Mössbauerov efekt

Uvod

- Rezonantno raspršenje γ-zračenja na atomskim jezgrama
- Veoma precizna mjerenja na energetskoj skali
- Komplikacije …
- Primjena …

Udarni presjek za raspršenje (apsorpciju) elektromagnetskog zračenja energije E na jezgri

$$\sigma_{rasp.} = \sigma_0 \frac{\Gamma_\gamma^{\ 2}}{4(E - E_r)^2 + \Gamma^2}$$

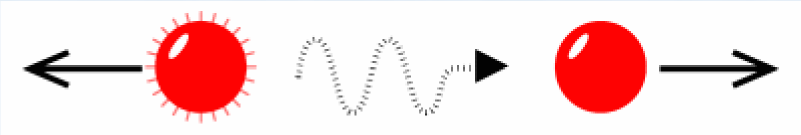
$$\sigma_{aps.} = \sigma_0 \frac{\Gamma \Gamma_\gamma}{4(E - E_r)^2 + \Gamma^2}$$

- Γ širina pobuđenog stanja
- Γ_γ parcijalna širina za emisiju gama zračenja
- Nuklearna stanja su "uska" $\Delta E = 10^{-7}$eV
- $E_r \sim$MeV
- Rezonantno ponašanje

Energija odboja i uvjet za rezonantno ponašanje

$$\vec{P} = -\vec{p}$$

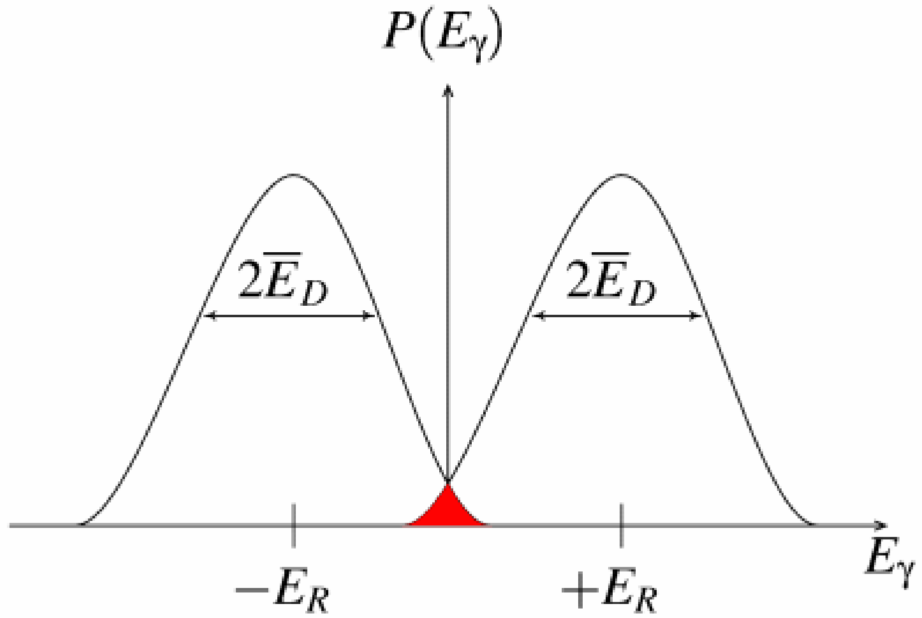
$$R = \frac{P^2}{2M} = \frac{p^2}{2M} = \frac{1}{2M}\left(\frac{E_\gamma}{c}\right)^2$$



$$\Gamma \geq 2R$$

Primjer

- A=100
- E_γ=66keV
- R=0.02eV
- $\Gamma=10^{-7}$ eV



Treba spriječiti odboj ako želimo rezonantno ponašanje!!!

Uloga Dopplerova efekta

Impuls izvora P_i

$$R' = \frac{(\vec{P}_i - \vec{p})^2}{2M} - \frac{P_i^2}{2M} = \frac{p^2}{2M} - \frac{\vec{p}\vec{P}_i}{M}$$

Pokrata

$$\varepsilon = \frac{P_i^2}{2M}$$

$$D = 2\sqrt{\varepsilon R}$$

$$E_\gamma = E_r - R' = E_r - R + D\cos\phi$$

Proširenje linije reda veličine

$$\overline{D} = 2\sqrt{\varepsilon\, R}$$

Problem

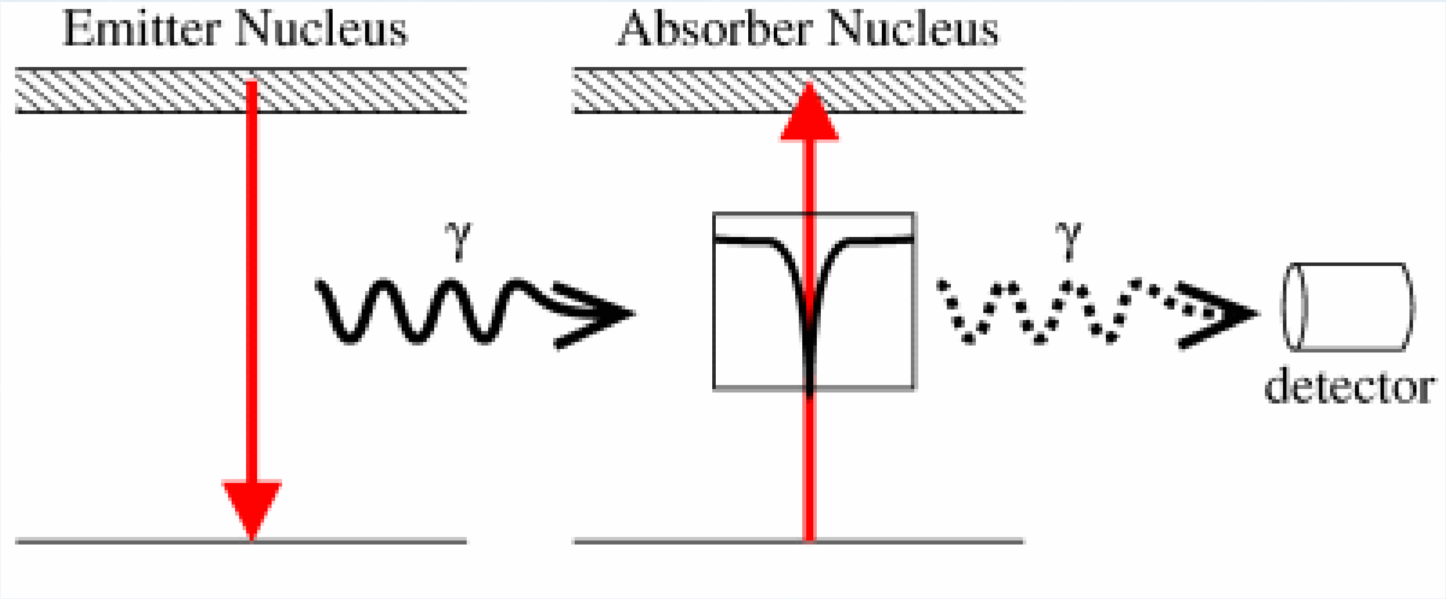
Pojava Dopplerova proširenja malo povećava vjerojatnost rezonantne apsorpcije ali bitno umanjuje rezonantni efekt smanjujući snažno rezonantni vrh

Za optimalno korištenja rezonantnog raspršenja trebalo bi istovremeno eliminirati odboj i smanjiti Dopplerov efekt

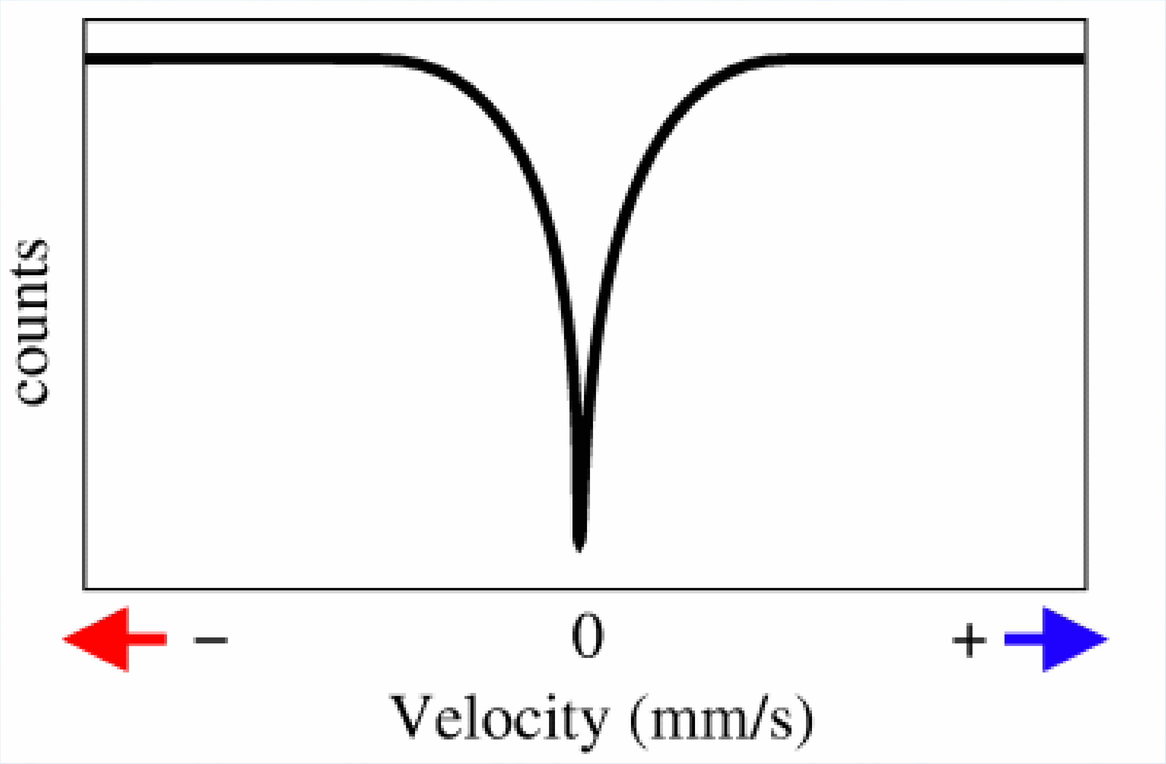
“Recoil-free” emisija ili apsorpcija

Jezgra se nalazi u čvrstoj matrici (kristalu) koji je pothlađen

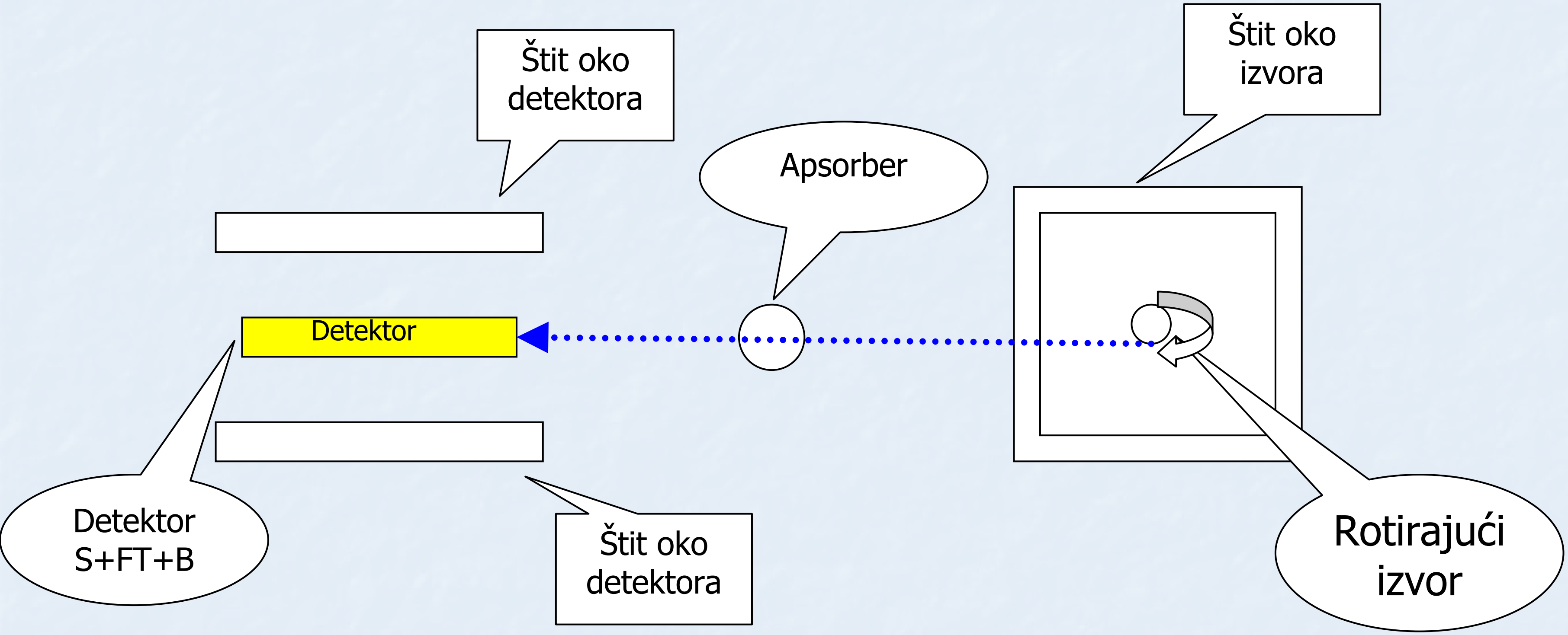
Mössbauerov spektar za identični izvor i apsorber

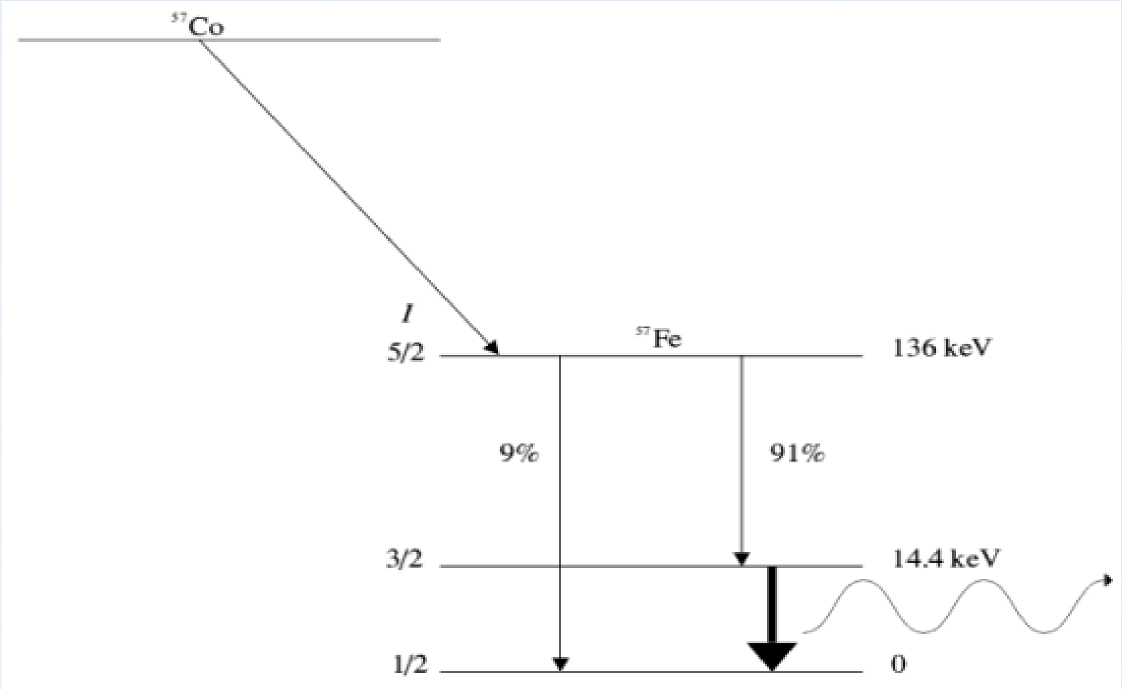


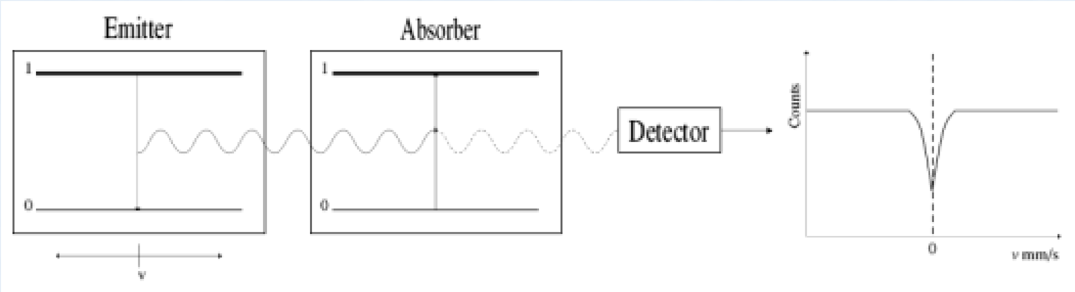
Jednostavni spektar - ovisnost relativnog gibanja izvora



Shema eksperimentalnog uređaja







Raspad ^{57}Co to ^{57}Fe za 14.4 keV Mössbauerovu gama zraku. Za izotop ^{57}Fe širina linije iznosi $5x10^{-9}$eV. U usporedbi s Mössbauerovom energijom gama zračenja od 14.4 keV dobivamo rezoluciju u omjeru $1:10^{12}$

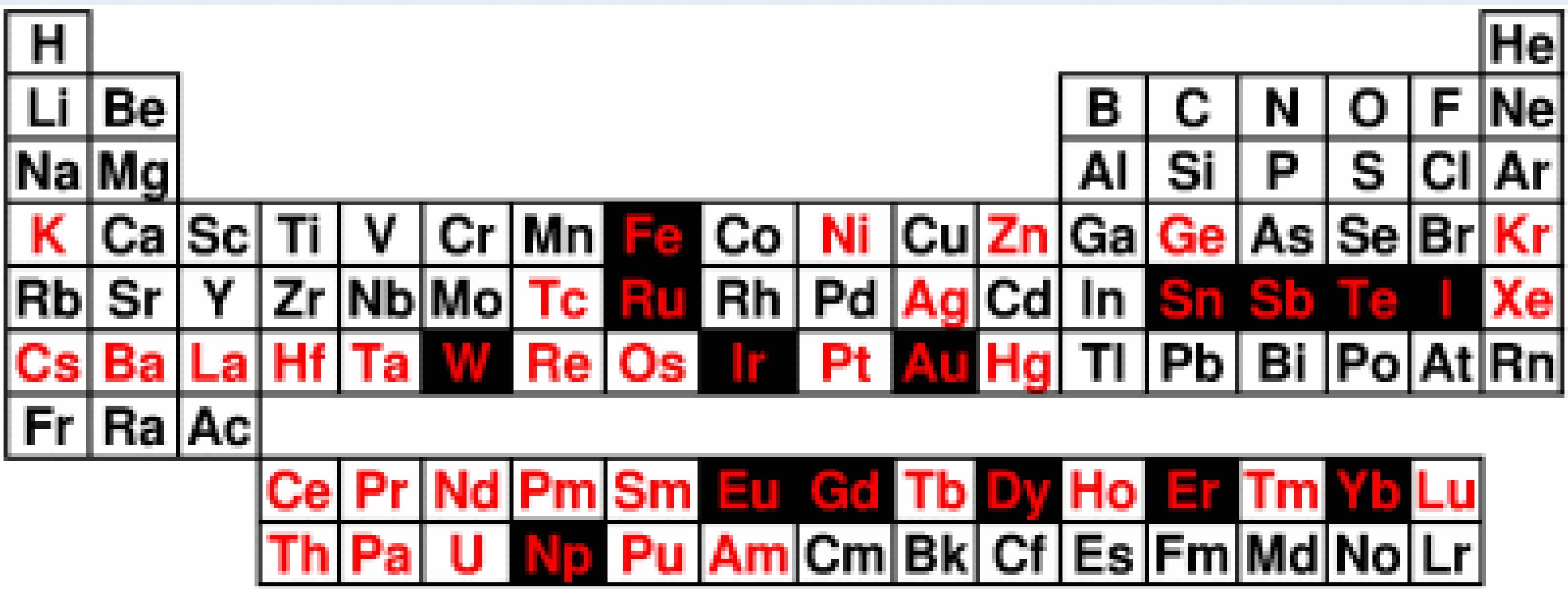
Eksperimentalni uređaj

Modulacija - Uvjeti

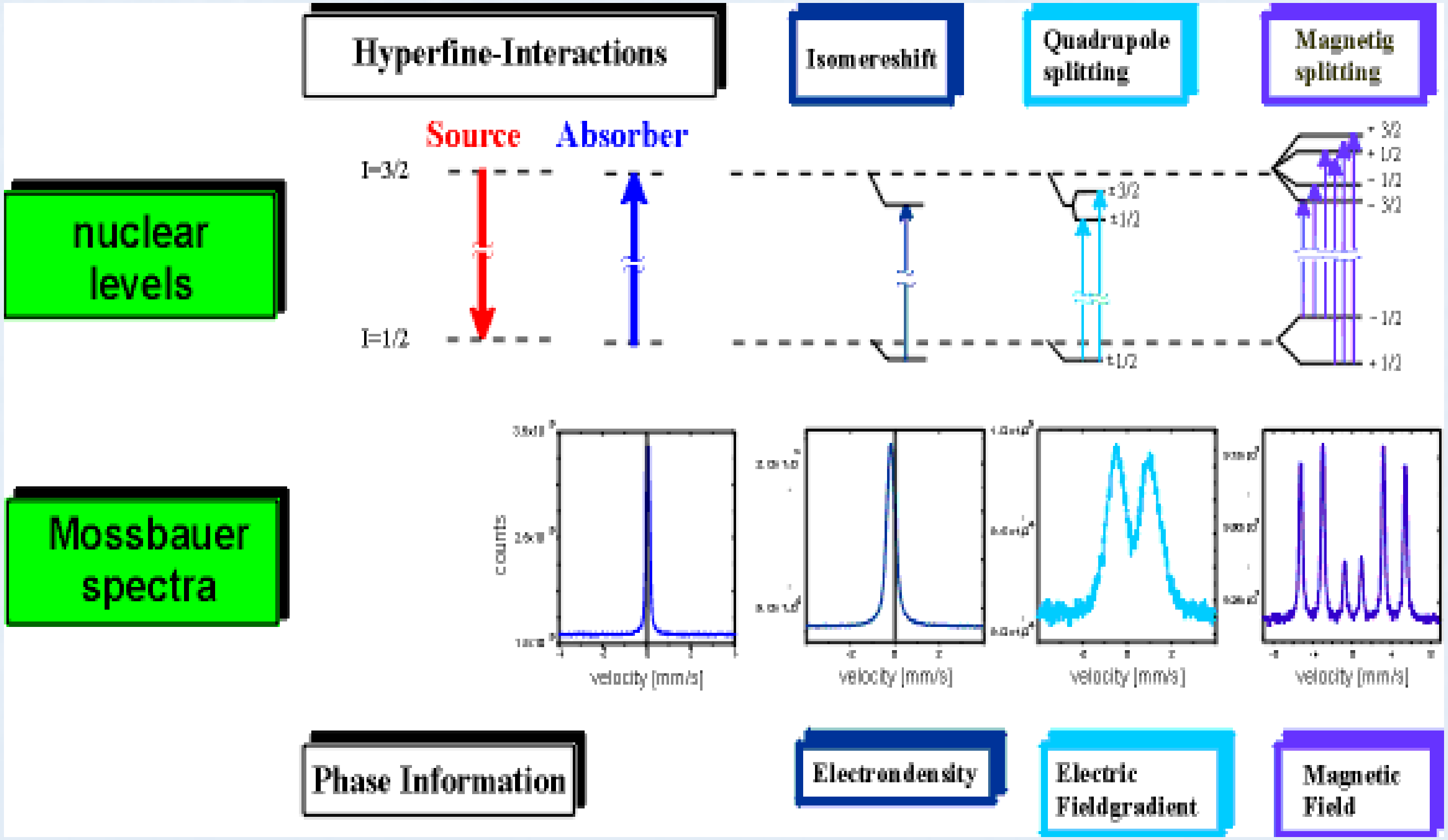
- Izomerski pomak
- Kvadrupolno cijepanje
- Magnetsko cijepanje

- Nuklearna stanja moraju imati različite radijuse
- Elektronska stanja moraju imati dobaro prekrivanje s jezgrom (*s*-stanja)
- Valne funkcije moraju biti osjetljive na vanjsku (kemijsku) promjenu

Rudolph L. Mössbauer 1957
Nobelova nagrada 1961



Elements of the periodic table which have known Mössbauer isotopes (shown in red font).
Those which are used the most are shaded with black


Hyperfine-Interactions
Isomereshift
Quadrupole splitting
Magnetig splitting
Source
Absorber
I=3/2
I=1/2
nuclear levels
Mossbauer spectra
counts
velocity [mm/s]
velocity [mm/s]
velocity [mm/s]
velocity [mm/s]
Phase Information
Electrondensity
Electric Fieldgradient
Magnetic Field

Izomerni pomak

- The isomer shift arises due to the non-zero volume of the nucleus and the electron charge density due to s-electrons within it. This leads to a monopole (Coulomb) interaction, altering the nuclear energy levels. Any difference in the s-electron environment between the source and absorber thus produces a shift in the resonance energy of the transition. This shifts the whole spectrum positively or negatively depending upon the s-electron density, and sets the centroid of the spectrum.
- As the shift cannot be measured directly it is quoted relative to a known absorber. For example ^{57}Fe Mössbauer spectra will often be quoted relative to alpha-iron at room temperature.
- The isomer shift is useful for determining valency states, ligand bonding states, electron shielding and the electron-drawing power of electronegative groups. For example, the electron configurations for Fe^{2+} and Fe^{3+} are (3d)6 and (3d)5 respectively. The ferrous ions have less s-electrons at the nucleus due to the greater screening of the d-electrons. Thus ferrous ions have larger positive isomer shifts than ferric ions.

Izomerni pomak

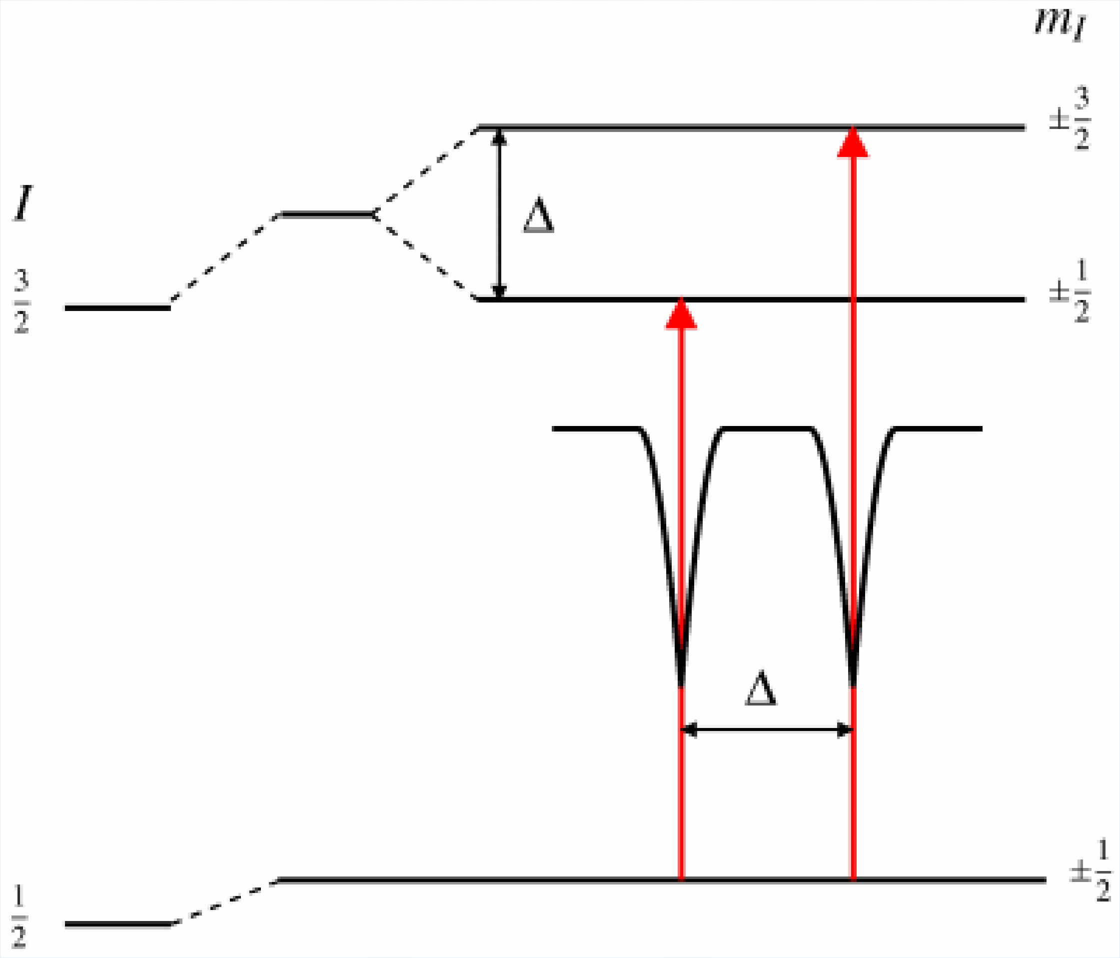
$$\delta = \left(\frac{Z.e^2.R^2.c}{5.\varepsilon_0.E_\gamma}\right).\left[\rho_a(0) - \rho_s(0)\right].\left[\frac{\Delta R}{R}\right]\ mm\ s^{-1}$$

- Z- redni broj,
- e- naboj elektrona,
- R- efektivni radijus nukleona,
- c- brzina svjetlosti,
- E_γ- energija Mössbauerovog gama kvanta
- $\rho(0)$ gustoća (elektronska) stanja oko jezgre za izvor i apsorber
- $\Delta R = R_{pobuđeno} - R_{osnovno}$.

Kvadrupolno cijepanje

- Nuclei in states with an angular momentum quantum number I>1/2 have a non-spherical charge distribution. This produces a nuclear quadrupole moment. In the presence of an asymmetrical electric field (produced by an asymmetric electronic charge distribution or ligand arrangement) this splits the nuclear energy levels. The charge distribution is characterised by a single quantity called the Electric Field Gradient (EFG).
- In the case of an isotope with a I=3/2 excited state, such as ^{57}Fe or ^{119}Sn, the excited state is split into two substates mI=±1/2 and mI=±3/2.
- The magnitude of splitting, Δ, is related to the nuclear quadrupole moment, Q, and the principle component of the EFG, V_{zz}, by the relation $\Delta = eQV_{zz}/2$.

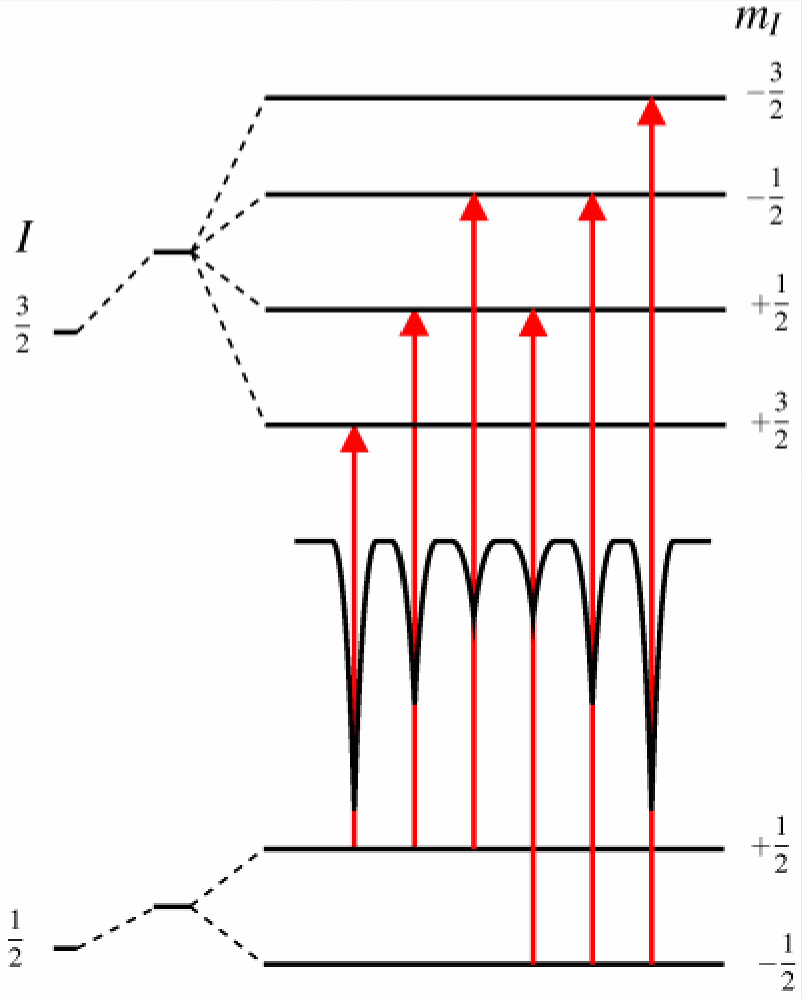
Shema kvadrupolnog cijepanja



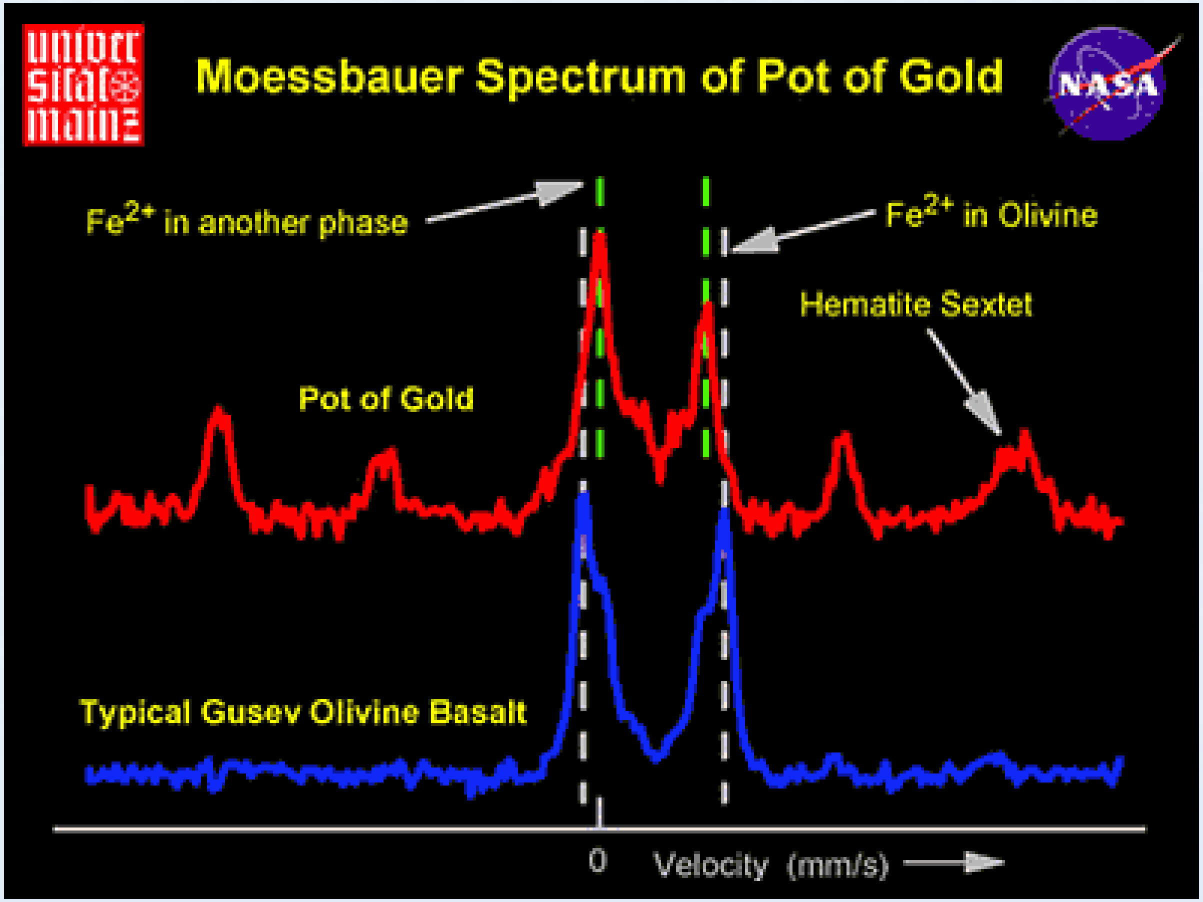
Magnetsko cijepanje

- In the presence of a magnetic field the nuclear spin moment experiences a dipolar interaction with the magnetic field ie Zeeman splitting. There are many sources of magnetic fields that can be experienced by the nucleus.
- This magnetic field splits nuclear levels with a spin of I into (2I+1) substates. Transitions between the excited state and ground state can only occur where mI changes by 0 or 1.
  The line positions are related to the splitting of the energy levels, but the line *intensities* are related to the angle between the Mössbauer gamma-ray and the nuclear spin moment.

Shema magnetskog cijepanja



Primjena – istraživanje Marsa



Laboratorijsko opažanje gravitacijskog pomaka

- $M=E/c^2$ – “masa fotona”
- $\Delta E/E = mgh/mc^2 = gh/c^2$

Literatura - www

http://www.cmp.liv.ac.uk/techniques_mossbauer.php
http://www.webres.com/mossbauer.html
http://faculty.knox.edu/cschulz/M%C3%B6ssbauer/index.html
http://physics.berea.edu/~lahamer/Mossbauer.html
Http://www.mossp2000.com/effect/index.html#

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