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# Gamma-Spectroscopy

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## Agenda

What is gamma spectroscopy?

Interactions in the Spectrum

Detectorsystems

Applications

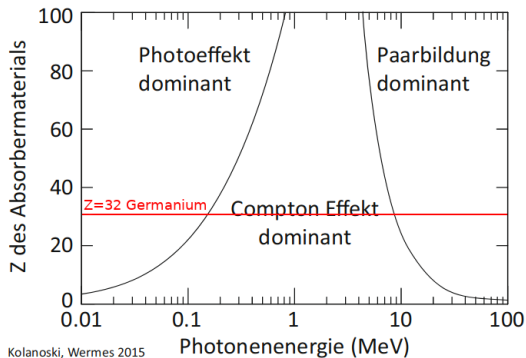
## What is gamma spectroscopy?

### **studies of energy spectra of gamma rays**

spectrum used to determine quantity and identity of  $\gamma$ -emitters

gamma ray sources emitters on earth, astrophysical sources

## Interaction of $\gamma$ -rays with matter



**Abbildung:** atomic number  $Z$  against photon energy  $E$ .

processes above ionization threshold

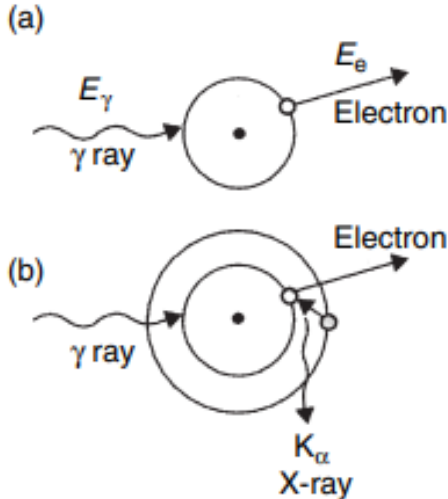
Gamma ray absorption  $\rightarrow$  intensity loss

Material thickness dependend intensity:

$$N(D) = N_0 e^{-\mu D}$$

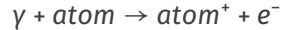
$D$ : thickness,  $\mu$ : absorption coefficient,  $N_0$ : initial intensity

## Photoeffect



$E_\gamma < \text{several } 100 \text{ keV}$

ionizing bound electron (K-shell)



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

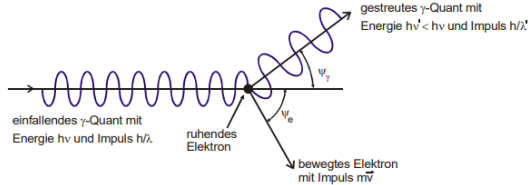


Abbildung: compton continuum

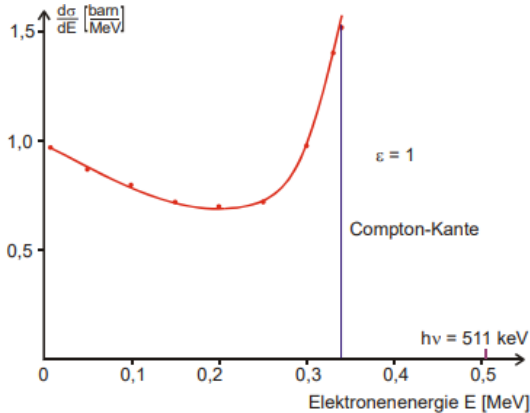
main interaction ( $100 \text{ keV} < E < 5 \text{ MeV}$ )

inelastic scattering

photons only transfers an energy  
fraction

cannot view full spectrum ☹

## Compton scattering



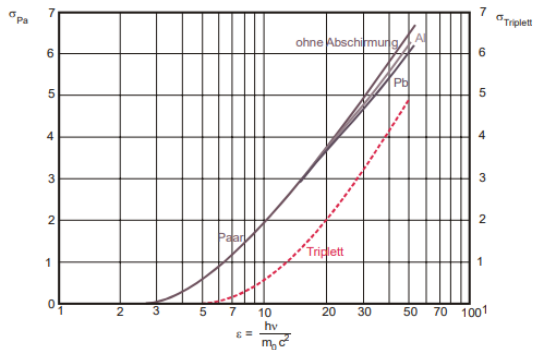
non-isotropic angular distribution

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

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

extreme cases: backward scattering,  
light graze

## Pair production



photon produces  $e^+e^-$  pair if  $E$  is high enough ( $5 \text{ MeV} < E < 10 \text{ MeV}$ )

occurs in proximity of nucleus/scattering partner

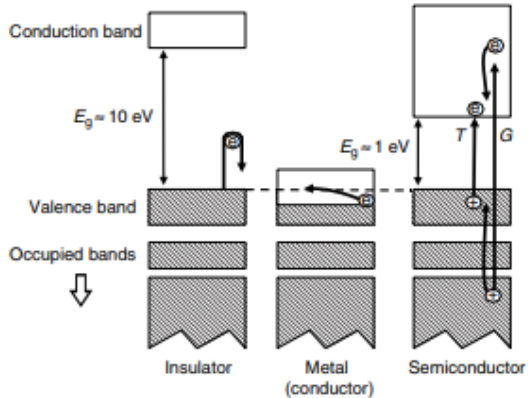
photon line visible if both leptons are absorbed;

annihilation peak : 511 keV ( $e^-$  mass) or doubled for both

single- and double-escape peaks



## Band structure

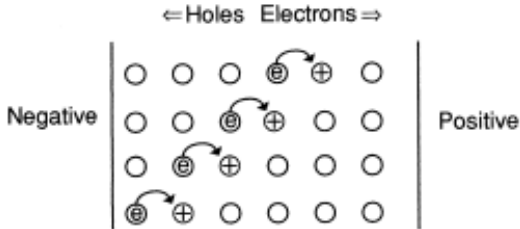


electrons in discrete/precise energy bands

valence band: outer band for chemical reactions; most inhibited

conduction band: migration of electrons

## Mobility of "Holes"



positive charge  $\equiv$  hole in the band  
 measuring the energy relies on  
 separating the charge carriers  
 electrons from valence band filling  
 holes  $\rightarrow$  effective moving  
 $\rightarrow$  conductivity

## Creation of charge carriers

excite electrons from low bands through  
high energies ( $E > E_{\text{therm}}$ )

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  $n = E_{\text{abs}}/\epsilon$

$\epsilon$ : average energy needed to create  
electron hole pair

$E_{\text{abs}}$ : absorbed gamma ray energy

## resolution and suitable semiconductors

resolution  $\propto$  number of pairs produced

- large absorption coefficient (high atomic number  $Z$ )

- low  $\epsilon$ : 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) <sup>a</sup>	$\epsilon$ (eV) <sup>a,b</sup>	Density (g cm <sup>-3</sup> )	Mobility(cm <sup>2</sup> V <sup>-1</sup> s <sup>-1</sup> ) <sup>a</sup>	
						Electrons	Holes
Si	14	RT	1.106	3.62	2.33	1350	480
Ge	32	Liquid N <sub>2</sub> (77 K)	0.67	2.96	5.32	$3.6 \times 10^4$	$4.2 \times 10^4$
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 <sub>2</sub>	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 <sub>2</sub>	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	—	—

<sup>a</sup> Values are given at 77 K for Ge and 300 K otherwise.

<sup>b</sup> Electron-hole creation energy.

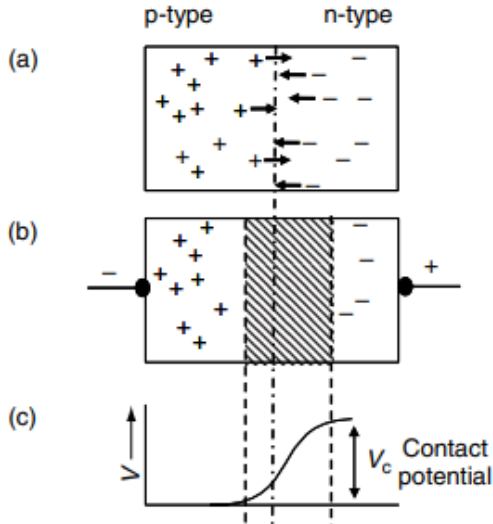
Silicon: highly pure, low-priced, low atomic number (low energy photons)

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

low temperature -> reduce leakage current

improvements reduced resolution to  $\approx$  1.8 keV

## Semiconductor detector (Germanium)



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

electrons and holes recombine by diffusion  $\rightarrow$  depletion zone

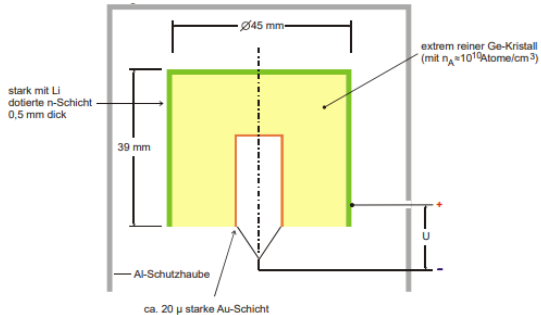
$\rightarrow$  only local donator and acceptor hulls remain

goal: separation via external field inside depletion zone

maximising the depletion zone  $\rightarrow$  hinder recombination  $\rightarrow$  reconstruct energy of the event

excitation:

## The Ge-detector



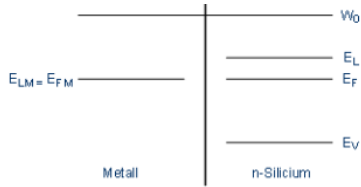
Aluminium casing as VETO region (40 - 50 keV)

Lithium doped outside: connecting reverse 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

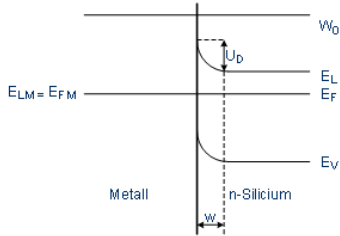
$E_V$ : valence band,  $E_{LM}$ : energy level in  
metal,  $E_{FM}$ : fermi energy in metal

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

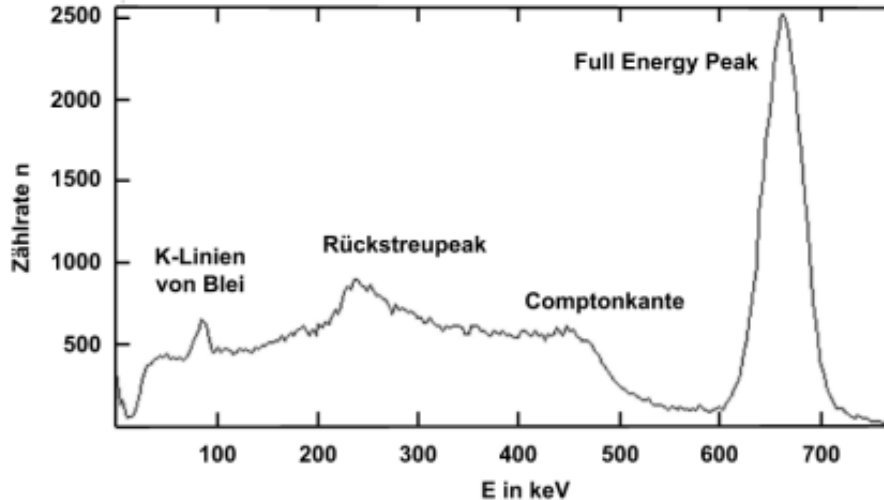
## Separation efficiency

minimal distance of 2 signals to register both

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

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

medical application: positron emission tomography (PET) [tumor therapy]

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

security scans for explosives

monitoring nuclear waste

**Thank you for listening!**

Questions?

Comments?

## Quellen

[https://onlinelibrary.wiley.com/doi/book/10.1002/9780470861981V18\\_Anleitung.pdf](https://onlinelibrary.wiley.com/doi/book/10.1002/9780470861981V18_Anleitung.pdf)

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

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



## Backup

Attenuation edge for caesium iodine  
(CsI)

2 K-lines and 2 L-lines

