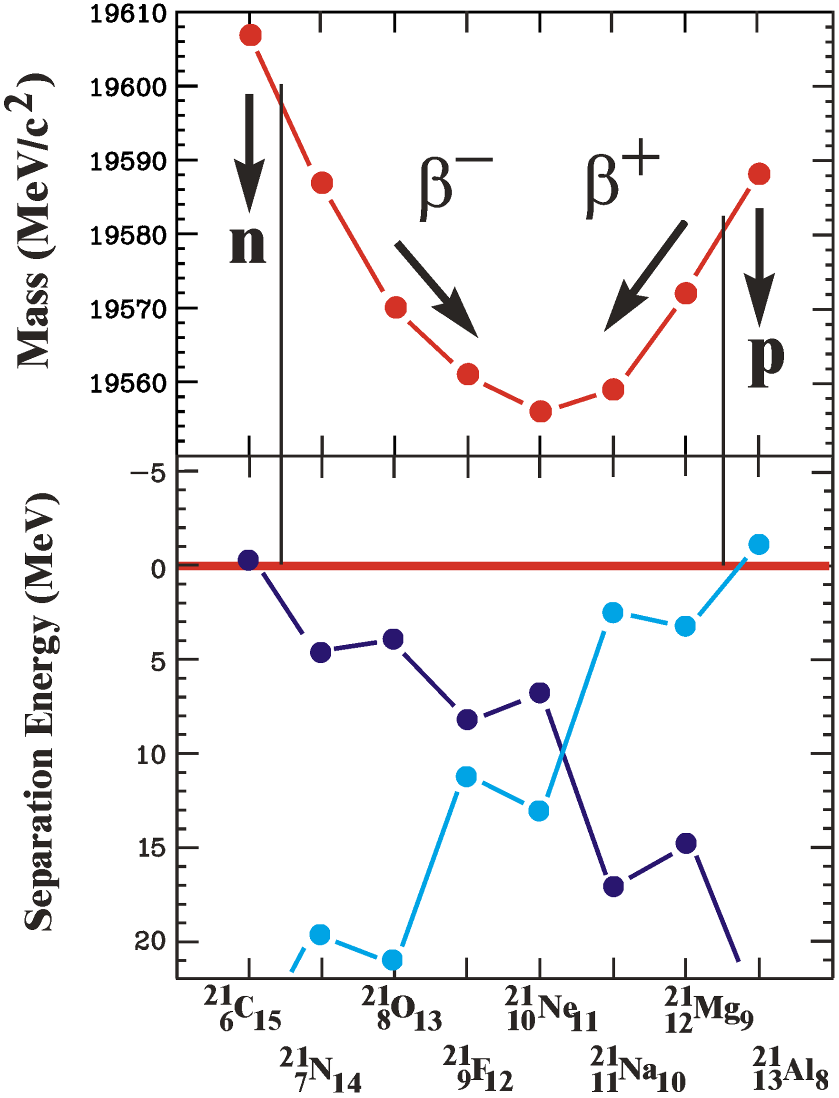
Separation energies



A = 21 isobaric chain

one-nucleon separation energies

$$S_{1n} = B(N,Z) - B(N-1,Z)$$

$$S_{1p} = B(N,Z) - B(N,Z-1)$$

two-nucleon separation energies

$$S_{2n} = B(N,Z) - B(N-2,Z)$$

$$S_{2p} = B(N,Z) - B(N,Z-2)$$

Using http://www.nndc.bnl.gov/chart/
find one- and two-nucleon separation energies of ^{8}He, ^{11}Li, ^{45}Fe, ^{141}Ho, and ^{208}Pb. Discuss the result.

Beta decay: energy relations

atomic mass $$Mc^2 = M'c^2 + Zm_ec^2 - \sum_{i=1}^{Z} B_{ei}$$

nuclear mass

electron binding energy

P(arent) D(aughter)

a) β⁻ decay

$${}^{A}_{Z}X_N \rightarrow {}^{A}_{Z+1}X_{N-1} + e^- + \bar{\nu}_e$$

Nuclear recoil is very small

$$Q_{\beta^-} = T_{e^-} + T_{\bar{\nu}_e} = M'_Pc^2 - M'_Dc^2 - m_ec^2$$

In the following, we assume that the neutrino mass is ~zero and that the very small differences in electron binding energy between the parent and daughter atoms can be neglected. This gives: $$Q_{\beta^-} = M_Pc^2 - M_Dc^2$$

Consequently, the β⁻ decay process is possible whenever $M_P > M_D$

b) β⁺ decay

$${}^{A}_{Z}X_N \rightarrow {}^{A}_{Z-1}X_{N+1} + e^+ + \nu_e$$

$$Q_{\beta^+} = T_{e^+} + T_{\nu_e} = M'_Pc^2 - M'_Dc^2 - m_ec^2$$

$$= M_Pc^2 - \left(M_Dc^2 + 2m_ec^2\right)$$

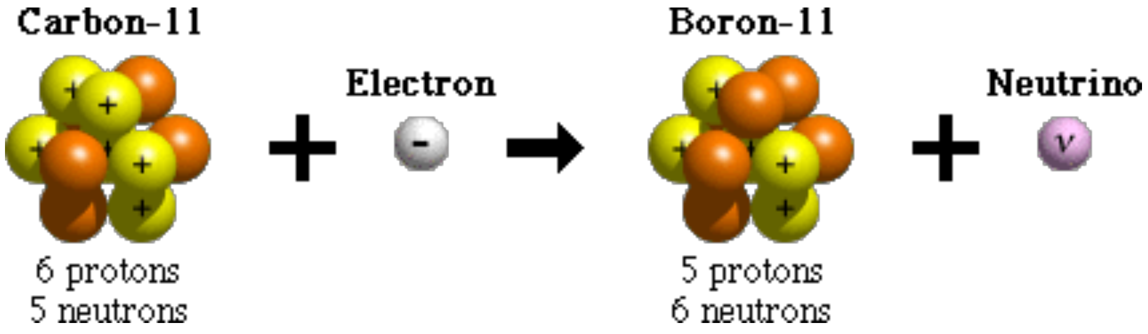
Consequently, the β⁺ decay process has a *threshold* $2m_ec^2$

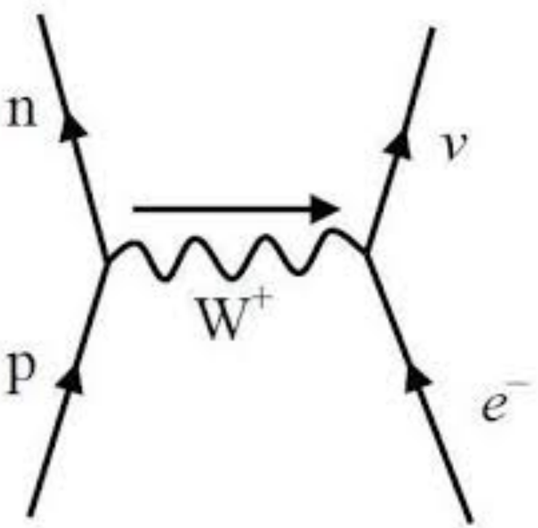
c) Electron capture (inverse beta decay)

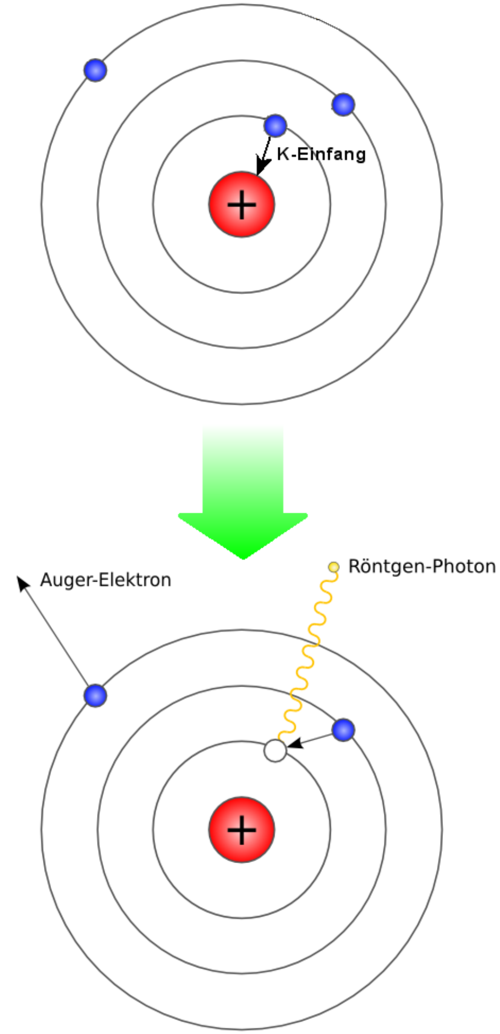
$$ {}^{A}_{Z}X_{N} + e^{-} \rightarrow {}^{A}_{Z-1}X_{N+1} + \nu_{e} $$

$$ Q_{EC} = M_{P}c^{2} - \left(M_{D}c^{2} - B_{en} \right) $$

Atomic electron is captured by a proton. This process leaves the atom in an excited state: a vacancy has been created! The vacancy is quickly filled by producing the characteristic X-ray cascade

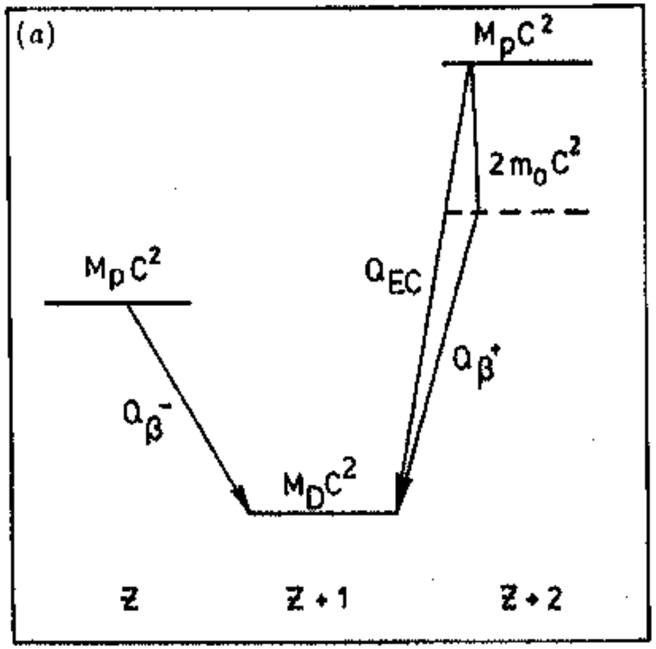




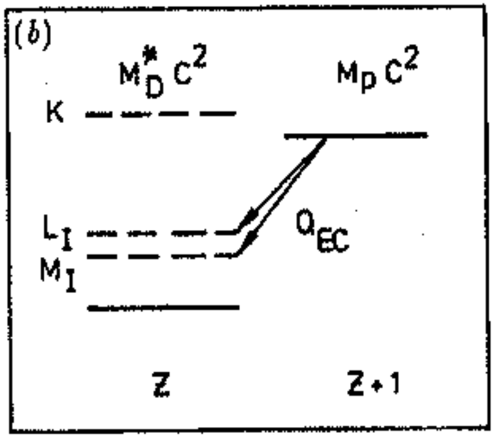


Decay	Type	Q (MeV)	T
${}^{23}\mathrm{Ne} \rightarrow {}^{23}\mathrm{Na} + e^- + \bar{\nu}_e$	β^-	4.38	38 s
${}^{99}\mathrm{Tc} \rightarrow {}^{99}\mathrm{Ru} + e^- + \bar{\nu}_e$	β^-	0.29	2.1×10^5 y
${}^{25}\mathrm{Al} \rightarrow {}^{25}\mathrm{Mg} + e^+ + \nu_e$	β^+	3.26	7.2 s
${}^{124}\mathrm{I} \rightarrow {}^{124}\mathrm{Te} + e^+ + \nu_e$	β^+	2.14	4.2 s
${}^{15}\mathrm{O} + e^- \rightarrow {}^{15}\mathrm{N} + \nu_e$	EC	2.75	1.22 s
${}^{41}\mathrm{Ca} + e^- \rightarrow {}^{41}\mathrm{K} + \nu_e$	EC	0.43	1.0×10^5 y

examples…



energy relations in various beta decay processes



mass relationship in electron capture between the parent and daughter atom

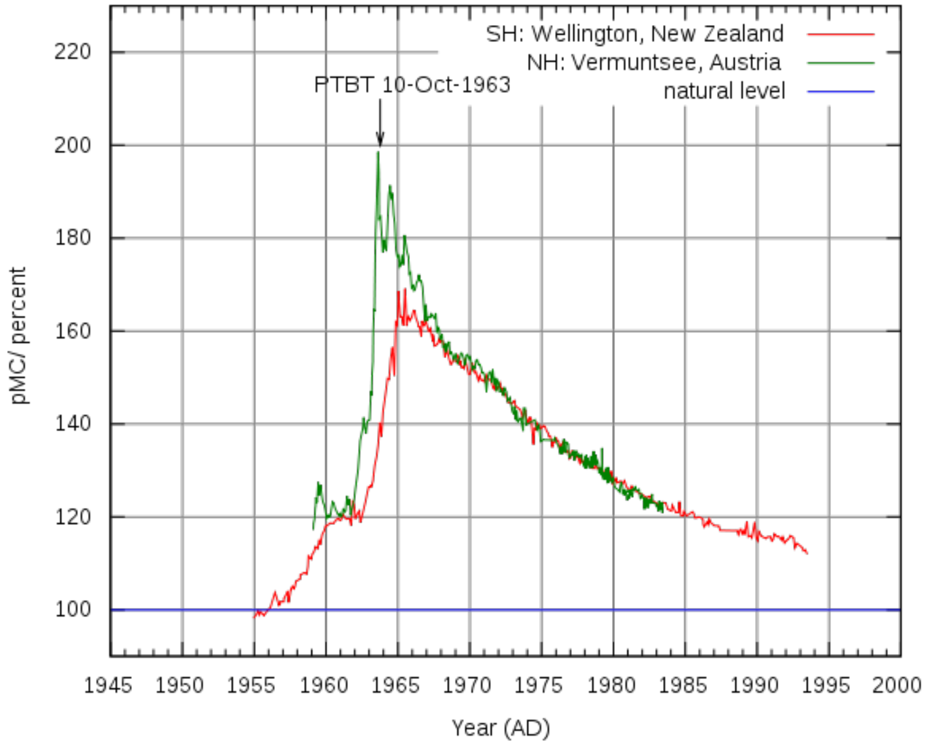
β^+ decay can occur when the mass of parent atom exceeds that of daughter atom by at least twice the mass of the electron

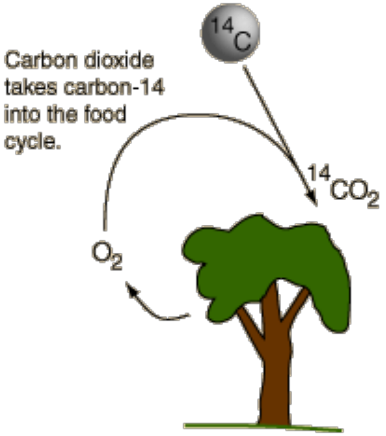
Radiocarbon dating

$$^{14}\mathrm{C} \rightarrow {}^{14}\mathrm{N} + e^{-} + \bar{\nu}_e$$

half-life of 5730 years

Radiocarbon dating is a radiometric dating method that uses ^{14}C to determine the age of carbonaceous materials up to about 60,000 years old. The technique was developed by Libby and his colleagues in 1949. In 1960, Libby was awarded the Nobel Prize in chemistry for this work. The level of ^{14}C in plants and animals when they die approximately equals the level of ^{14}C in the atmosphere at that time. However, it decreases thereafter from radioactive decay.





Atmospheric nuclear weapon tests almost doubled the concentration of ^{14}C in the Northern Hemisphere. The date that the Partial Test Ban Treaty (PTBT) went into effect is marked on the graph.