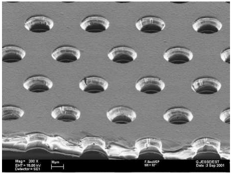
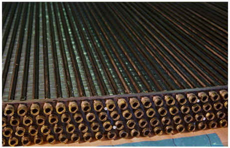
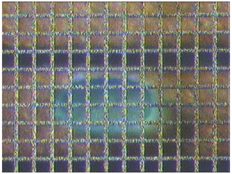
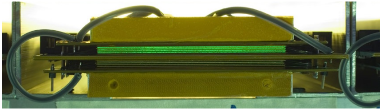
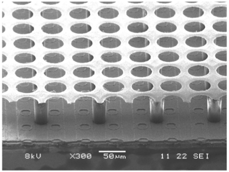

Mag = 200 X
EHT = 15.00 kV
Detector = SE1
G.JESSE/EST
Date :3 Sep 2001








8kV X300 50µm 11 22 SEI

Basics of Gaseous Detectors

S. F. Biagi, H. Schindler, R. Veenhof

EDIT 2011

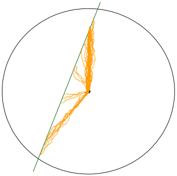
Overview

The detectors discussed in today's workshop rely essentially on the same principles:

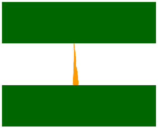
- a charged particle (or a photon) ionizes gas atoms/molecules along its track,
- an electric field transports electrons (and ions) towards electrodes,
- electrons are multiplied in a strong electric field,
- the motion of electrons and ions induces a current on the readout electrodes.

Overview

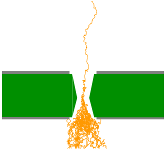
- drift tube



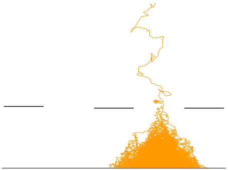
- RPC



- GEM



- Micromegas/InGrid

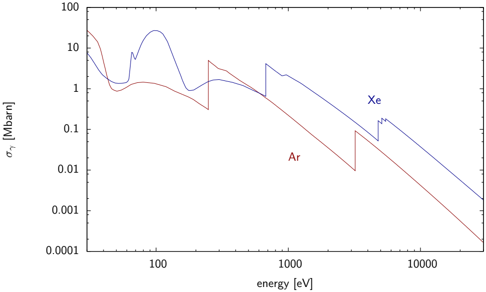


Aside: Gas Choice

- The examples on the following slides focus on argon, which is a commonly used detection gas.
- Why?
  - third most common gas in the atmosphere (0.93%), cheap
  - inert, not toxic
  - more detailed motivation $\rightarrow$ later
- Typically, a "quenching gas" (e. g. CH_4 or CO_2) is added for stability.

Photo-Ionization

The (photo-electric) interaction of a photon with a gas molecule is described by the photoabsorption cross-section σ_γ.



Example: 5.9 keV γ in Ar

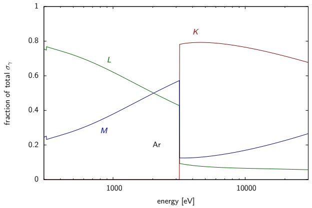
- $\sigma_\gamma \approx 0.019$ Mbarn
- attenuation length at RT, $p = 1$ atm: $\lambda \approx 2$ cm

B. L. Henke et al.,

At. Data Nucl. Data Tables **54** (1993), 181-342

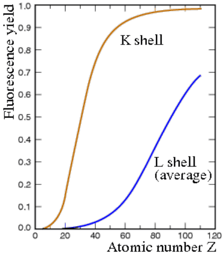
Photo-Ionization

Ionization of core shells is followed by atomic relaxation processes.

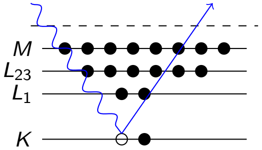


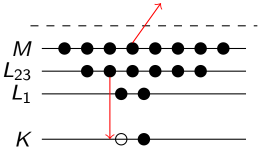
D. A. Verner et al.,

At. Data Nucl. Data Tables **55** (1993), 233-280



- K shell ionization
- Auger effect
- fluorescence





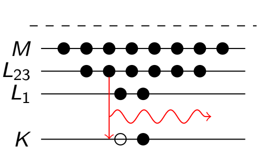
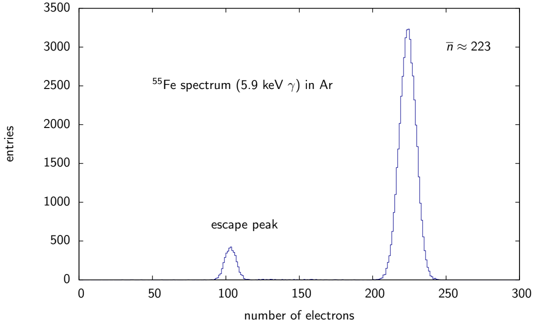


Photo-Ionization

The emerging δ electrons (i. e. photoelectrons and Auger electrons) ionize and excite gas atoms along their path $\rightarrow$ secondary electrons



Calculation: Heed + Magboltz

W Value and Fano Factor

- mean number of electrons

$$\bar{n} = \frac{E_\gamma}{W}$$

- variance

$$\sigma^2 = F\bar{n}$$

W value and Fano factor F are determined by the partitioning of ionizing collisions vs. excitations in the photoelectron degradation process.

- photons/electrons at $\approx$ keV energies:

Gas	W [eV]	F
Ne	35.4	0.13 - 0.17
Ar	26.4	0.16
Xe	22.1	0.17
CO_2	33.0	0.32
CH_4	27.3	0.26 - 0.29

ICRU Technical Report 31 (1979)
IAEA TECDOC 799 (1995)

Ionization by Charged Particles

Charged particle interaction with the gas is described by the differential cross-section $\mathrm{d}\sigma/\mathrm{d}E$, where E is the energy transfer in a collision.

- average number of collisions per cm (cluster density)

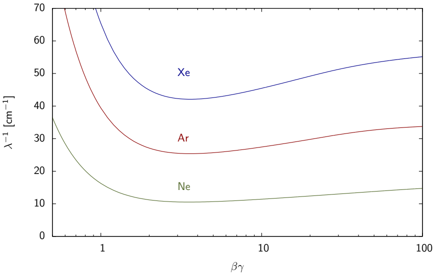
$$\lambda^{-1} = N \int_0^{E_{\text{max}}} \mathrm{d}E \, \frac{\mathrm{d}\sigma}{\mathrm{d}E}$$

- average energy loss per cm (stopping power)

$$\frac{\mathrm{d}E}{\mathrm{d}x} = N \int_0^{E_{\text{max}}} \mathrm{d}E \, \frac{\mathrm{d}\sigma}{\mathrm{d}E} E$$

Cluster Density

- cluster density at
  $T = 20^\circ$ C, $p = 1$ atm:



Calculation: Heed

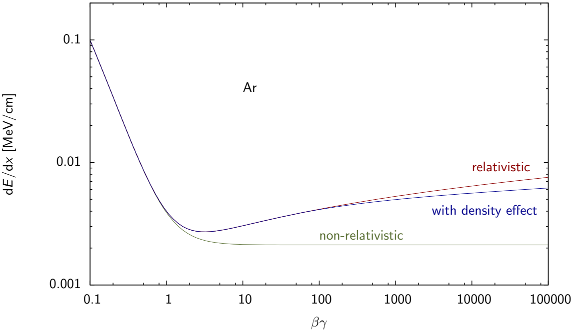
- minimum ionizing electrons:

Gas	λ^{-1} [cm^{-1}]
Ne	11
Ar	23
Xe	43
CO_2	34
CH_4	25

F. Rieke and W. Prepejchal,
Phys. Rev. A **6** (1972), 1507-1519

Stopping Power

- Bethe-Bloch formula

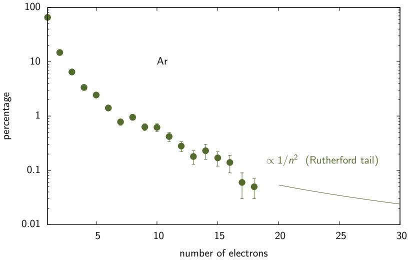


$$\frac{\mathrm{d}E}{\mathrm{d}x} = -\frac{4\pi z^2 e^4}{mc^2} NZ \frac{1}{\beta^2} \left[\ln \frac{2mc^2\beta^2\gamma^2}{I} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right].$$

Energy Loss Fluctuations

Fluctuations in the ionization process:

- number of collisions over a distance → Poisson distribution,
- number of electrons produced in a single collision → cluster size distribution



H. Fischle et al.

Nucl. Instr. Meth. A **301** (1991), 202-214

Dielectric Theory of Energy Loss

Classical approach:

- moving charged particle (velocity $\boldsymbol{\beta} c$) polarizes the medium (characterized by complex dielectric function ε)
- the resulting electric field $\mathbf{E}$ slows down the particle

$$\frac{\mathrm{d}E}{\mathrm{d}x} = q\mathbf{E} \cdot \frac{\boldsymbol{\beta}}{\beta}$$

- Fourier transform

$$\frac{\mathrm{d}E}{\mathrm{d}x} = -\frac{2q^2}{\beta^2\pi} \int \mathrm{d}\omega \int \mathrm{d}k \left[\omega k \left(\beta^2 - \frac{\omega^2}{k^2 c^2}\right) \mathrm{Im}\left(\frac{1}{-k^2c^2 + \varepsilon(k,\omega)\omega^2}\right) + \frac{\omega}{kc^2} \mathrm{Im}\left(\frac{-1}{\varepsilon(k,\omega)}\right)\right]$$

Reinterpretation in quantum picture:
discrete collisions with energy transfer $E = \hbar\omega$ and momentum transfer $\hbar k$ $\rightarrow$ exchange of virtual photons

Photoabsorption-Ionization Model

Model for $\varepsilon(k, \omega)$

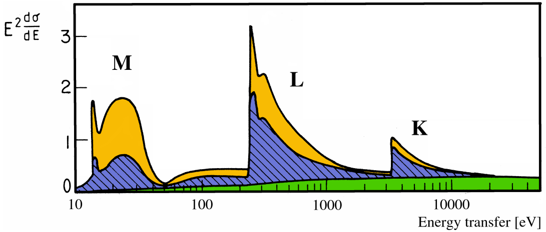
- small momentum transfer: use optical data, $\varepsilon'' \approx (N\hbar c/E)\,\sigma_\gamma$
- large k: scattering by free electrons

$$\frac{\beta^2 \pi \hbar c}{z^2 \alpha_f} N \frac{\mathrm{d}\sigma}{\mathrm{d}E} = \mathrm{Im}\left(\frac{-1}{\varepsilon(E)}\right) \ln \frac{2m\beta^2 c^2}{E}$$
$$+ \mathrm{Im}\left(\frac{-1}{\varepsilon(E)}\right) \ln \frac{1}{|1 - \beta^2 \varepsilon(E)|}$$
$$+ \left(\beta^2 - \frac{\varepsilon'(E)}{|\varepsilon(E)|^2}\right)\left(\frac{\pi}{2} - \arctan \frac{1 - \beta^2 \varepsilon'(E)}{\beta^2 \varepsilon''(E)}\right)$$
$$+ \frac{1}{E^2} \int_0^E \mathrm{d}E' \mathrm{Im}\left(\frac{-1}{\varepsilon(E')}\right) E'$$

W. W. M. Allison and J. H. Cobb,
Ann. Rev. Nucl. Part. Sci. **30** (1980), 253-293

Photoabsorption-Ionization Model

$$\frac{\beta^2 \pi \hbar c}{z^2 \alpha_f} N \frac{d\sigma}{dE} = \operatorname{Im}\left(\frac{-1}{\varepsilon(E)}\right) \ln \frac{2m\beta^2 c^2}{E}$$
$$+ \operatorname{Im}\left(\frac{-1}{\varepsilon(E)}\right) \ln \frac{1}{|1-\beta^2 \varepsilon(E)|}$$
$$+ \left(\beta^2 - \frac{\varepsilon'(E)}{|\varepsilon(E)|^2}\right)\left(\frac{\pi}{2} - \arctan \frac{1-\beta^2 \varepsilon'(E)}{\beta^2 \varepsilon''(E)}\right)$$
$$+ \frac{1}{E^2} \int_0^E dE' \operatorname{Im}\left(\frac{-1}{\varepsilon(E')}\right) E'$$



Implementations:

- Heed
- G4PAIModel

Energy Loss Fluctuations

- Number of ionization electrons over 1 cm Ar