Week 6 Lecture 3 – Nuclear Energy Levels

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Gamma Radiation

-- Industrial Applications of Radiation
-- Internal Transitions revisited
-- Nuclear Energy Levels
-- Mössbauer Spectroscopy

5th Homework
due Monday

Atomium, Brussels, Belgium

Photons Emission Review

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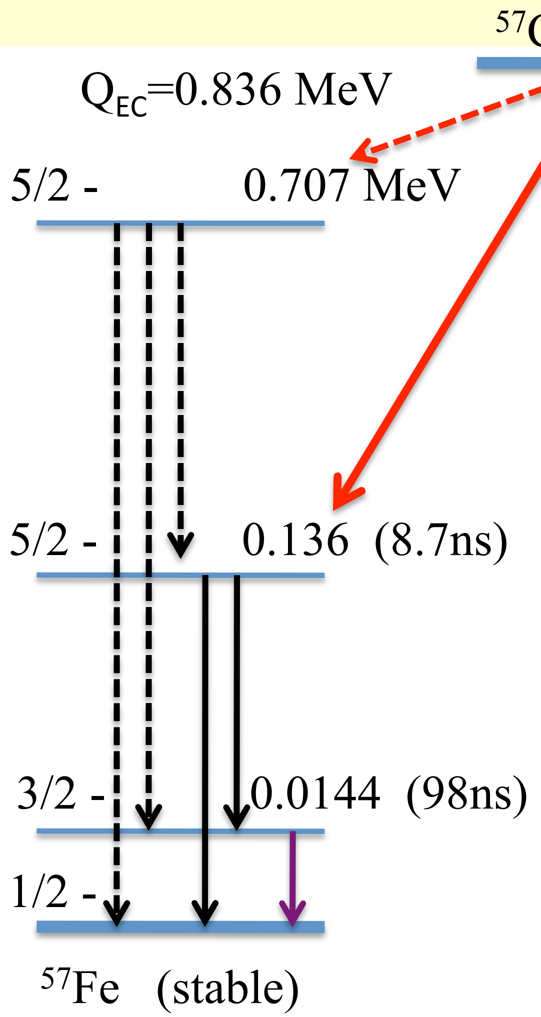

Notes about this decay:

^{57}Co $\pi(1f_{7/2}^{7})\,\nu(2p_{3/2}^{2})$ or $\pi(1f_{7/2}^{-1})\,\nu(2p_{3/2}^{2})$

Electron Capture only, not enough energy for β+

Allowed beta decay from 7/2- to 5/2- state

Subsequent photon decay:

5/2- to 1/2- E_γ= 0.136 MeV (E2 type)

or

5/2- to 3/2- E_γ=0.122 MeV (M1)

followed by 3/2- to 1/2- E_γ=0.014 MeV (M1)

$\lambda_{SP}(M1) = 3.15\text{x}10^{13}\, E_\gamma^{3}$ /s

$T_{½}(M1) = \ln 2/\lambda_{SP} = 2.20\text{x}10^{-14}\, E_\gamma^{-3}$ (s)

$7.37\text{x}10^{-9}$ s for 0.0144 MeV M1

^{57}Fe $\pi(1f_{7/2}^{6})\,\nu(2p_{3/2}^{3})$ or $\pi(1f_{7/2}^{6})\,\nu(2p_{3/2}^{-1})$ or $\pi(1f_{7/2}^{-2})\,\nu(2p_{3/2}^{-1})$

Photon Emission Causes Recoil

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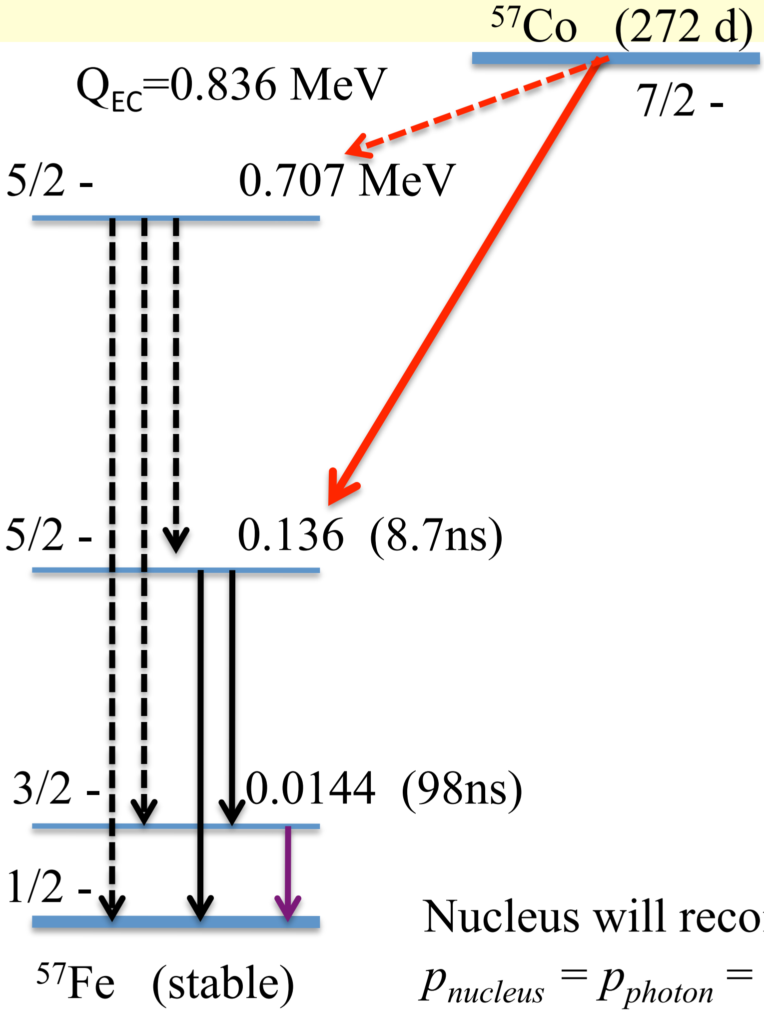
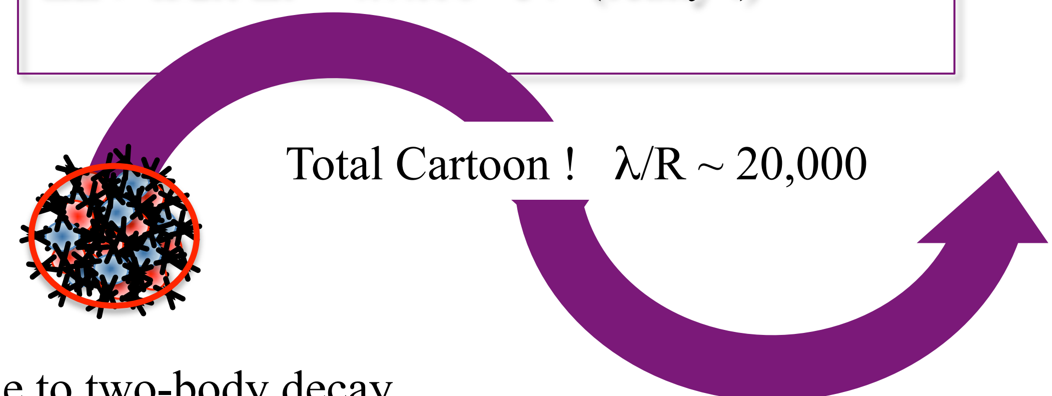


Fig. 9-10
in the text

Focus on the low energy photon decay to g.s.:
3/2- to 1/2- E_γ=0.014 MeV (M1)

R = 1.2 $A^{1/3}$ fm = 4.6fm
$\lambda = hc/E_\gamma = 8.6\text{x}10^{-11}$ m = $8.6\text{x}10^{4}$ fm

Intrinsic uncertainty (linewidth), $\Delta E\ \Delta t > h/2\pi$
$\Delta E > h/2\pi\ \Delta t = 4.7\text{x}10^{-9}$ eV (really !)



Nucleus will recoil due to two-body decay

$$p_{nucleus} = p_{photon} = E_\gamma/c$$

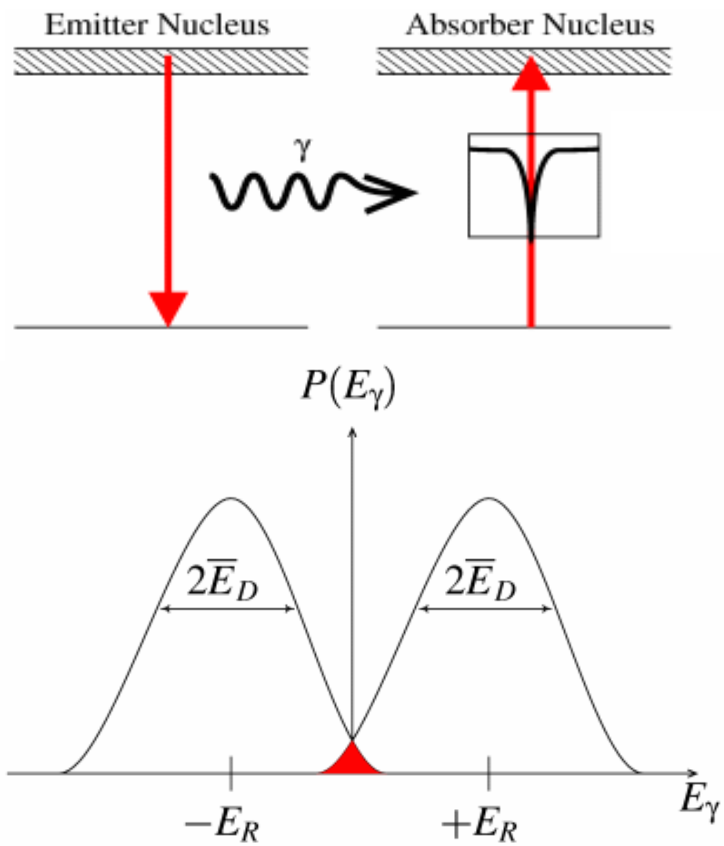
$$p_{nucleus} = \sqrt{2mT} = \frac{E_\gamma}{c}$$

$$T = \frac{E_\gamma^2}{2mc^2} = \frac{0.0144\,MeV}{2*57*c^2*931.5\,MeV/uc^2} = 0.136x10^{-6}\,MeV$$

(E_R = 0.14 eV)

Can Nuclei Absorb Photons?

There is no reason to think that the emission of photons by a nucleus cannot be reversed. However, the energy necessary to excite nuclear energy levels is so large that only the emission by another nucleus will match.



$E_R = 0.14$ eV

Fig. 9-9 in the text

We might imagine that a photon could travel from one to another and be absorbed but we just calculated the recoil energy. It is small but essentially blocks the absorption because it enters twice.

The energy of the recoil is small but is not too far away from the thermal energy available in thermal motion in a gas. Emission from a moving nucleus will be Doppler shifted and have a distribution width:

$\sigma^2 \sim E_\gamma^2 \, k_B T / mc^2$ where m is the nucleus

$k_B T = 0.025$ eV at room temperature

$\sigma \sim 0.01$ eV for ^{57}Fe

Mössbauer's Idea

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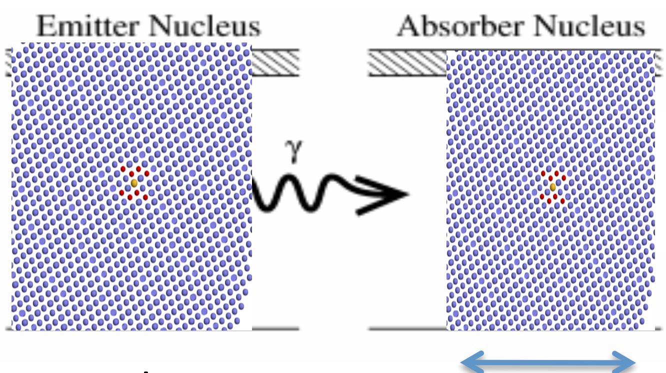
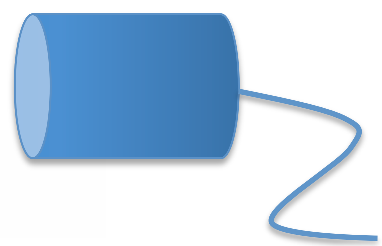
Lock down the emitting nucleus in a metal lattice. The recoil energy from these photons is small compared to chemical bond energies (in contrast to α or β decay) and the mass of the entire lattice absorbs the recoil energy. Thus, effectively no recoil. Good enough to use twice.

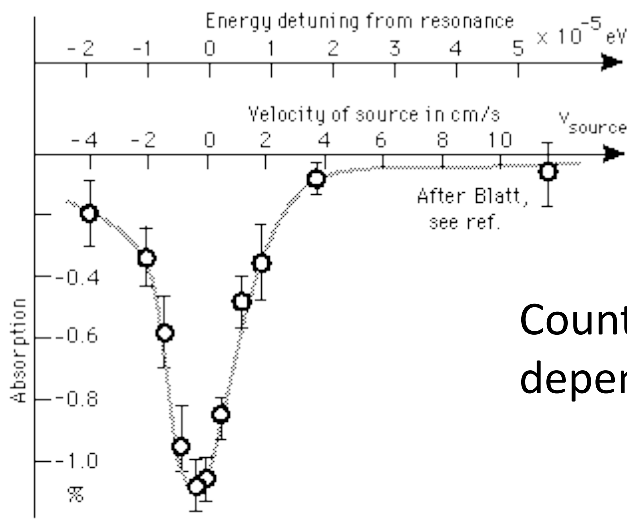


Radiation Detector



Rigid

Move (back/forth)



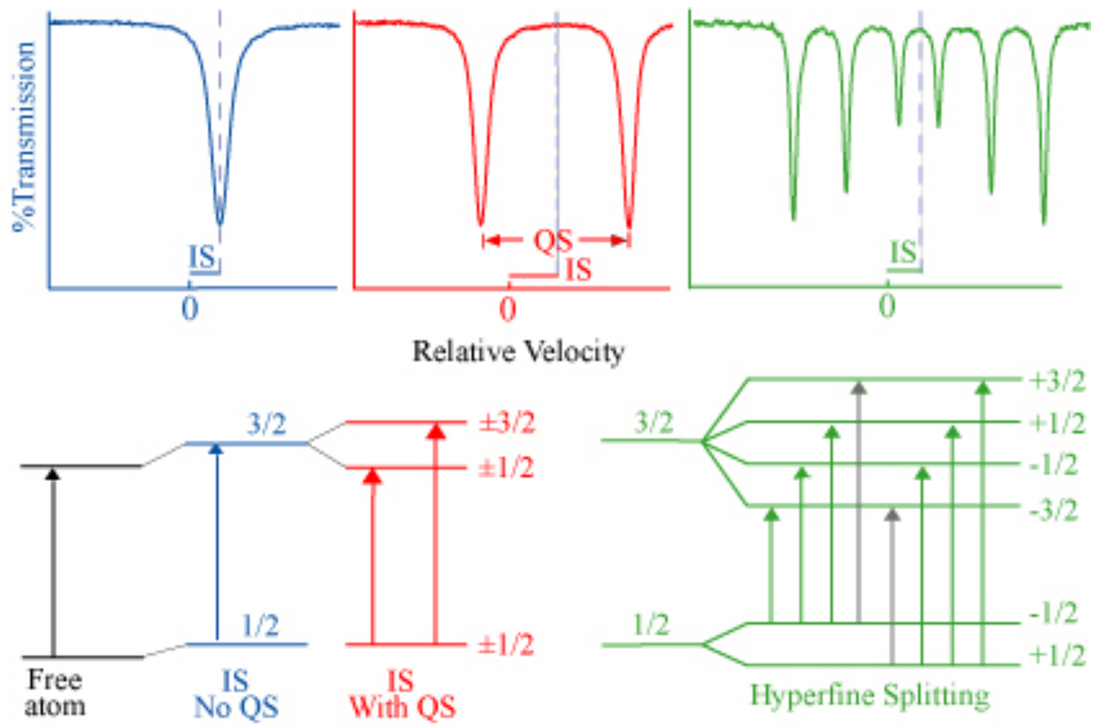
Counting rate in Radiation Detector is dependent on absorber velocity.

Observed Spectra

When source and absorber atoms are in different local environments, their nuclear energy levels are slightly different. The simplest effect (blue) is a shift of the minimum away from zero velocity in the transmission spectrum called isomer shift (IS). Interaction of the nuclear quadrupole moment with the electric field gradient leads to splitting of the nuclear energy levels (red). For ^{57}Fe, this causes individual peaks in the transmission spectrum to split into doublets (red). When a magnetic field is present at the nucleus, Zeeman splitting takes place, yielding a sextet pattern (green); in the simplest case, the areas of the lines should vary in the ratio of 3:2:1:1:2:3.

Observed absorption

Nuclear energy levels
Isotope shift – atomic
quadrupole shift – nuclear
hyperfine splitting – atomic



http://serc.carleton.edu/research_education/geochemsheets/techniques/mossbauer.html