Gamma-Spectroscopy

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12.07.2022

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Agenda

What is gamma spectroscopy?

Interactions in the Spectrum

Detectorsystems

Applications

Summary

What is gamma spectroscopy?

studies of energy spectra of gamma rays

identification of gamma-emitting radionuclides

Interactions: Photoeffect, Compton scattering, Pair production

Interaction of γ-rays with matter

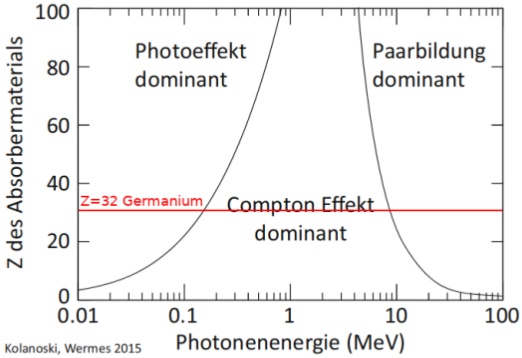


Abbildung: atomic number Z against photon energy E.

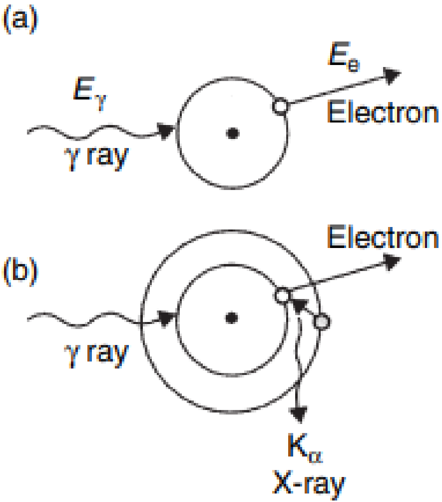
processes above ionization threshold

Gamma ray absorption →intensity loss

Material thickness dependend intensity: $N(D) = N_0 e^{-\mu D}$

D: thickness, μ: absoption coefficient, N_0: initial intensity

Photoeffect



- E_γ < several 100 keV
- ionizing bound electron (K-shell)
- $\gamma + atom \rightarrow atom^+ + e^-$
- hole is filled with electrons from higher shells recursively
- energy diff. release as x-rays characteristic
- rarely: photon leaves absorber. often excite more electrons inside
- K-L-M-absorption edge: Quantumenergy enough to release bound electron from

Compton scattering

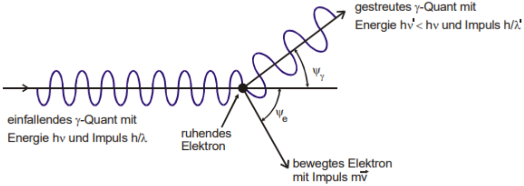
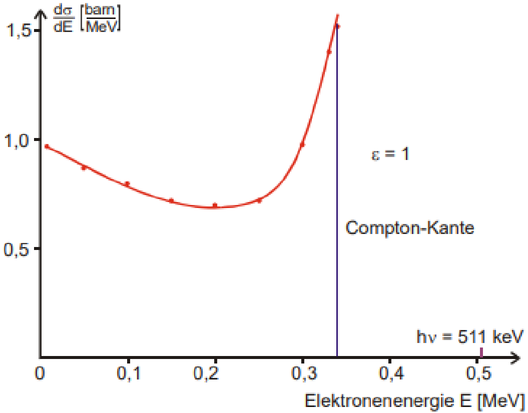


Abbildung: compton continuum

- main interaction (100 keV < E < 5 MeV)
- inelastic scattering
- photons only transfers an energy fraction
- cannot view full spectrum ☹

Compton scattering



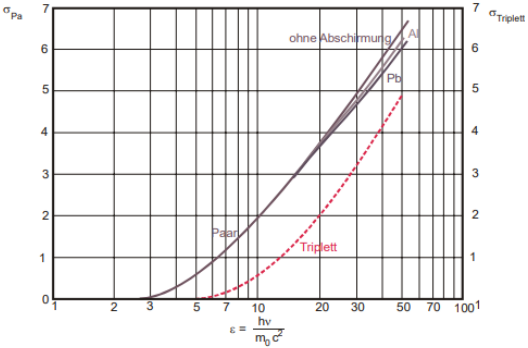
non-isotropic angular distribution

$$E_\gamma{}' = \frac{E_\gamma}{1+\left(\frac{E_\gamma}{511keV}(1-cos\theta)\right)}$$

$$E_{e^-} = E_\gamma\left(\frac{\frac{E_\gamma}{511keV}(1-cos\theta)}{1+\frac{E_\gamma}{511keV}(1-cos\theta)}\right)$$

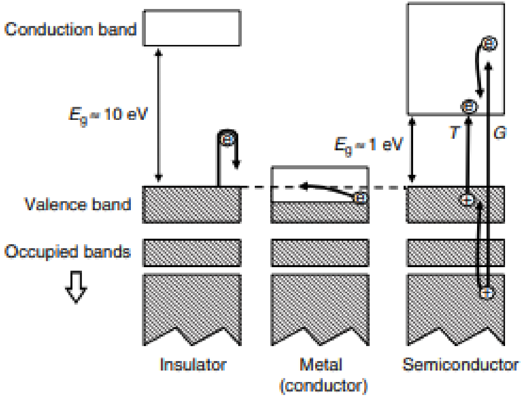
extreme cases: backward scattering, light graze

Pair production



- photon produces e+e- pair if E is high enough (5 MeV < E < 10 MeV)
- occurs in proximity of nucleus/scattering partner
- photon line visible if both leptons are absorbed;
- annihilation peak : 511 keV (e- mass) or doubled for both
- single- and double-escape peaks

Band structure

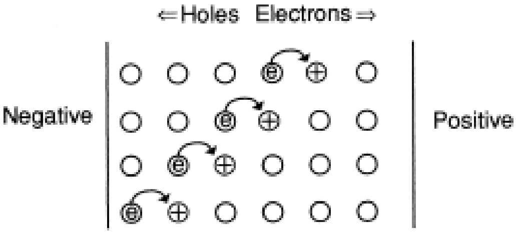


electrons in discrete/precise energy bands

valence band: outer band for chemical reactions; most inhibited

conduction band: migration of electrons

Mobility of ”Holes”



positive charge ≡ hole in the band

measuring the energy relies on separating the charge carriers

electrons from valence band filling holes -> effective moving

-> conductivity

Creation of charge carriers

- excite electrons from low bands through high energies (E > E_{therm})
- redistribution of electrons-holes throughout energy-bands
- holes: top of valence band
- electrons: bottom of conduction band
- external field: charge carriers migrate towards respective electrode

- number of electron-hole pairs $n = E_{abs}/\epsilon$
- ϵ: average energy needed to create electron hole pair
- E_{abs}: absorbed gamma ray energy

resolution and suitable semiconductors

resolution $\propto$ number of pairs produced

- large absorption coefficient (high atomic number Z)
- low ϵ: to produce many electron-hole pairs
- allow good Mobility (trapping inside semiconductor lattice)
- pure crystal structure (traps for charge carriers)
- cannot be too expensive

Why Germanium as detector material?

Material	Atomic number	Operating temperature	Band gap (eV)[a]	ε (eV)[a,b]	Density ($g\,cm^{-3}$)	Mobility($cm^2\,V^{-1}\,s^{-1}$)[a]	
						Electrons	Holes
Si	14	RT	1.106	3.62	2.33	1350	480
Ge	32	Liquid N_2 (77 K)	0.67	2.96	5.32	3.6×10^4	4.2×10^4
CdTe	48, 52	RT	1.47	4.43	6.06	1000	80
CdZnTe	48, 30, 52	RT	1.57	4.64	5.78	1000	50–80
HgI_2	80, 53	RT	2.13	4.22	6.30	100	4
GaAs	31, 33	RT	1.45	4.51	5.35	8000	400
TlBr	81, 35	−20 °C	2.68	?	7.56	—	—
PbI_2	82, 53	—	2.6	7.68	6.16	8	2
GaSe	31, 34	—	2.03	6.3	4.55	—	—
AlSb	13, 51	—	1.62	5.05	4.26	—	—
CdSe	48, 34	—	1.75	?	5.74	—	—

[a] Values are given at 77 K for Ge and 300 K otherwise.
[b] Electron–hole creation energy.

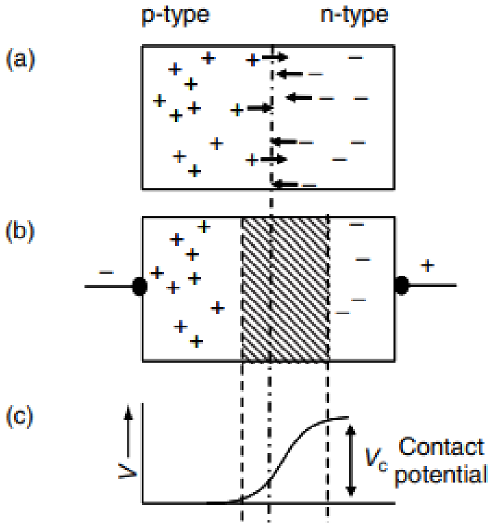
Silicon: highly pure, low-priced, low atomic number (low energy photons)

Germanium: higher Z -> good for higher energy gamma radiation

low temperature -> reduce leakage current

improvements reduced resolution to ≈ 1.8 keV

Semiconductor detector (Germanium)



p-type, n-type germanium (3 and 5 valent impurities)

electrons and holes recombine by diffusion -> depletion zone

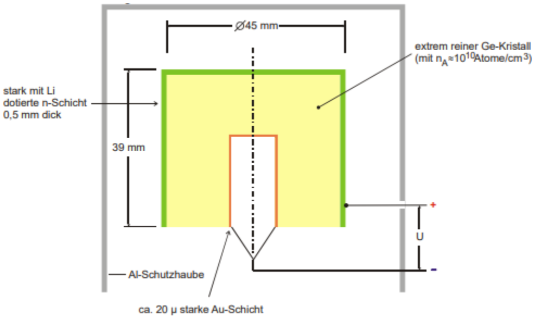
-> only local donator and acceptor hulls remain

goal: seperation via external field inside depletion zone

maximising the depletion zone -> hinder recombination -> reconstruct energy of the event

excitation:

The Ge-detector



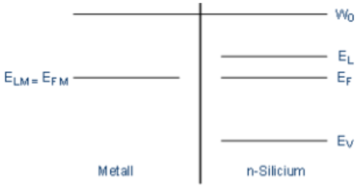
Aluminium casing as VETO region (40 - 50 keV)

Lithium doped outside: connecting rreverse voltage

inside steamed with gold (M-S junction)

electronic signal: spectrum-histogram from Multichannel analyzer (MCA)

Metal-Semiconductor junction (n-Si)



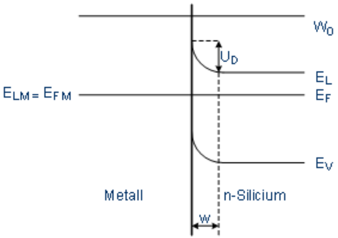
W_0: vacuum level, E_L: conduction band, E_F: fermi energy

E_V: valence band, E_{LM}: energy level in metal, E_{FM}: fermi energy in metal

electrons can migrate from Semiconductor to metal since E-level is lower

probability of finding electrons in conduction band gets lower

Metal-Semiconductor junction (n-Si)



migrated charge carriers form depletion zone and lower fermi level

additional e^- must overcome the Schottky-barrier to flow into Metal

fermi levels in metal and semiconductor equalize via diffusion process

Why is this junction used over p-n?

Si-Schottky diodes are substantially faster changing from forward bias to reverse bias

-> switching action: 10 - 100 GHz possible because no moving ”holes” in metal

low forward voltage drop (0.15 - 0.45V) p-n: 0.6 - 0.75 V

But: higher reverse leakage current

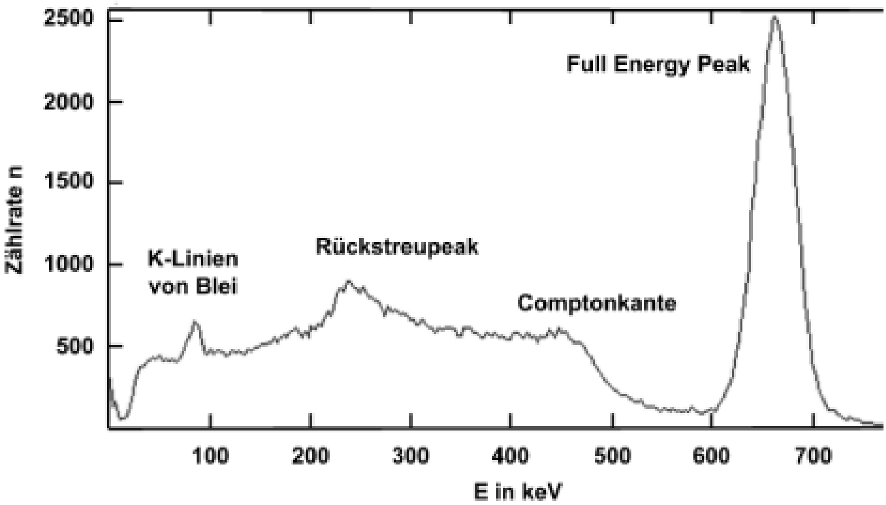
Separation efficiency

minimal distance of 2 signals to register both

Full Width at Half Maximum $\Delta E_{1/2} \approx 2.35\sqrt{F E_\gamma \epsilon}$

Fano factor of germanium $F = 0.1$

Energy spectra



Evaluation of gamma spectroscopy

PRO:

- quite cheap in material costs
- relatively fast result evaluation
- multinuclide analysis (distinct lines visible for all nuclides)
- non-destructive for emitter (radiation hardness of detector given)
- remote measurement

CONTRA:

- often less sensitive
- require large sample masses (if not gamma rays from space)

Applications

medial application: positron emission tomography (tumor therapy)

-> positron-emitting pharmaceutical injection near tumor -> imaging through 511 keV lines

security scans for explosives

monitoring nuclear waste

Quellen

https://onlinelibrary.wiley.com/doi/book/10.1002/9780470861981

V18_Anleitung.pdf

https://www.nrc.gov/docs/ML1122/ML11229A699.pdf

https://www.electrical4u.com/schottky-diode/

Backup

Attenuation egde for caesium iodine (CsI)

2 K-lines and 2 L-lines