Electromagnetic Rates

$$B(\lambda; J_i\zeta \to J_f\xi) = \sum_{\mu M_f} \left| \langle J_f M_f \zeta | O_{\lambda\mu} | J_i M_i \xi \rangle \right|^2 = \frac{1}{2J_i+1} \left| \langle J_f \zeta \| O_{\lambda\mu} \| J_i \xi \rangle \right|^2$$

$$O_{\lambda\mu}(E\lambda) = \sum_{i=1}^{A} e(i) r_i^{\lambda} Y_{\lambda\mu}(\Omega_i) \qquad \vec{j}_i = \vec{s}_i + \vec{l}_i$$

$$O_{\lambda\mu}(M\lambda) = \sum_{i=1}^{A} \left[g_s(i)\vec{s}_i + g_l(i)\frac{2\vec{l}_i}{\lambda+1} \right] \vec{\nabla}_i \left[r_i^{\lambda} Y_{\lambda\mu}(\Omega_i) \right]$$

gyromagnetic factors

Selection Rules

$$\frac{\mathcal{W}(\lambda+1)}{\mathcal{W}(\lambda)} \sim (kR)^2$$

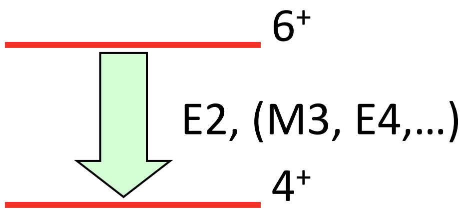
large reduction in probability
with increasing multipolarity order!

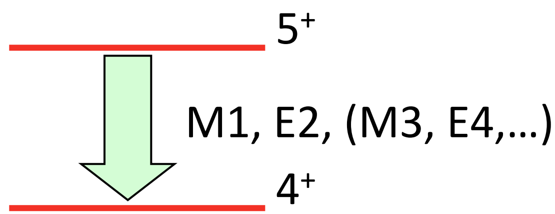
$$|J_f - J_i| \leq \lambda \leq J_f + J_i$$

$$PO_{\lambda\mu}(E\lambda)P^{-1} = (-1)^{\lambda} O_{\lambda\mu}(E\lambda), \quad PO_{\lambda\mu}(M\lambda)P^{-1} = (-1)^{\lambda+1} O_{\lambda\mu}(M\lambda)$$

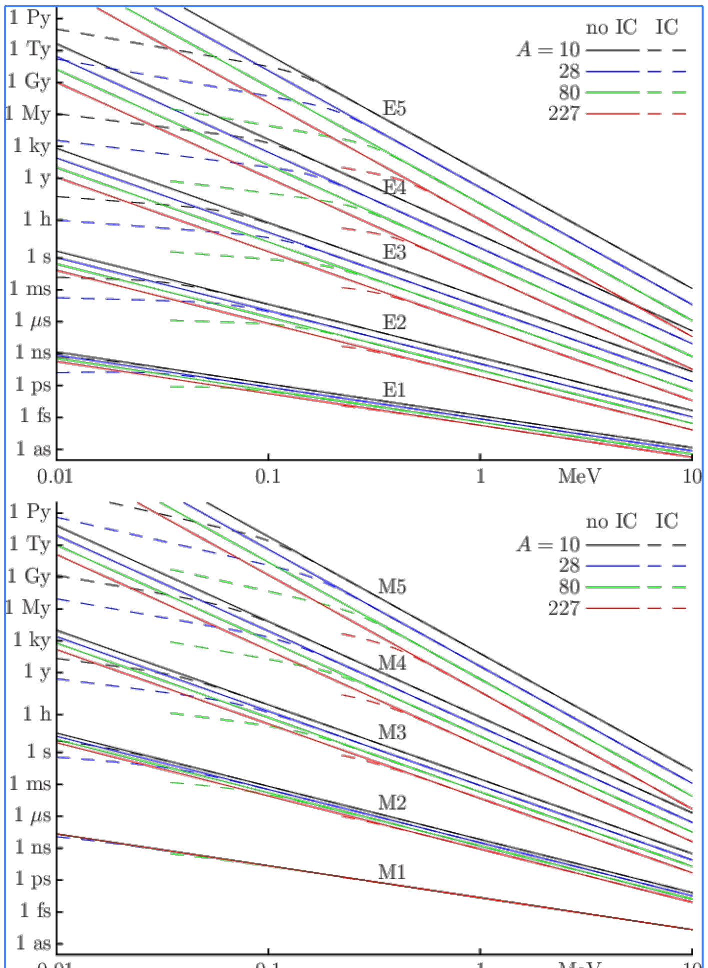
$$\pi_i \pi_f = (-1)^{\lambda} \qquad \pi_i \pi_f = (-1)^{\lambda+1}$$

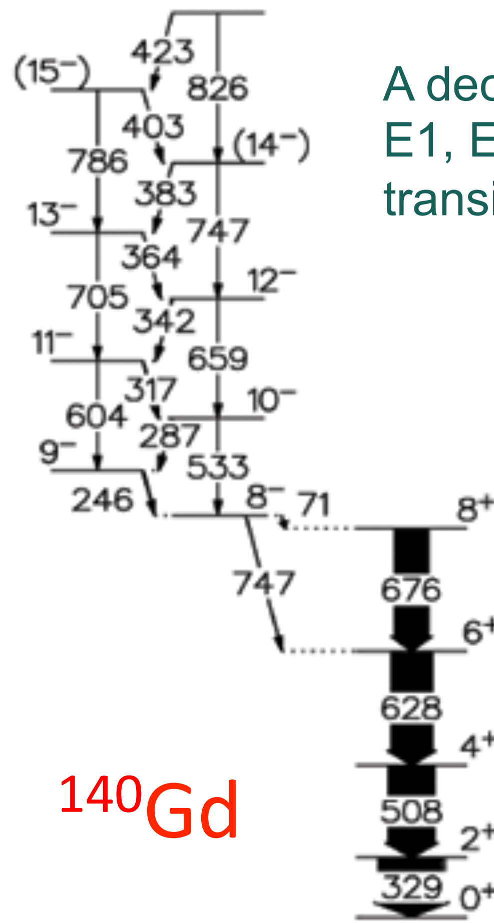
Magnetic transitions are weaker than electric transitions of the same multipolarity





mixed M1+E2 transition





A decay scheme: E1, E2 and M1 transitions

^{140}Gd

HW: What is the radiative width corresponding to:

a) 1 fs
b) 1ps
c) 1ns

gamma decays? Find the radiative widths of the lowest 0^+, 2^+, 4^+, and 6^+ states of ^{166}Er. What are the corresponding recoil energies?

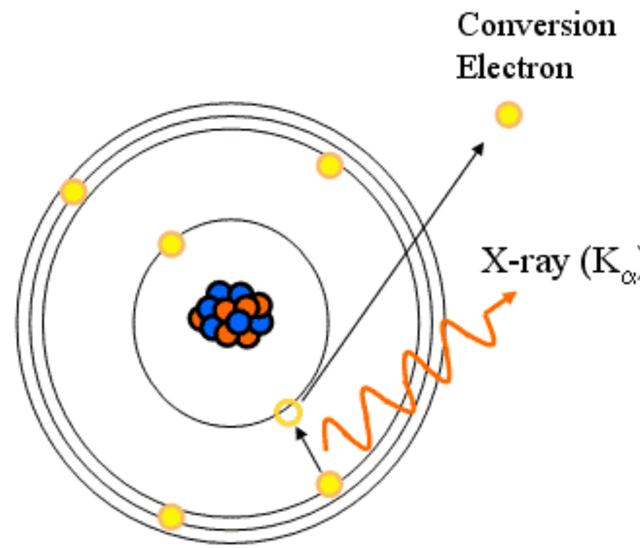
Internal conversion

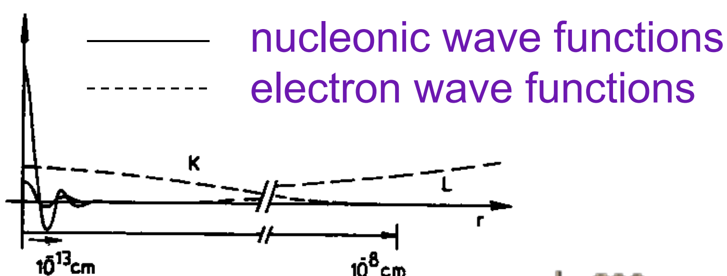
An atomic electron is ejected instead of gamma-ray (atomic Auger effect). Atomic electrons, especially those in the inner orbits, such as K- and L-orbits, spend a large fraction of their time in the vicinity of the nucleus, the source of the EM field.

$$T_{e^-} = \left(E_i - E_f\right) - B_n$$

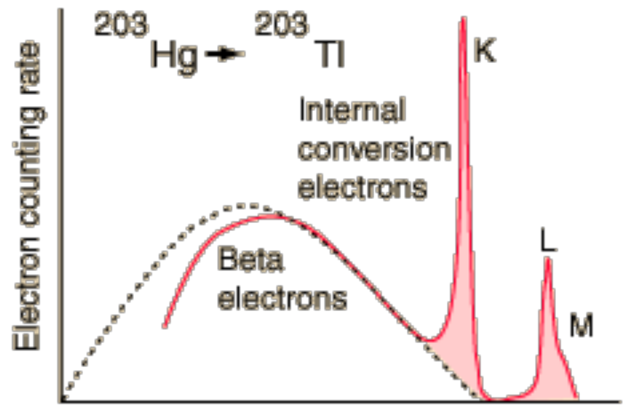
Electron kinetic energy

Electron binding energy





Virtual photon exchange. This process can occur between I=0 states!



Electron spectrum: internal conversion + beta-decay background

Important for heavy nuclei (large Z): it goes as Z^3 !!!

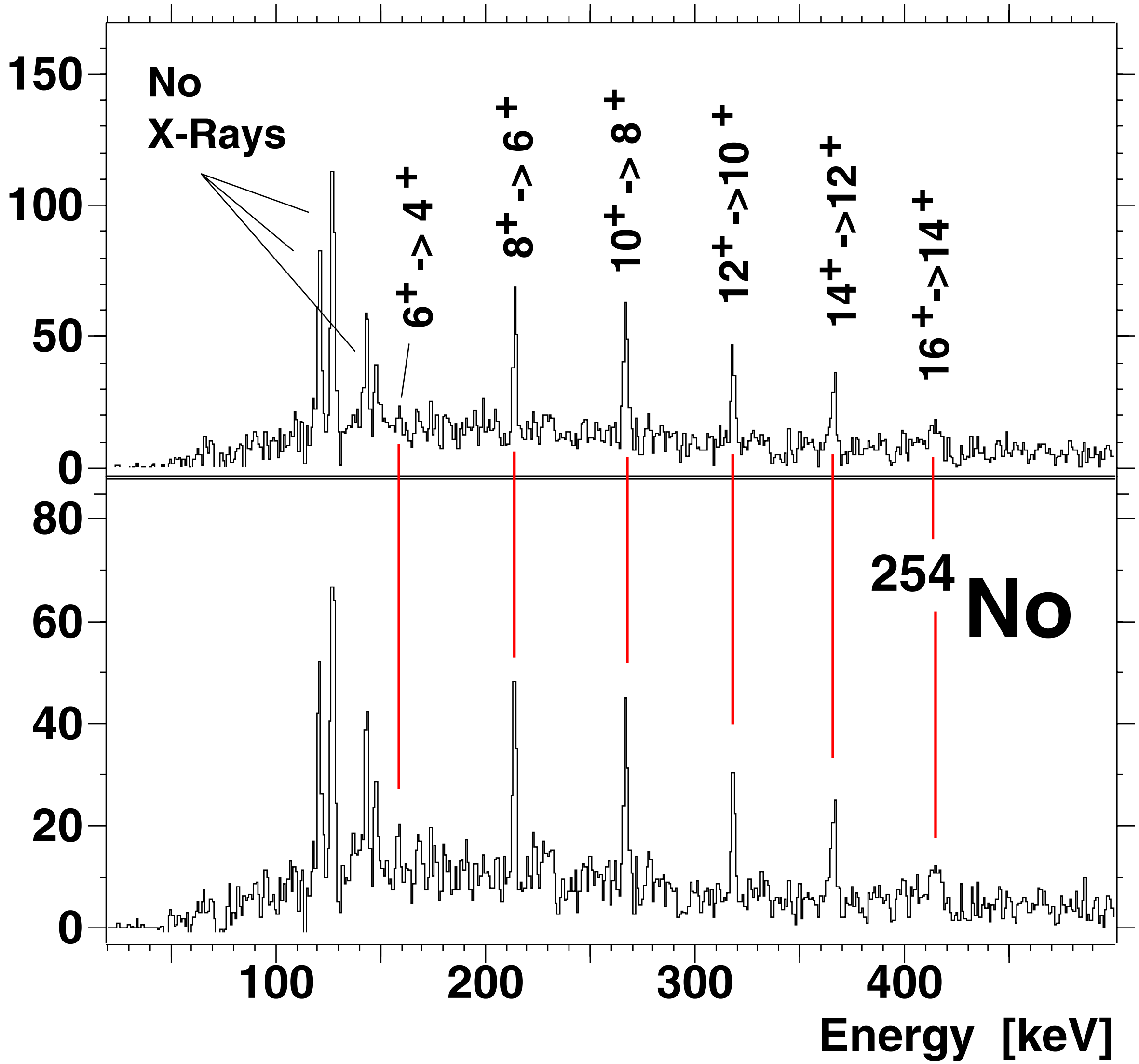


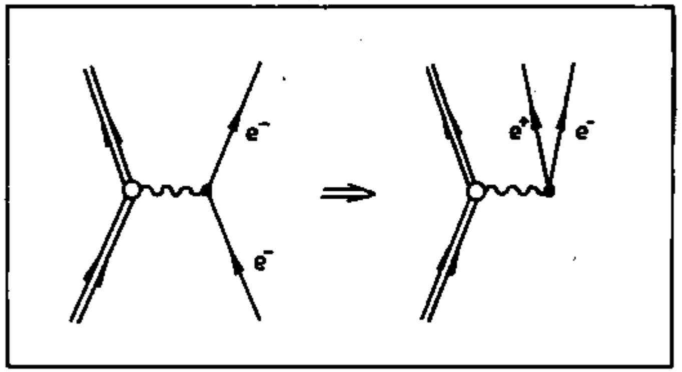
Fig. 20. A singles γ-ray spectrum (upper) from the ^{48}Ca + ^{208}Pb reactions gated with fusion-evaporation residues. The same γ-ray spectrum but in addition, tagged with the ^{254}No α decays (lower)

Internal pair production

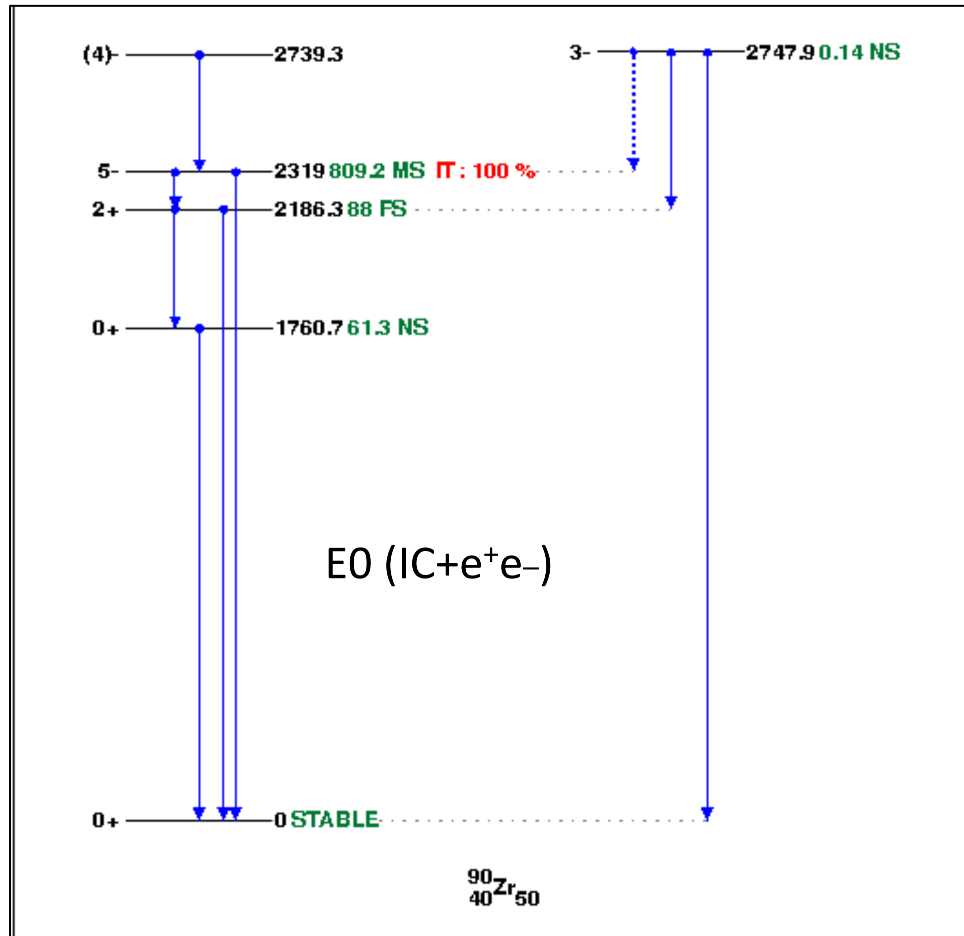
An electron-positron pair is emitted in the place of gamma-ray. This can happen if the energy of the decay

$$E_\gamma > 2m_e c^2 = 1.02\text{MeV}$$

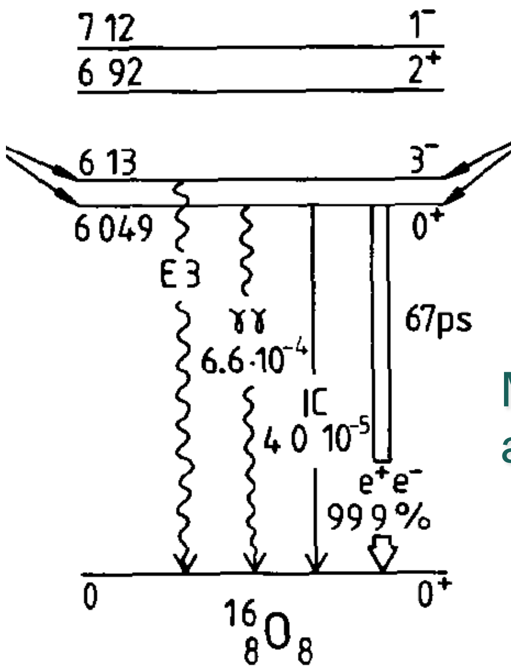
electron scattering pair creation



Usually, this process is several orders of magnitude retarded compared to allowed gamma-ray decays. The pair production rate is largest where the internal conversion rate is smallest. That is in the region of low atomic number and high transition energies.



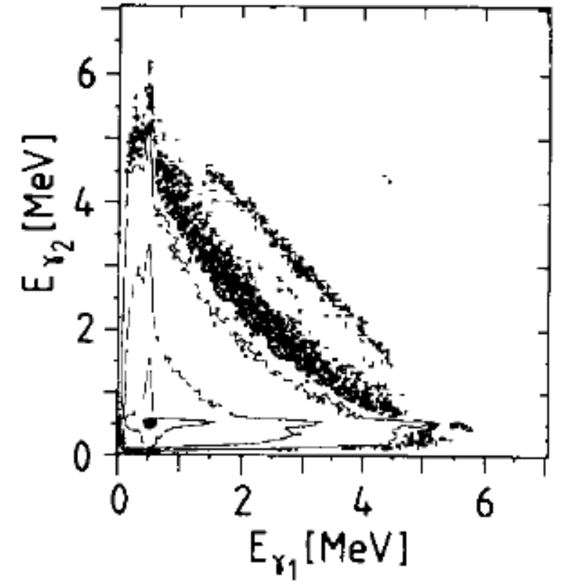
2-gamma decay



$\gamma\gamma$ = 2E1+2M1

M1 and E1 transitions
are similar in strength!

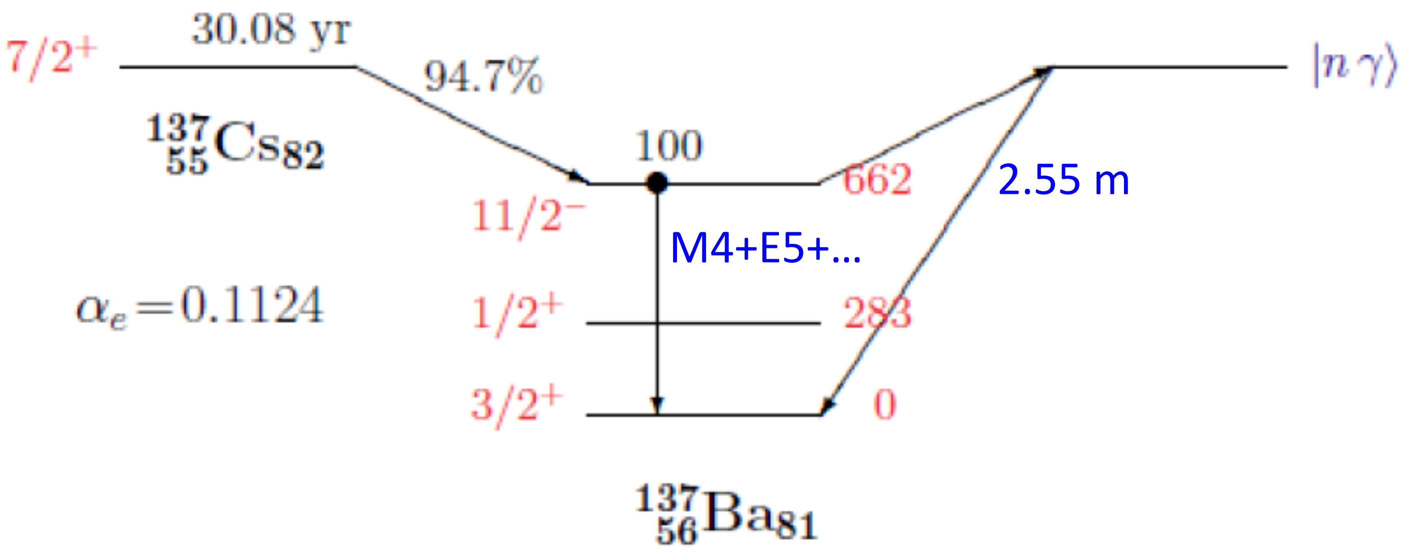
Nucl. Phys. A474, 412 (1987)



Best candidates: ^{16}O, ^{40}Ca, ^{90}Zr

Provides important structural information about nuclear electric polarizability and diamagnetic susceptibility.

^{137}Cs is formed as one of the more common fission products by the nuclear fission of ^{235}U. About 95% decays by beta emission to a metastable ^{137m}Ba. It has a number of practical uses…



In ^{16}O, ^{40}Ca, ^{90}Zr, $\gamma\gamma$ = E1⊕E1+M1⊕M1

In ^{137}Ba, $\gamma\gamma$ = E2⊕M2+E1⊕M3+M1⊕E3

Just measured: Waltz et al., Nature 526, 406 (2015)

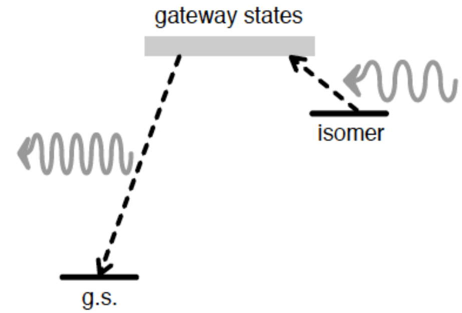
http://www.nature.com/nature/journal/v526/n7573/abs/nature15543.html

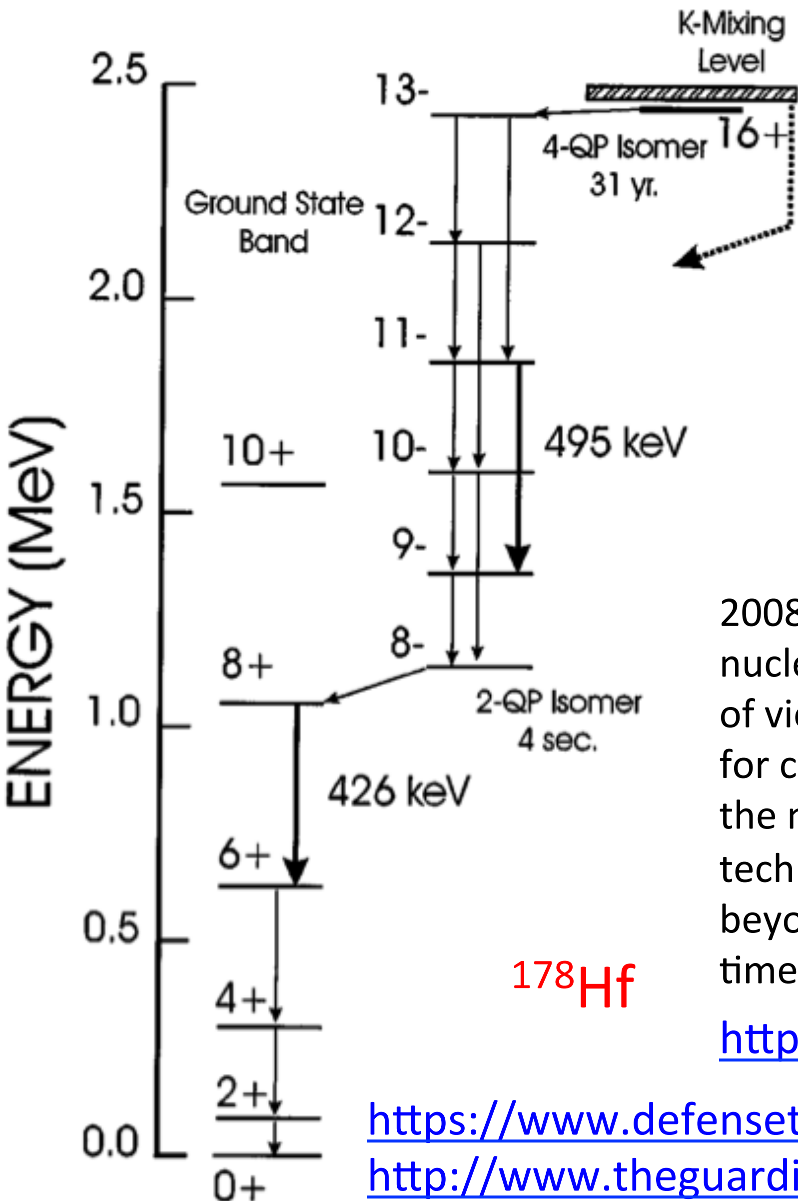
http://www.nature.com/nature/journal/v526/n7573/full/526330a.html

http://phys.org/news/2015-10-competitive-double-gamma-nuclear.html

γ-ray laser?

http://physics.aps.org/synopsis-for/10.1103/PhysRevA.84.053429





Hafnium-178m has a long half-life of 31 years and a high excitation energy of 2.4 MeV. As a result, 1 kilogram of pure ^{178m}Hf contains approximately 10^{12} J of energy. Some estimates suggest that, with accelerated decay, 1 gram of 100-percent isomeric ^{178m}Hf could release more energy than the detonation of 200 kilograms of TNT.

2008 LLNL report: "Our conclusion is that the utilization of nuclear isomers for energy storage is impractical from the points of view of nuclear structure, nuclear reactions, and of prospects for controlled energy release. We note that the cost of producing the nuclear isomer is likely to be extraordinarily high, and that the technologies that would be required to perform the task are beyond anything done before and are difficult to cost at this time."

https://str.llnl.gov/str/JulAug05/Becker.html

https://www.defensetech.org/2006/06/13/superbomb-or-crapshoot/
http://www.theguardian.com/science/2008/aug/14/particlephysics.research
http://journals.aps.org/prc/abstract/10.1103/PhysRevC.82.034607