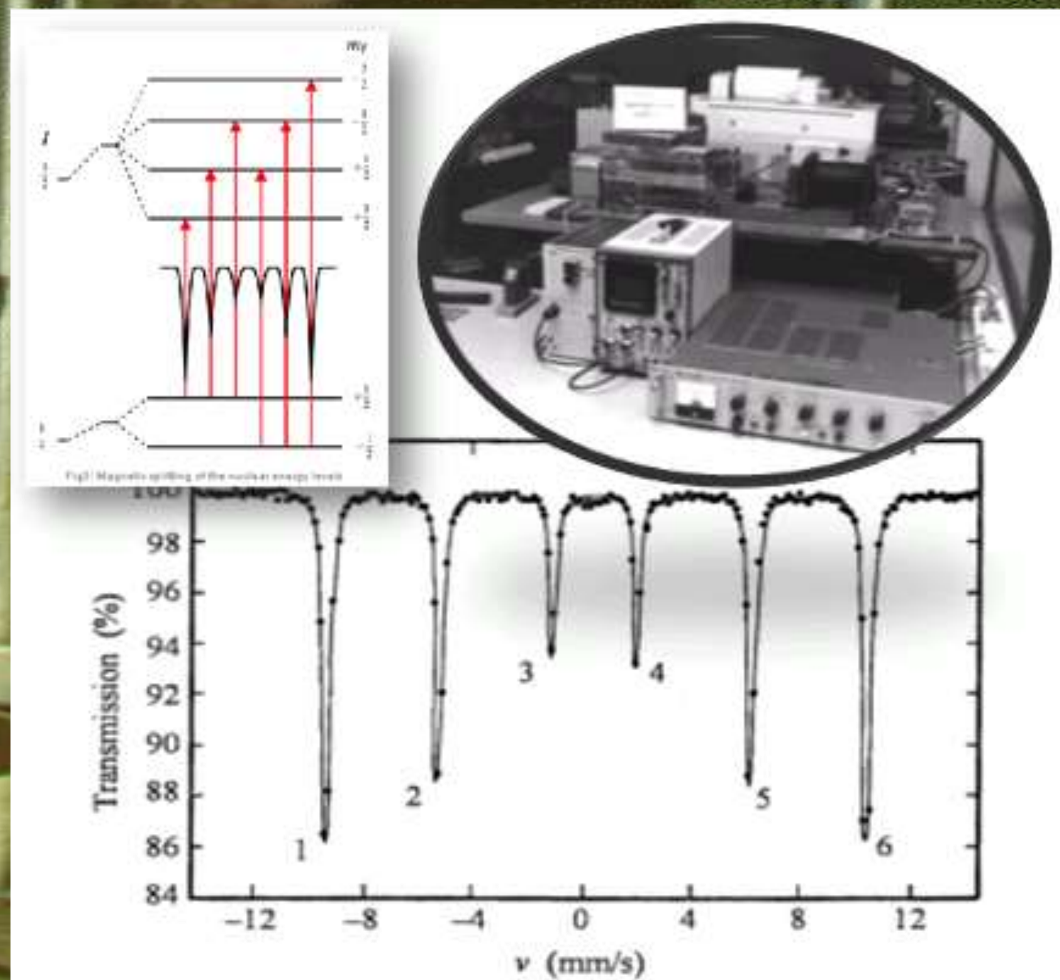
Mőβbauer Spectroscopy



Agenda: ANSEL Mössbauer Experiment

Möβbauer (Mössbauer) Spectroscopy with proportional counters:

Ultra-high-precision photon energy measurement:
Precision scanning resonant-absorption spectroscopy
with doppler-shifted photon energy, using gas amplification counters.

- Gas amplification counters, proportional counters, electronics.

- Mössbauer Principles:

Resonant γ absorption.

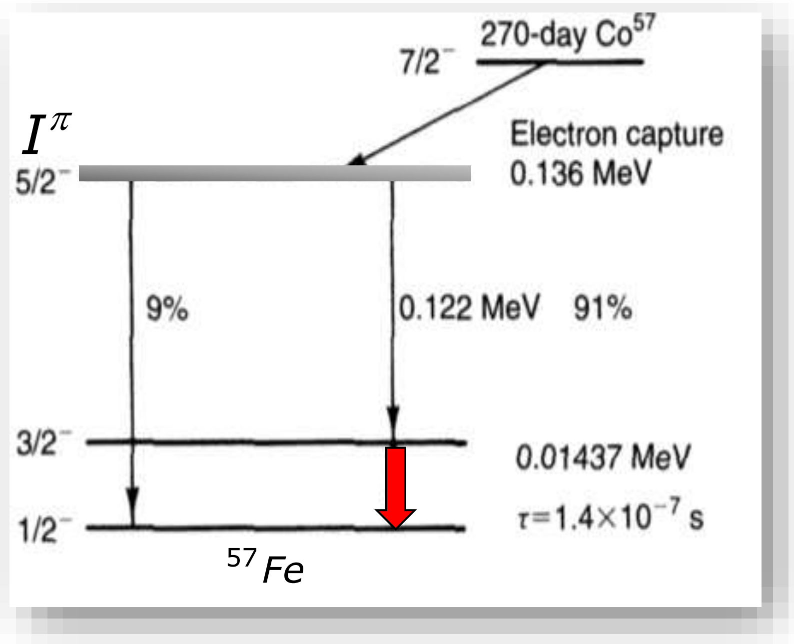
Recoil effects in γ emission and absorption,

Recoilless γ absorption by macroscopic samples,

- Determination of electric and magnetic HF interactions in various chemical Fe compounds

Reading Assignments:
(Knoll, LN): X ray spectroscopy with proportional counters (PC),
E_γ-dependent absorption coefficients, gas amplification counters,
Response of proportional counters to γ - and X rays, spurious peaks.

Precision Absorption Spectroscopy with ^{57}Fe



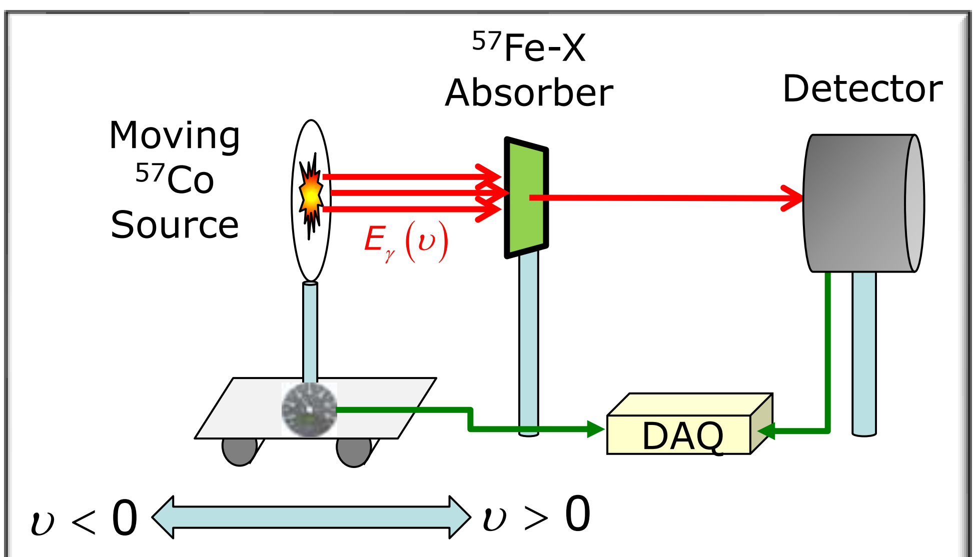
^{57}Co *source emits* $14.4-keV\ \gamma-rays$

Measure scanning resonance absorption with Doppler – tunable γ – ray energies

→ *chemical compounds with* ^{57}Fe

Resolving power $\Gamma/E_{\gamma} = 3\cdot 10^{-13}$

γ *detectors* : $\Gamma_{FWHM}/E_{\gamma} \sim 10^{-3} - 10^{-2}$

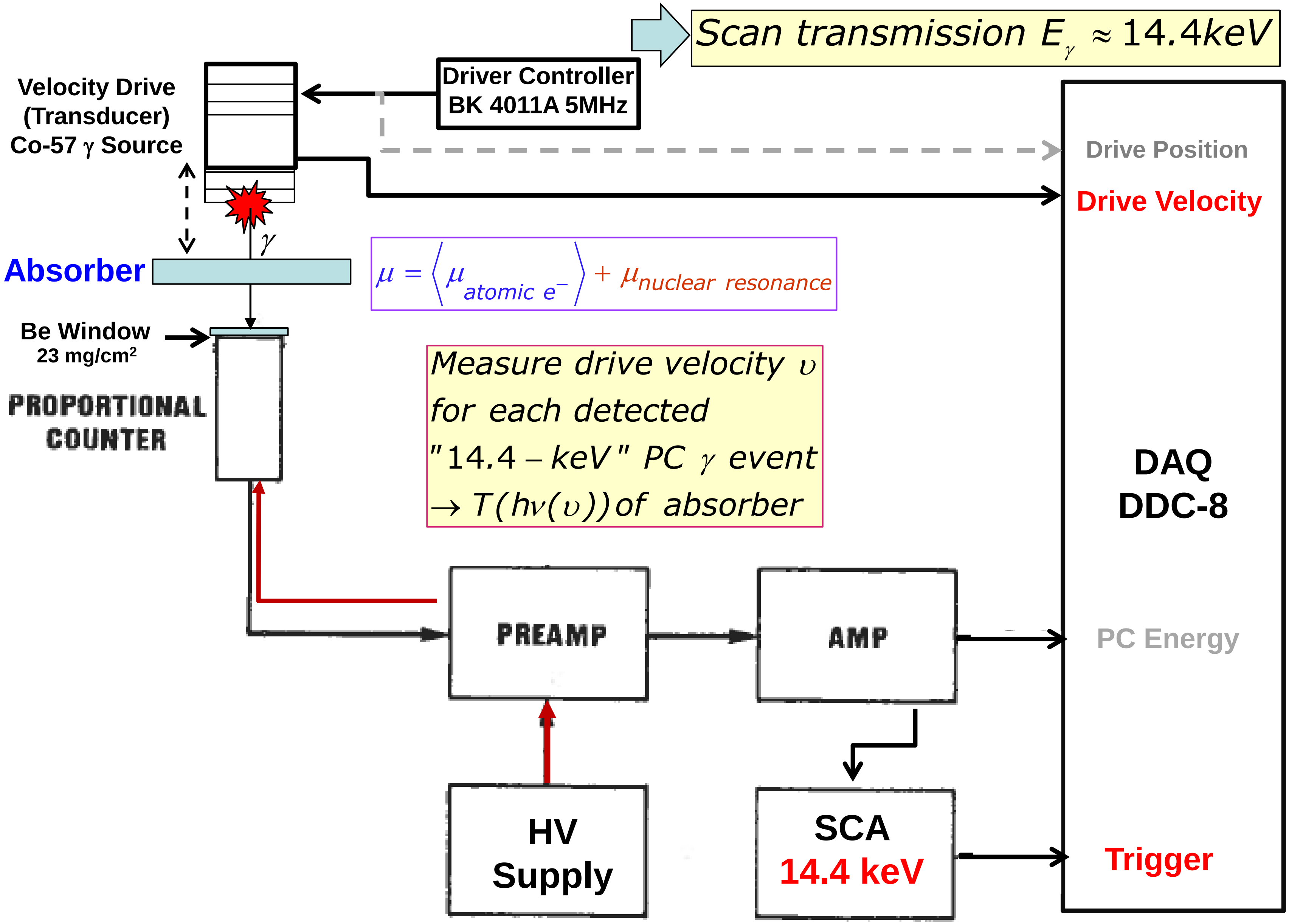


^{57}Co *source moving with velocity* υ *emits precisely controlled Doppler – shifted* $E_{\gamma}(\upsilon)$

"Tunable" γ – rays

$E_{\gamma}(\upsilon) = 14.4(1 \pm \upsilon/c)\,keV$

Mőβbauer Experiment DAQ Setup



Intro to MB Principles/ANSEL Setup/Tasks

Experimental and analytical tasks

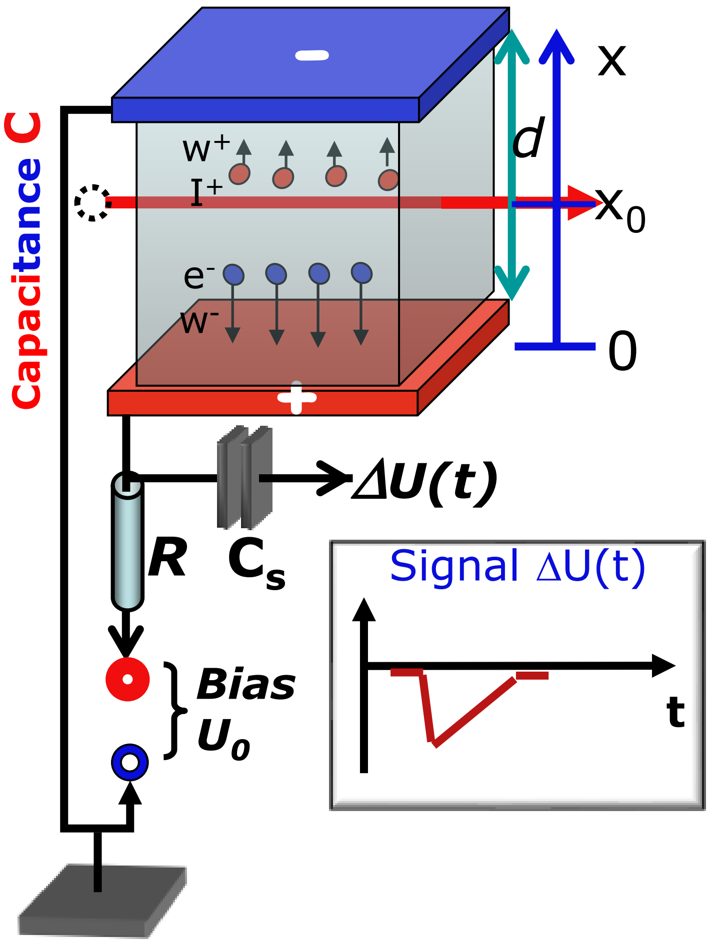
- Set up electronics for PC
- Calibrate PC for very low γ energies (absorber method)
- Identify characteristic spectral features of PC

- Adjust transducer frequency to mechanical drive resonance
- Measure transducer velocity (interpret spectral features, absorber method)

- **Goals/Theory**: Hyperfine interactions → Lifting of level degeneracy through interaction with external fields
- Functionality of ANSEL setup for scanning absorption spectroscopy
- Explain/interpret shape and specific features of velocity spectra:
  1) no absorbers or non-resonant ("background") absorption,
  2) resonant absorption for specific Fe compound absorbers,
  3) method of background correction.
- Deduce isomer shift, electric quadrupole and magnetic HF interaction energies and related nuclear electric/magnetic moments for given chemical Fe environments.

Signal Generation in Gas Amplification Counters

Primary ionization: **Gases** I ≈ 20-30 eV/IP, **Si**: I ≈ 3.6 eV/IP **Ge**: I ≈ 3.0 eV/IP



Energy loss Δε: $n = n_I = n_e = \Delta\varepsilon / I$ number of ***n*** primary ion pairs (I^+, e^-) *at* x_0, t_0

Electrostatic force: $F_e = -eU_0/d = -F_I$

Energy content of detector capacitance C:

$$1)\; W(t) = \frac{C}{2}\left[U_0^2 - U^2(t)\right] \approx CU_0 \Delta U(t)$$

$$2)\; W(t) = n_e F_e\left[x_e(t) - x_0\right] + n_I F_I\left[x_I(t) - x_0\right]$$

$$= +\frac{neU_0}{d}\left[x_I(t) - x_e(t)\right]$$

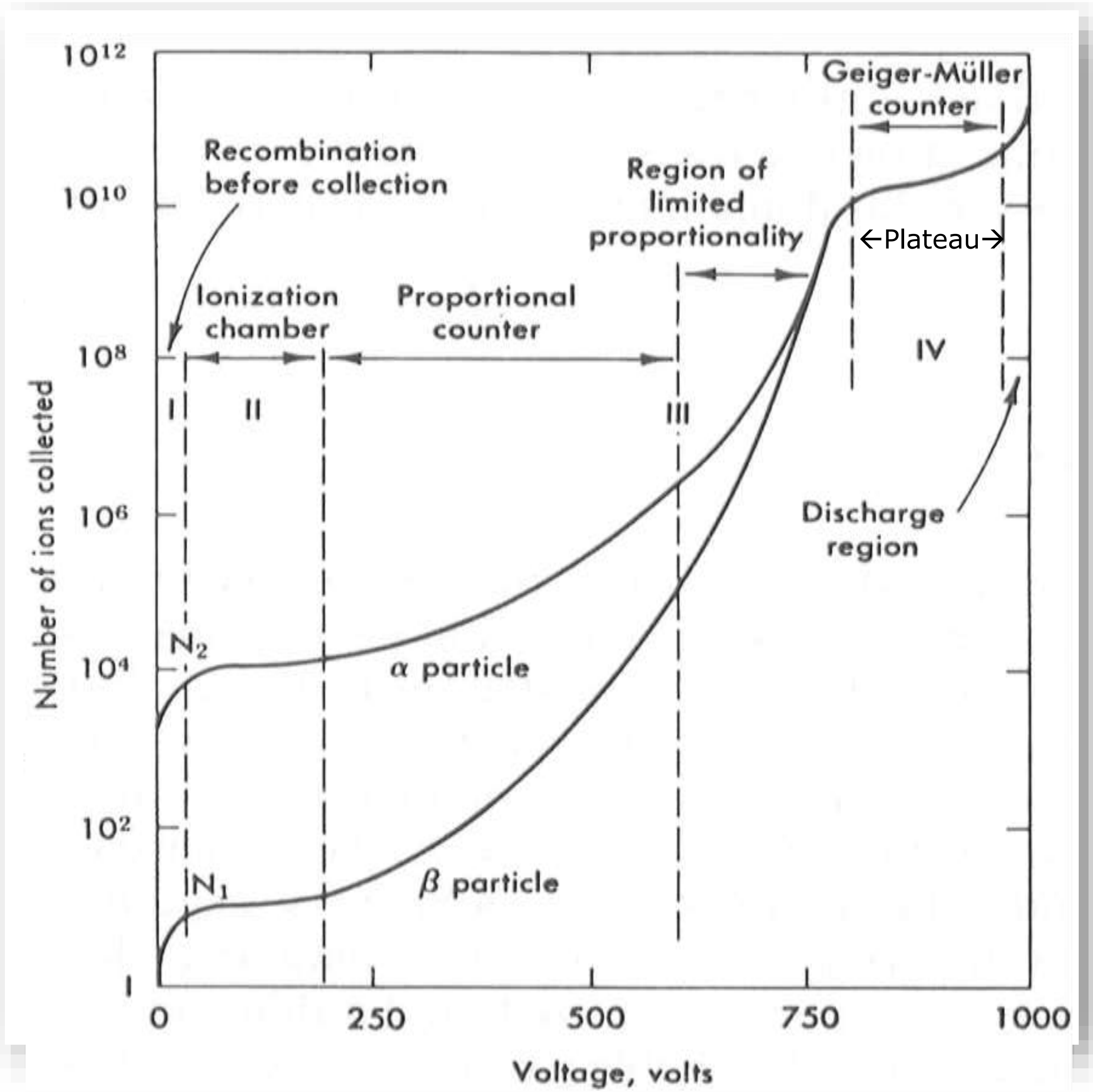
$w^+(t)(t-t_0)$ $w^-(t)(t-t_0)$

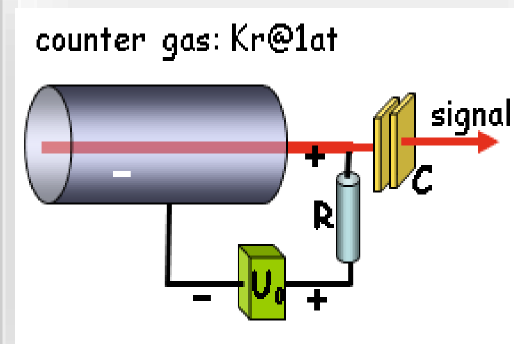
1) + 2) ↘

$$\Delta U(t) = \frac{W(t)}{CU_0} = \frac{ne}{Cd}\left[\cancel{w^+(t)} - w^-(t)\right](t - t_0)$$

$w^\pm$ Drift Velocities

Gas Counters



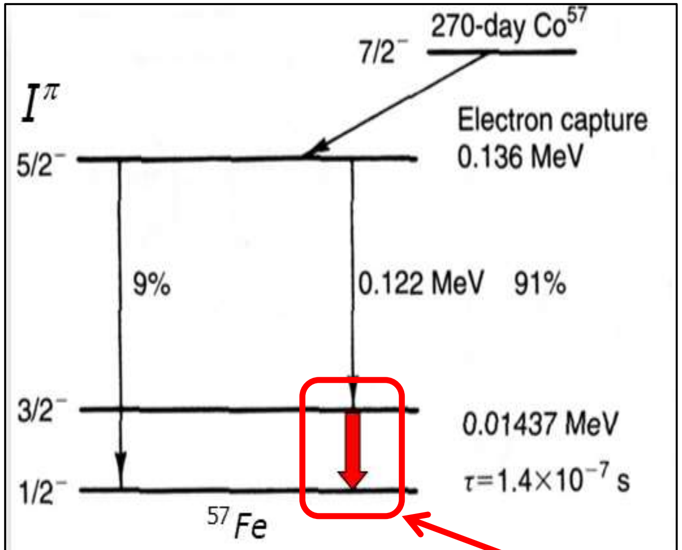


Most commercial counters are permanently sealed.

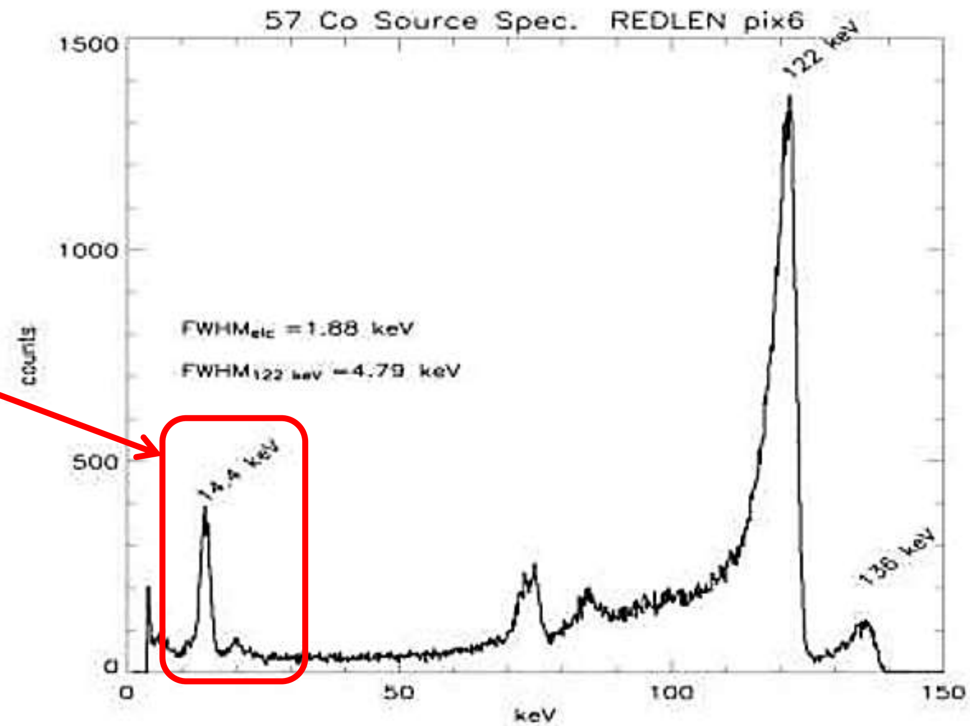
Exponential increase of signal amplitude with voltage.

Moderate (10%) resolution, but economic counter.

Experimental Task



Measure very small differences in $3/2^- \rightarrow 1/2^-$ transition energy depending on differences of environments of ^{57}Fe nuclei embedded in source and absorber.
Scanning resonance absorption spectroscopy.



Measurement with CdZnTe (CZT) solid-state detector.

ANSEL Mössbauer experiment uses a (Kr) gas PC.

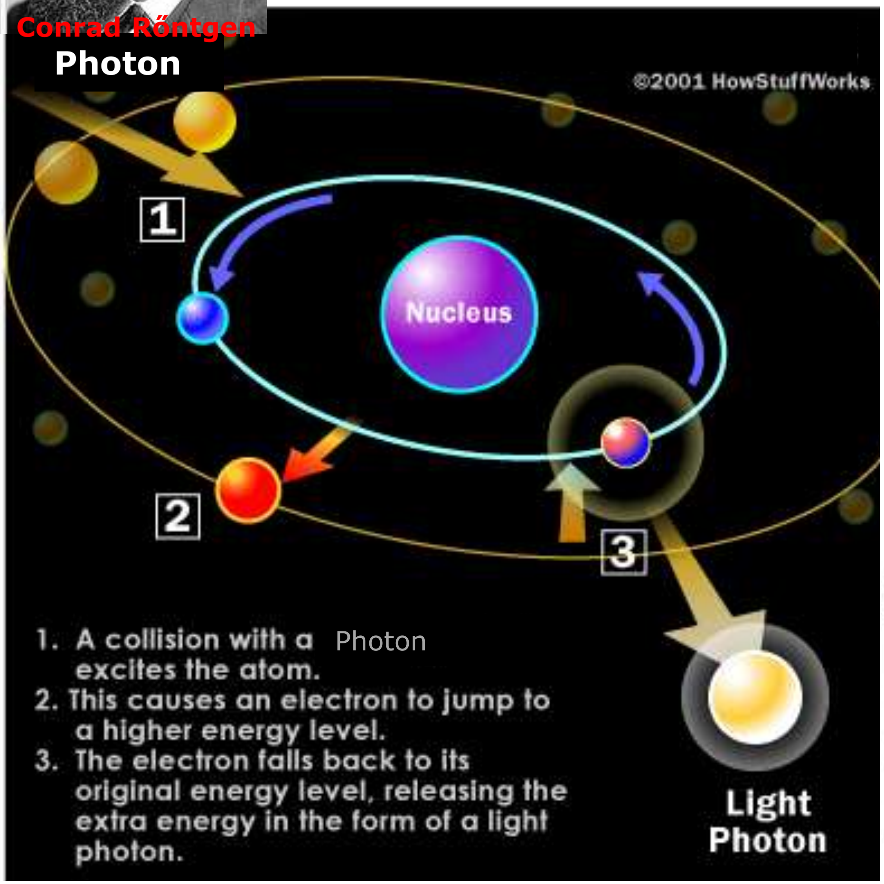
Now calibrate the PC for low energies (tens of keV)!

X Ray Energies

Conrad Rőntgen

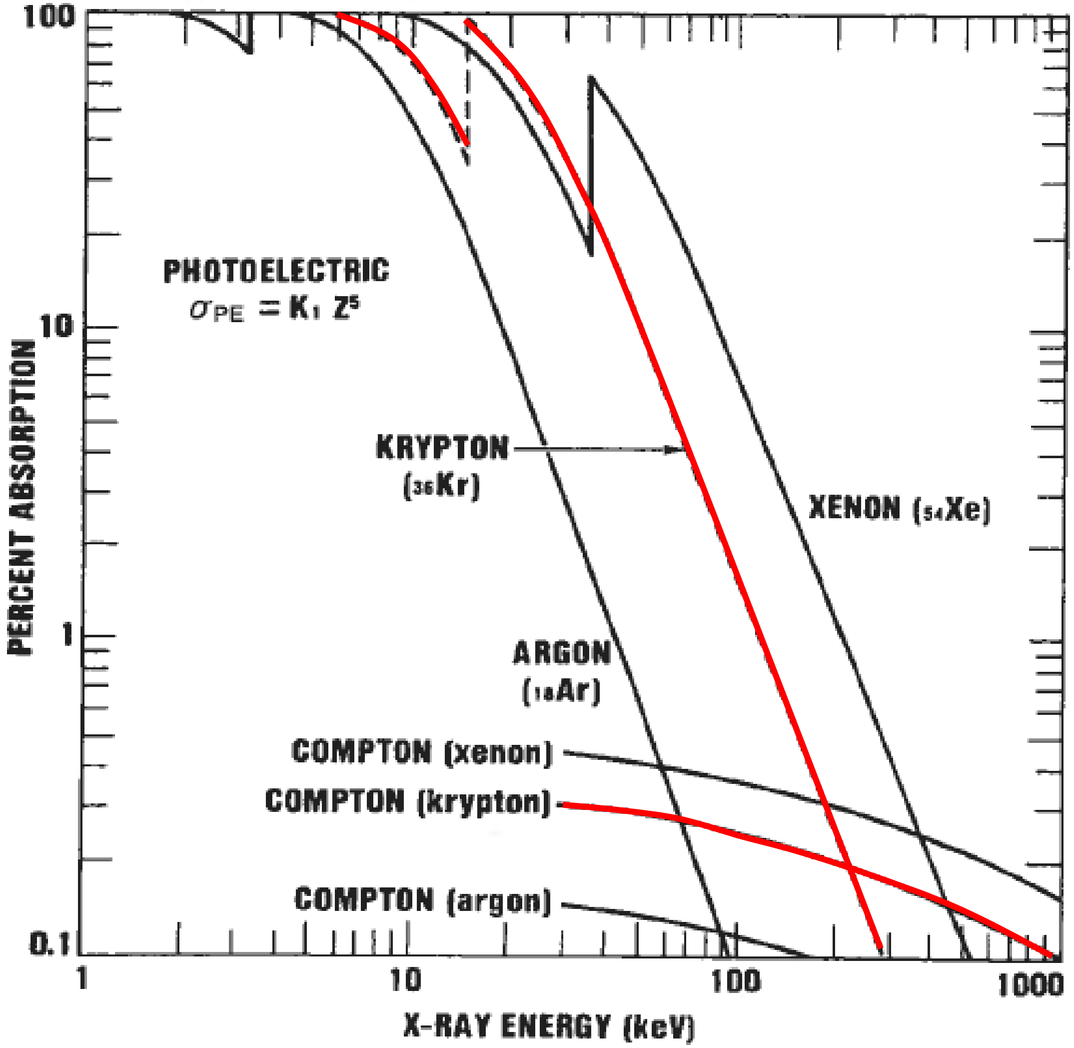
Discovered X rays:

Electron Transitions

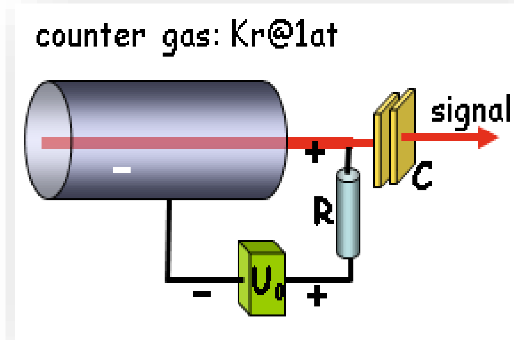


Nuclide	Energy of X-Rays and Low-Energy Gamma (keV)	Energy of High-Energy Gamma (keV)	Intensity Ratio x/γ
^{54}Mn	5.414 ($K\alpha$) 5.946 ($K\beta$)	834.8	0.2514 (±0.5%) $K\alpha + K\beta$
^{57}Co	6.40 ($K\alpha$) 7.06 ($K\beta$) 14.43 (γ)	122.1	0.5727 (±2.0%) 0.7861 (±2.9%) 0.112 (±1.8%)
^{65}Zn	8.04 ($K\alpha$) 8.9 ($K\beta$)	1115.5	0.6596 (±0.8%) 0.0911 (±2.0%)
^{241}Am	11.89 N_pL_l 13.90 $N_pL\alpha$ 17.8 $N_pL\beta$ 20.8 $N_pL\gamma$ 26.35 γ	59.5	0.022 0.375 0.512 0.138 0.07
^{85}Sr	13.38 ($K\alpha$) 15.0 ($K\beta$)	514.0	0.5020 (±0.65%) 0.0880 (±1.4%)
^{88}Y	14.12 ($K\alpha$) 15.85 ($K\beta$)	898.0	0.5491 (±1.2%) 0.0989 (±1.9%)
^{109}Cd	22.10 ($K\alpha$) 25.0 ($K\beta$)	88.0	22.02 (±4.9%) 4.68 (±5.0%)
^{113}Sn	24.14 ($K\alpha$) 27.4 ($K\beta$)	391.7	1.219 (±3.5%) 0.267 (±3.6%)

Absorption of X Rays in Gases



Relative absorption of various proportional counter gases for low energy x-rays (Taken from Reference 1) .



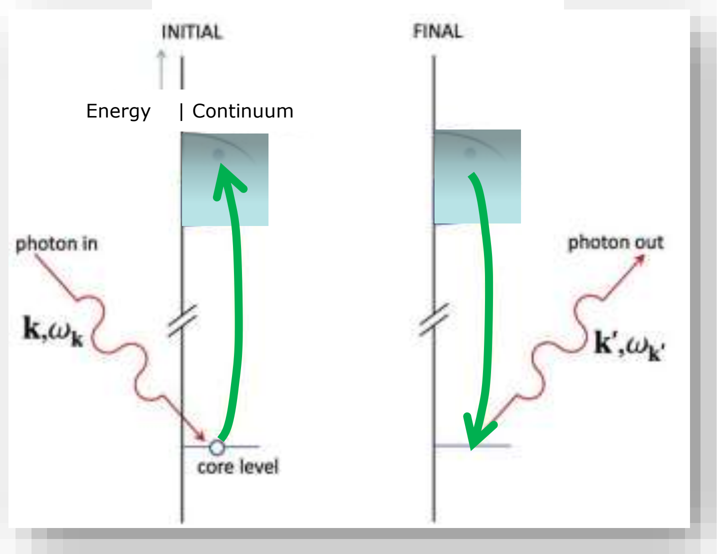
Low-energy X and γ-ray photons interact with matter dominantly via photo effect (ionization), mostly with K-shell (1s) electrons.
→ Mössbauer expt.

$$\sigma_{PE} \propto Z^5_{absorber}$$

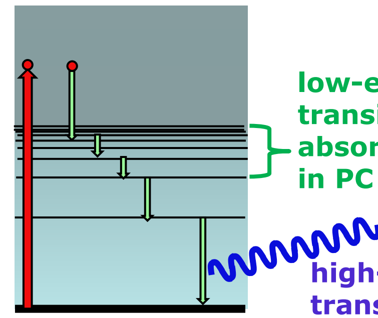
→High-Z counting gas

Complex PC Response to he Photons

Recombination



Auger Cascade



High-energy:
2p-1s, 3d-2p
E1 transitions

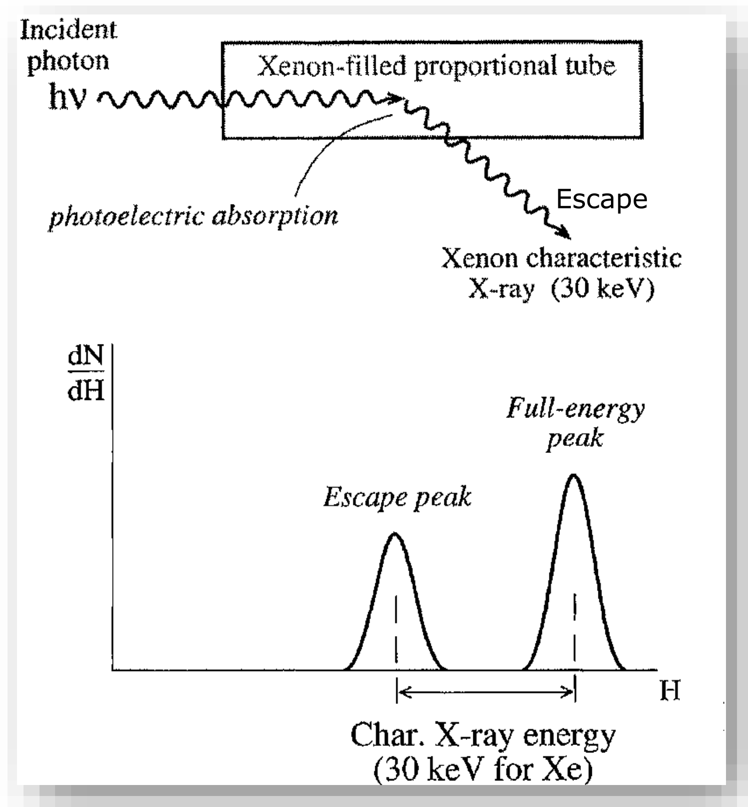
K-X ray energy missing from full-energy peak

X ray photons from recombination or Auger cascade can escape a "thin" detector → escape lines

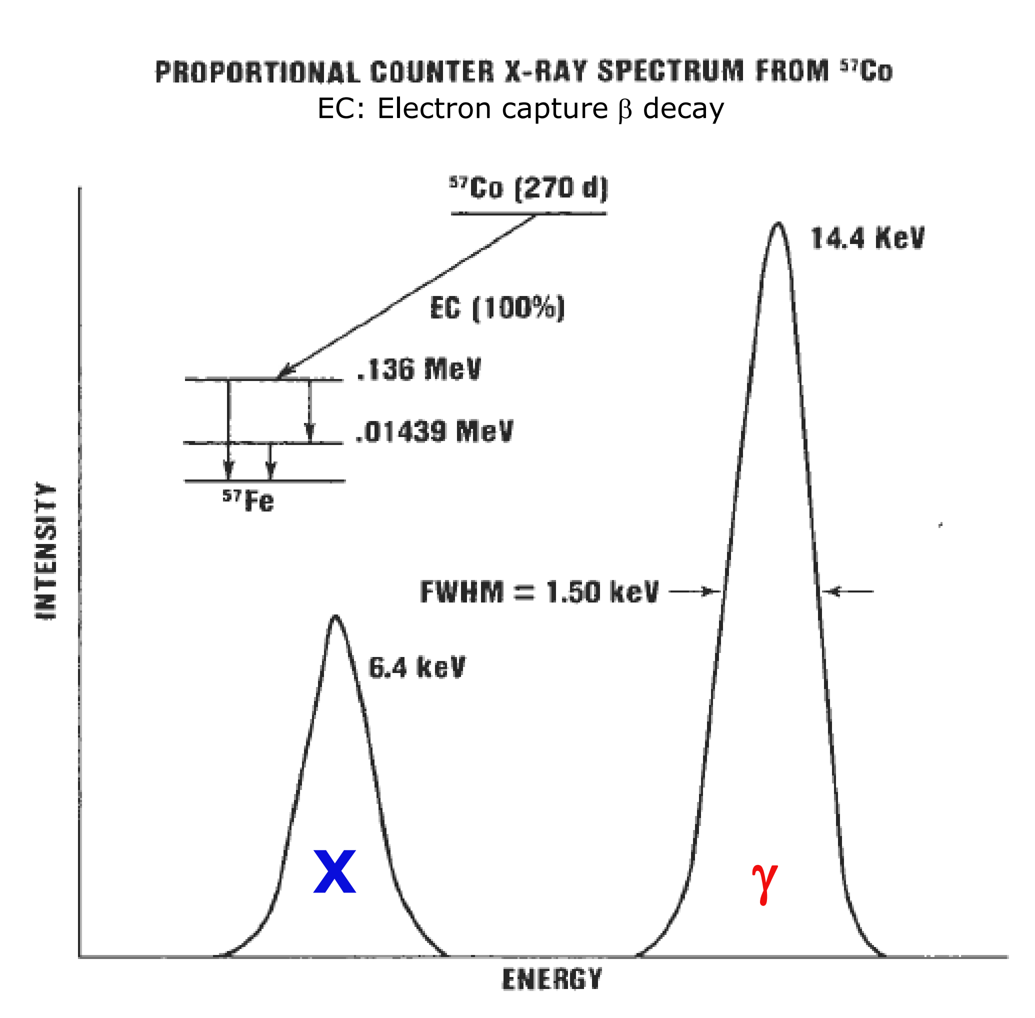
(remember escape lines for scintillation/SSD gamma detectors)

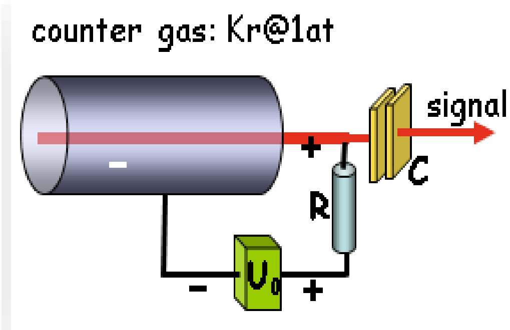
Also: Wall effects.

Kr: IE(K)=14.263 keV
2p-1s 12.6 keV
3d-2p 1.64 keV



Example: ^{57}Co γ-Rays





Low-energy X rays: interact with matter dominantly via photo effect, mostly with K shell (1s → ∞).
K-hole migrates to higher atomic levels in cascade of additional electronic X ray transitions

PC Calibration Analytical Tasks

1. Give a plausible explanation of the specific energy dependence of the photon detection efficiency of the ANSEL gas proportional counter (PC). The data have been provided in a data graph, both above and in the ANSEL Manual.
2. Explain the main process(es) that produce the response of the ANSEL PC to mono-energetic X-rays and γ-rays. What would look the response structure for a 50-keV γ-ray look like on the PC pulse height (energy) scale?
3. Given the ANSEL gas proportional counter (PC) detector technical characteristics provided, what are the main X-rays and γ-rays from the radioactive ^{57}Co source one would expect to detect within a reasonable run time?
4. What differences from the Ba-133 spectrum measured with a *CdTe* crystal shown previously can be expected?
5. Analyze and fit the lines in the Ba-133 photon spectrum, where the source was placed directly in front of the Be window of the ANSEL PC.
6. Provide an educated guess about what process within the counter gas each line may represent.
7. In the further PC calibration procedure for low-energy X-rays and γ-rays analyze spectra obtained with aluminum absorbers placed between calibration source and PC. Assess web data on aluminum photon absorption coefficients (e.g. https://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z13.html)