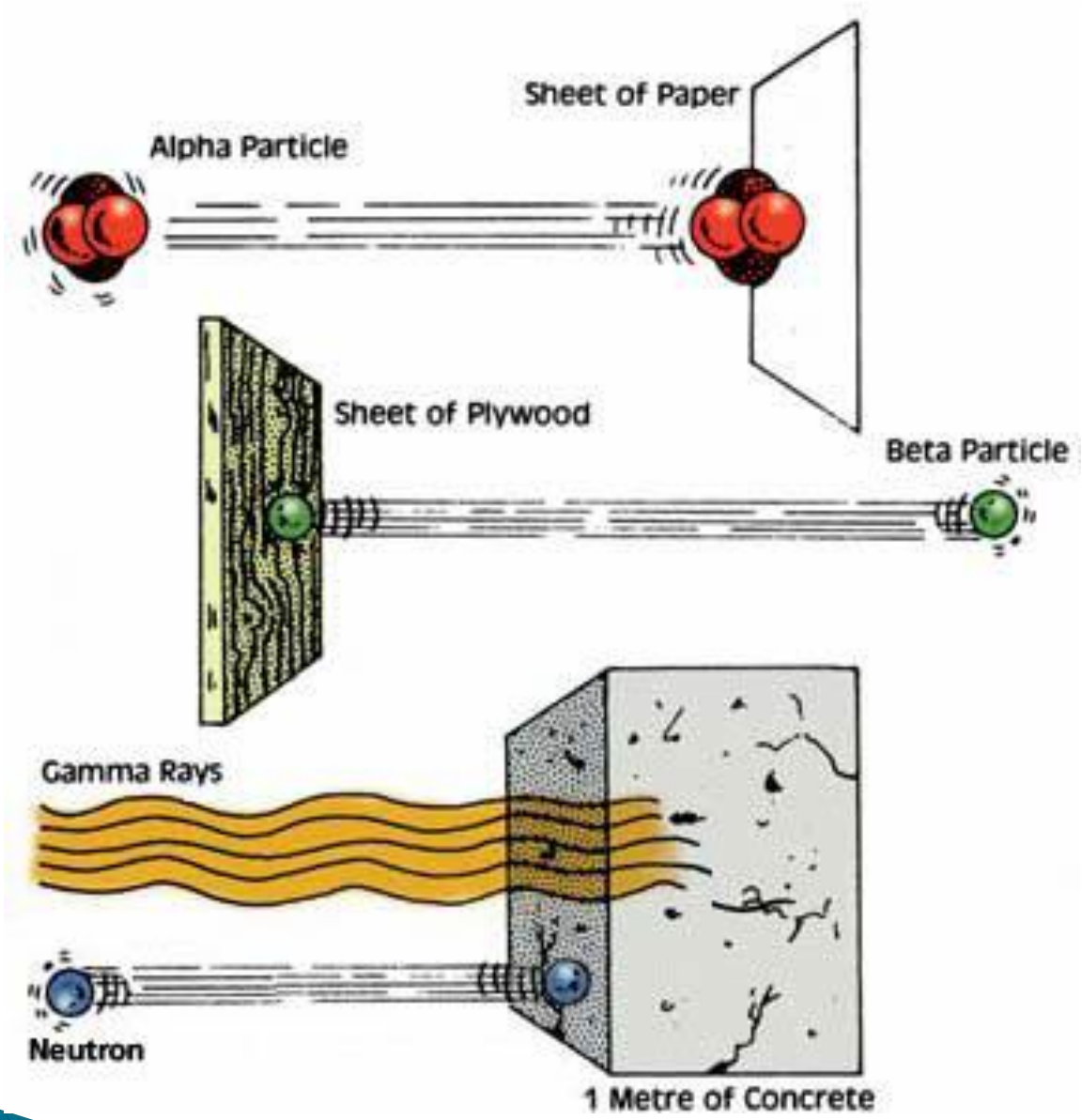
β^+: $^{A}_{Z}N \rightarrow {}^{A}_{Z-1}N' + e^+ + \nu$

EC: $^{A}_{Z}N + e^- \rightarrow {}^{A}_{Z-1}N' + \nu$

γ: $^{A}_{Z}N^* \rightarrow {}^{A}_{Z}N + \gamma$



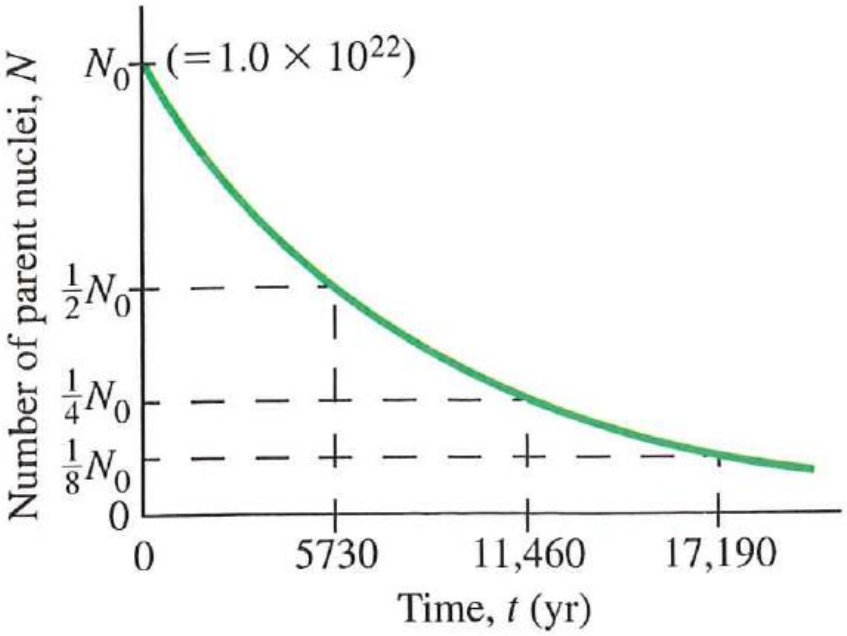
$$^{226}_{88}\mathbf{Ra} \rightarrow {}^{222}_{86}\mathbf{Rn} + {}^{4}_{2}\mathbf{He}$$

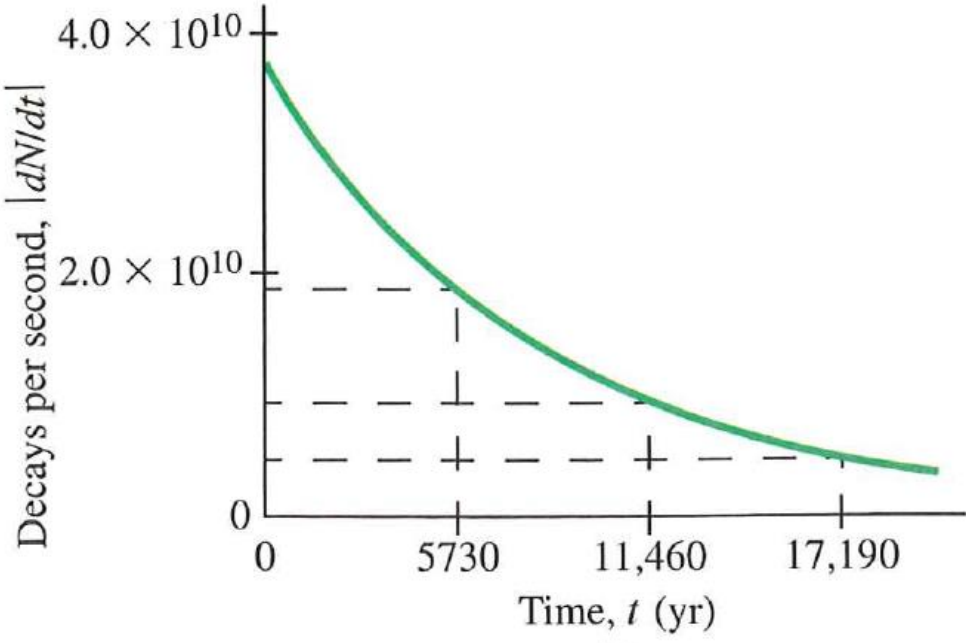


$\alpha = {}^{4}_{2}\mathrm{He}^{2+}$

$\beta = e^{-} / e^{+}$

$\gamma = \text{photon}$





Decay law : $dN/dt = -\lambda N \rightarrow N(t) = N_0 \cdot e^{-\lambda t}$

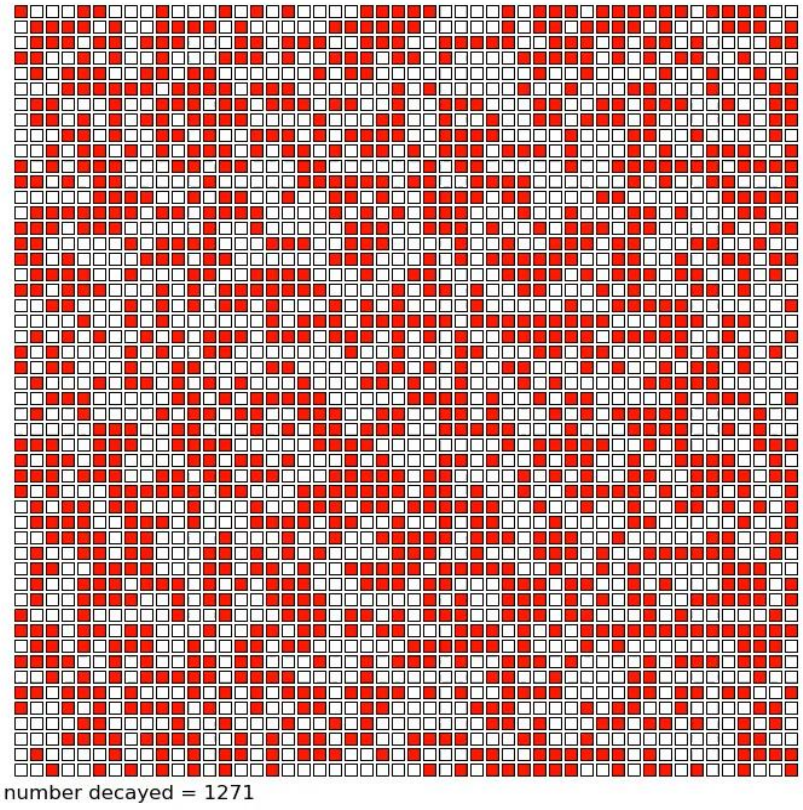
Activity : $R = dN/dt \rightarrow R(t) = R_0 \cdot e^{-\lambda t} = \lambda N_0 \cdot e^{-\lambda t}$

Half-life : $T_{1/2} = \ln(2)/\lambda = 0.693/\lambda$

Lifetime : $\tau = 1/\lambda$

Unit : 1 Becquerel (Bq) = 1 decay/s

Activiteit



$$\frac{dN(t)}{dt} = -A(t); \quad A(t) = \lambda N(t)$$

$$\frac{dN(t)}{dt} = -\lambda N(t)$$

$$\frac{dN(t)}{N(t)} = -\lambda\, dt$$

$$\ln\left[N(t)\right] = -\lambda t + C$$

$$N(t) = C\exp(-\lambda t); C = N(0)$$

$$A(t) = \lambda N(0)\exp(-\lambda t)$$

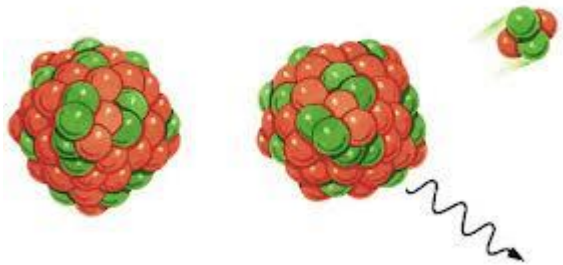
Eenheden:
Bq = 1 decay/sec
Ci = 3.7 x 10^{10} Bq

Specifieke Activiteit en Halveringstijd

- Specifieke activiteit = activiteit per massa eenheid
  - massa = Activiteit/λ x A/N_A
- Halveringstijd = tijd waarin de activiteit A(t) met de helft is afgenomen
  - $A(0) / 2 = A(T_{1/2}) = A(0) \exp [- \lambda T_{1/2}]$
  - $\lambda T_{1/2} = \ln(2) = 0.69315$
  - $A(t) = A(0) (1/2)^{t/T_{1/2}}$

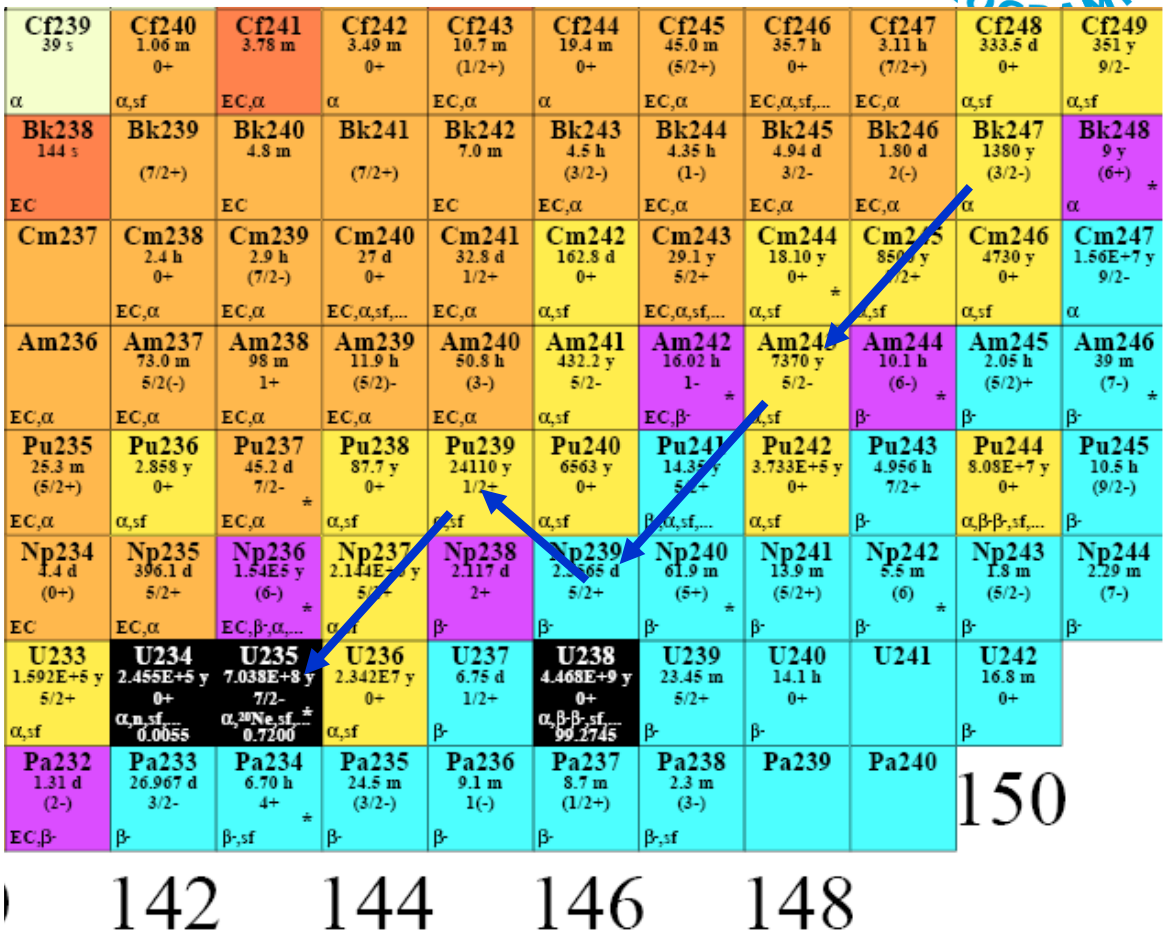
α verval

$$ {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha $$



Terugstoot

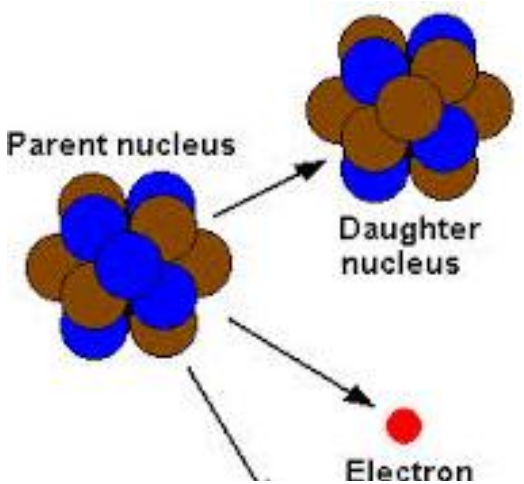
$$ E = \frac{A_\alpha}{A - A_\alpha} E_\alpha = \frac{4}{A-4} E_\alpha $$



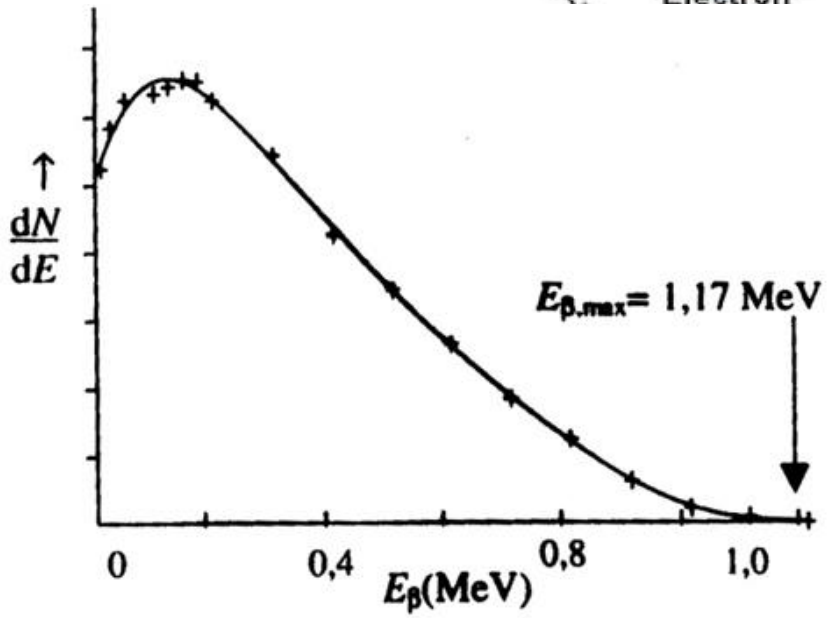
β^- verval

$$n \rightarrow p + \beta^- + \bar{\nu}$$

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^- + \bar{\nu}$$



$$\overline{E_\beta} \approx \frac{1}{3} E_{\beta,max}$$

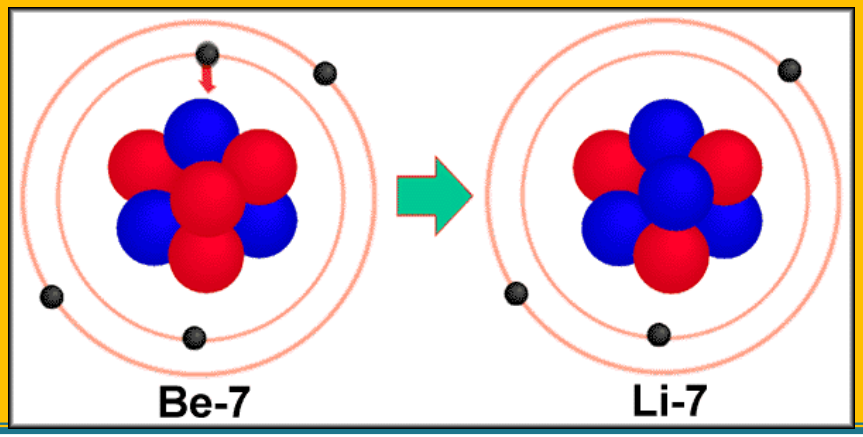


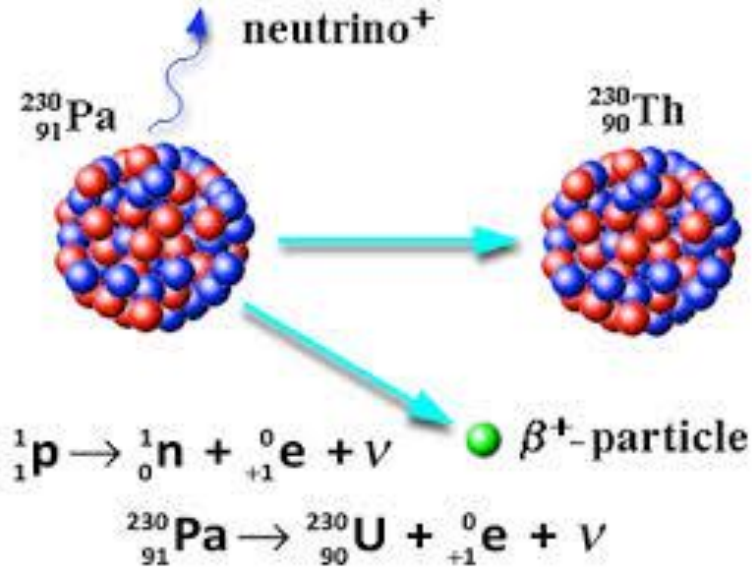
β^+ verval en elektronvangst

Electron Capture (EC)

$$p + e^- \rightarrow n + \nu$$

$$^{A}_{Z}X + e^- \rightarrow {}^{A}_{Z-1}Y + \nu$$





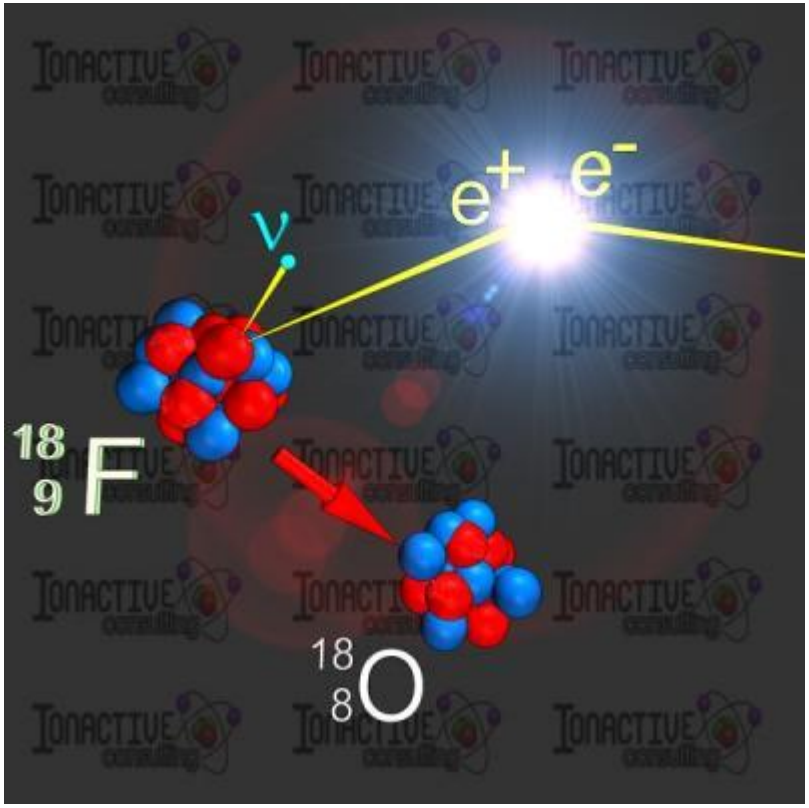
®$^+$ verval

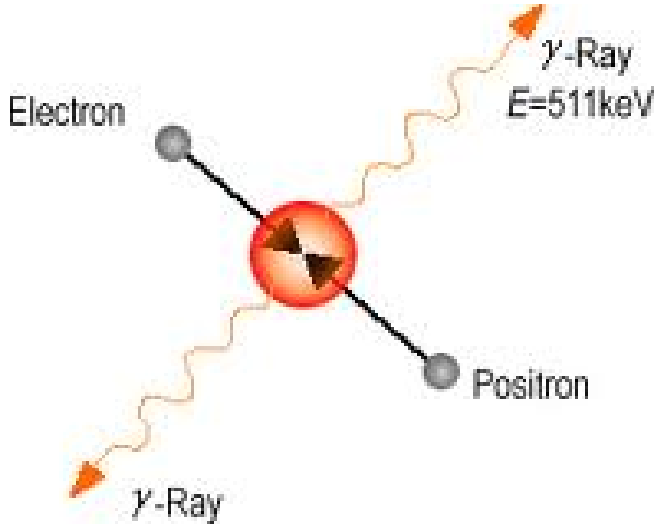
$$p \rightarrow n + \beta^+ + \nu$$

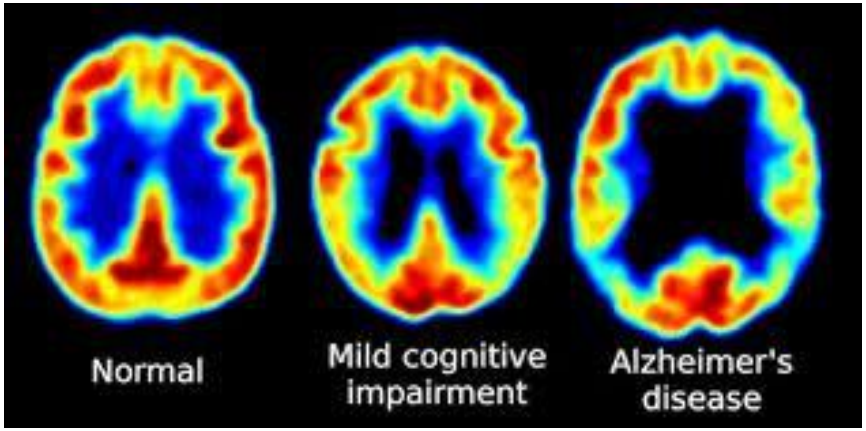
$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \beta^+ + \nu$$

$$\overline{E_\beta} \approx 0{,}4\, E_{\beta,max}$$

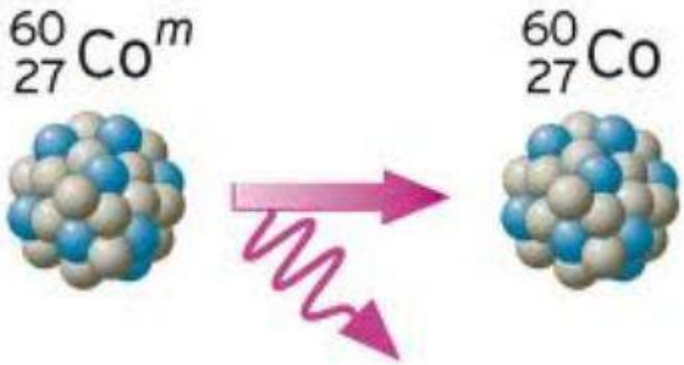
Annihilatie en PET







γ verval en interne conversie

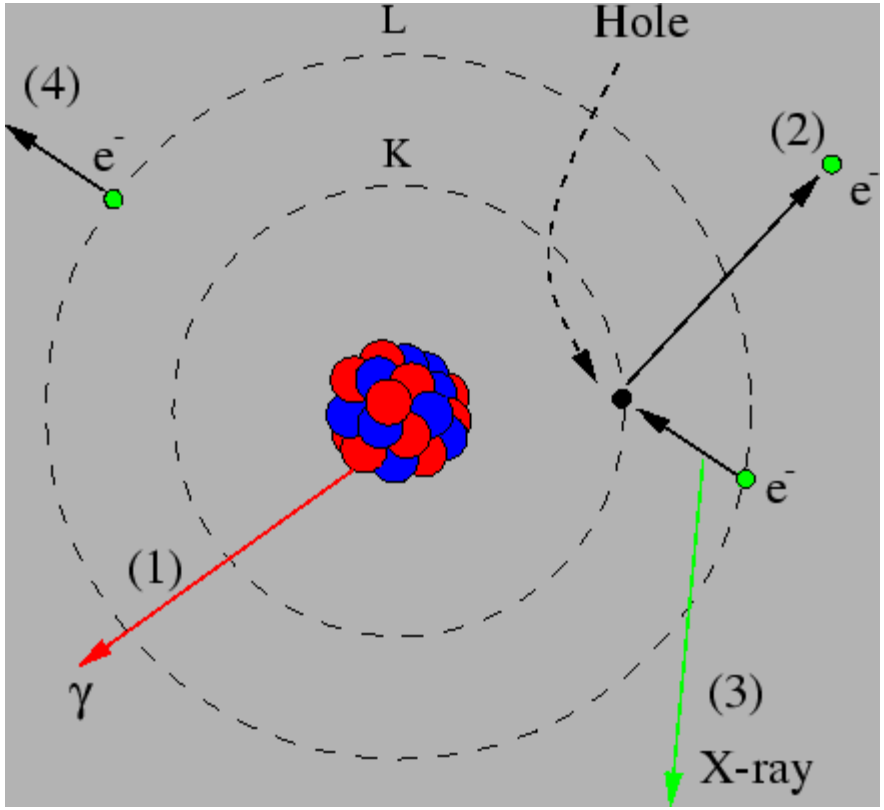


(1) γ verval
(2) interne conversie (K-conversie)
(3) Röntgen straling (opvullen gat)
(4) Auger electron (opvullen gat)

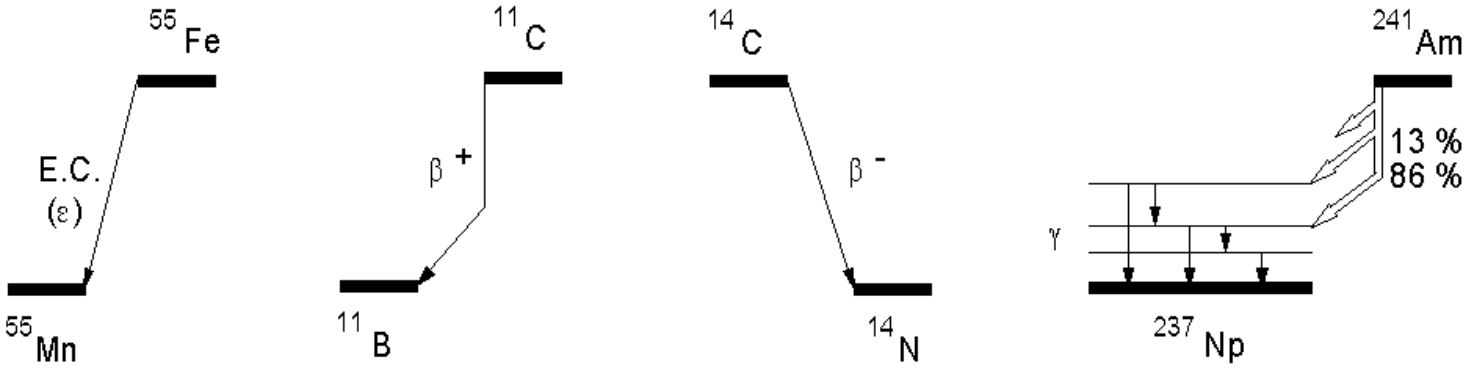
$$E_{ce} = E_{\gamma} - B_{ce}$$

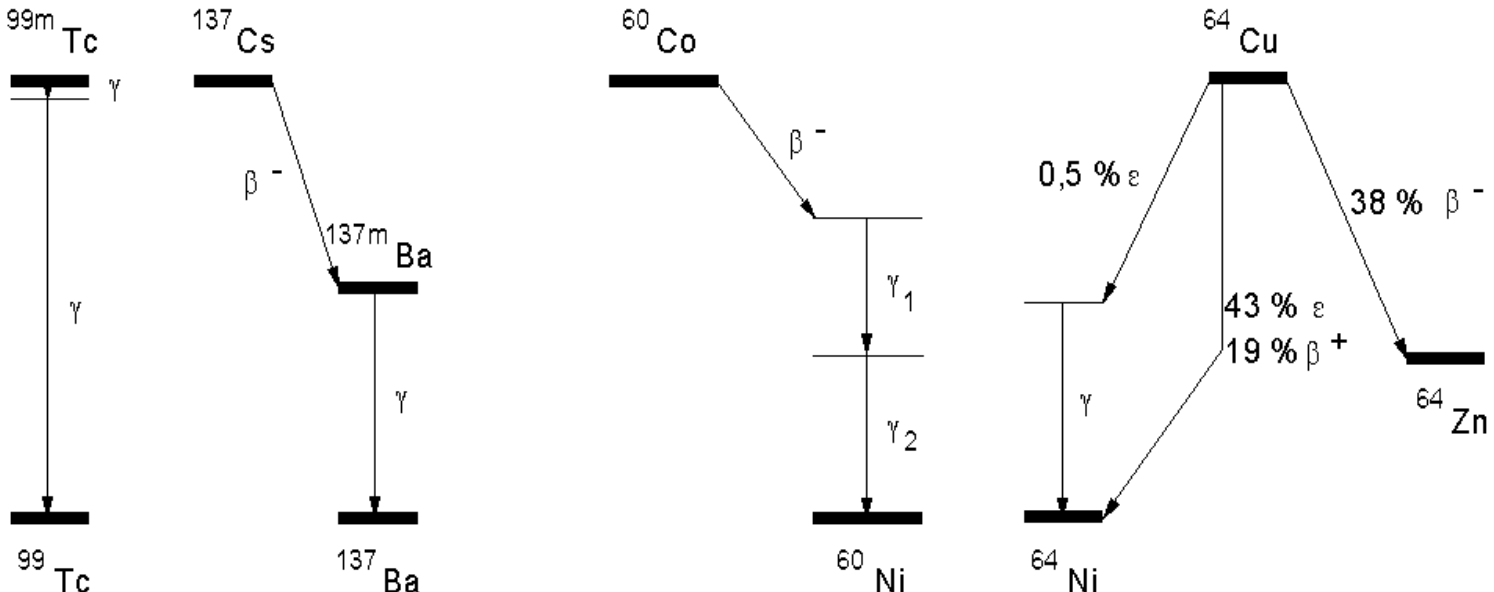
conversie coëfficiënt

$$\alpha_K = \frac{N_{ce,K}}{N_{\gamma}}$$

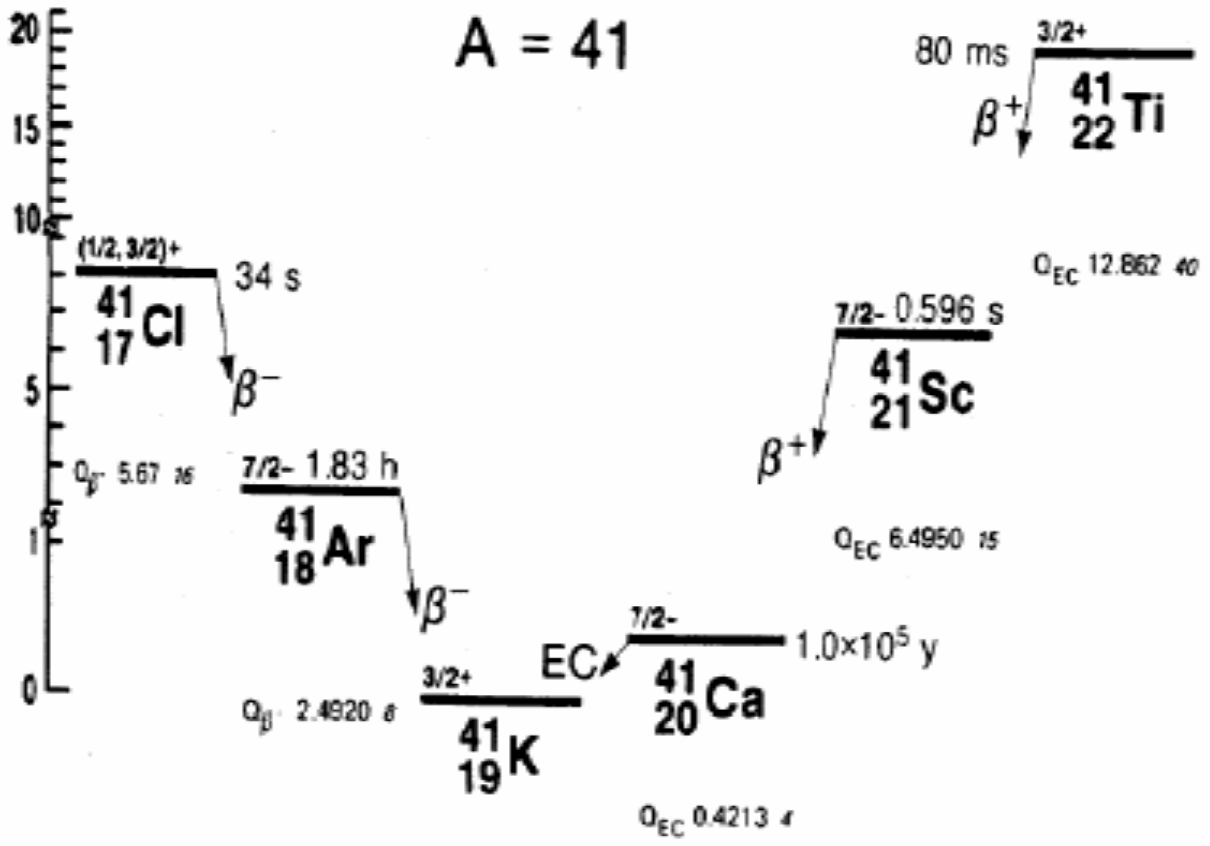


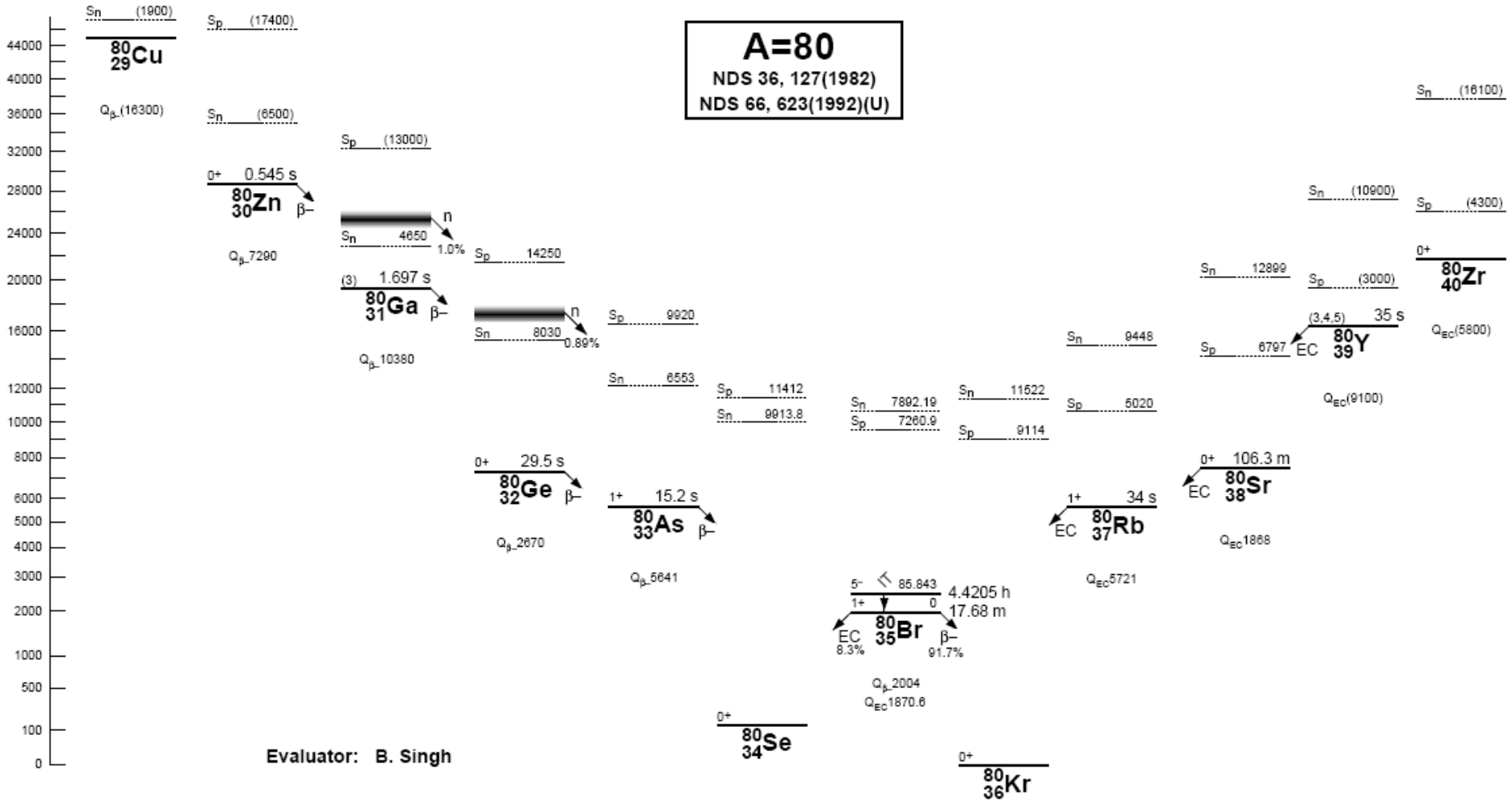
Vervalschemas





Isobaren


A = 41
20
15
10
5
1
0
(1/2, 3/2)+
41 17 Cl
34 s
β−
Qβ− 5.67 16
7/2− 1.83 h
41 18 Ar
β−
Qβ 2.4920 6
3/2+
41 19 K
EC
7/2−
41 20 Ca
1.0×10^5 y
QEC 0.4213 4
80 ms
3/2+
β+
41 22 Ti
QEC 12.862 40
7/2− 0.596 s
41 21 Sc
β+
QEC 6.4950 15


A=80
NDS 36, 127(1982)
NDS 66, 623(1992)(U)
80 29 Cu
Sn (1900)
Sp (17400)
Qβ-(16300)
80 30 Zn
0+ 0.545 s
β-
Sn (6500)
Qβ-7290
80 31 Ga
(3) 1.697 s
β-
n
Sn 4650
1.0%
Sp 14250
Qβ-10380
80 32 Ge
0+ 29.5 s
β-
n
Sn 8030
0.89%
Sp 9920
Sn 6553
Qβ-2670
80 33 As
1+ 15.2 s
β-
Sp 11412
Sn 9913.8
Qβ-5641
80 34 Se
0+
Sn 7892.19
Sp 7260.9
5- 85.843
1+ 0
4.4205 h
17.68 m
80 35 Br
EC 8.3%
β- 91.7%
Qβ-2004
QEC1870.6
Sn 11622
Sp 9114
80 36 Kr
0+
Sn 9448
Sp 5020
80 37 Rb
1+ 34 s
EC
QEC5721
Sn 12899
Sp 6797
80 38 Sr
0+ 106.3 m
EC
QEC1868
Sn (10900)
Sp (3000)
80 39 Y
(3,4,5) 35 s
EC
QEC(9100)
Sn (16100)
Sp (4300)
80 40 Zr
0+
QEC(5800)
Evaluator: B. Singh


ECp EC ECp EC EC EC EC EC EC 51.45 11.22 17.1
Y79 14.8 s (5/2+) ECp
Y80 35 s (3,4,5) EC
Y81 70.4 s (5/2+) EC
Y82 9.5 s 1+ EC
Y83 7.08 m (9/2+) * EC
Y84 4.6 s 1+ * EC
Y85 2.68 h (1/2)- * EC
Y86 14.74 h 4- * EC
Y87 79.8 h 1/2- * EC
Y88 106.65 d 4- * EC
Y89 1/2- * 100
Y90 64.10 h 2- * β-
Y91 58.51 1/2-
Sr78 2.5 m 0+ EC
Sr79 2.25 m 3/2(-) EC
Sr80 106.3 m 0+ EC
Sr81 22.3 m 1/2- EC
Sr82 25.55 d 0+ EC
Sr83 32.41 h 7/2+ * EC
Sr84 0+ 0.56
Sr85 64.84 d 9/2+ * EC
Sr86 0+ 9.86
Sr87 9/2+ * 7.00
Sr88 0+ 82.58
Sr89 50.53 d 5/2+ β-
Sr90 28.78 0+ β-
Rb77 3.75 m 3/2- EC
Rb78 17.66 m 0(+) * EC
Rb79 22.9 m 5/2+ EC
Rb80 34 s 1+ EC
Rb81 4.576 h 3/2- * EC
Rb82 1.273 m 1+ * EC
Rb83 86.2 d 5/2- EC
Rb84 32.77 d 2- * EC,β-
Rb85 5/2- 72.165
Rb86 18.631 d 2- * EC,β-
Rb87 4.75E10 y 3/2- β- 27.835
Rb88 17.78 m 2- β-
Rb89 15.15 3/2- β-
Kr76 14.8 h 0+ EC
Kr77 74.4 m 5/2+ EC
Kr78 0+ 0.35
Kr79 35.04 h 1/2- * EC
Kr80 0+ 2.25
Kr81 2.29E+5 y 7/2+ * EC
Kr82 0+ 11.6
Kr83 9/2+ * 11.5
Kr84 0+ 57.0
Kr85 10.756 y 9/2+ * β-
Kr86 0+ 17.3
Kr87 76.3 m 5/2+ β-
Kr88 2.84 0+ β-
Br75 96.7 m 3/2- EC
Br76 16.2 h 1- * EC
Br77 57.036 h 3/2- * EC
Br78 6.46 m 1+ EC,β-
Br79 3/2- * 50.69
Br80 17.68 m 1+ * EC,β-
Br81 3/2- 49.31
Br82 35.30 h 5- * β-
Br83 2.40 h 3/2- β-
Br84 31.80 m 2- * β-
Br85 2.90 m 3/2- β-
Br86 55.1 s (2-) β-
Br87 55.60 3/2- β-n
Se74 0+ 0.89
Se75 119.779 d 5/2+ EC
Se76 0+ 9.36
Se77 1/2- * 7.63
Se78 0+ 23.78
Se79 1.13E6 y 7/2+ * β-
Se80 0+ 49.61
Se81 18.45 m 1/2- * β-
Se82 1.08E+20 y 0+ β-β- 8.73
Se83 22.3 m 9/2+ * β-
Se84 3.1 m 0+ β-
Se85 31.7 s (5/2+) β-
Se86 15.3 0+ β-
As73 80.30 d 3/2- EC
As74 17.77 d 2- EC,β-
As75 3/2- * 100
As76 1.0778 d 2- β-
As77 38.83 h 3/2- β-
As78 90.7 m 2- β-
As79 9.01 m 3/2- β-
As80 15.2 s 1+ β-
As81 33.3 s 3/2- β-
As82 19.1 s (1+) * β-
As83 13.4 s (5/2-,3/2-) β-
As84 4.02 s * β-n
As85 2.021 (3/2- β-n
Ge72 Ge73 Ge74 Ge75 82.78 m Ge76 Ge77 11.30 h Ge78 88.0 m Ge79 18.98 s Ge80 29.5 s Ge81 7.6 s Ge82 4.60 s Ge83 1.85 s Ge84 966 n