

Ionization detectors (Leo ch. 6)

Lecture 1:

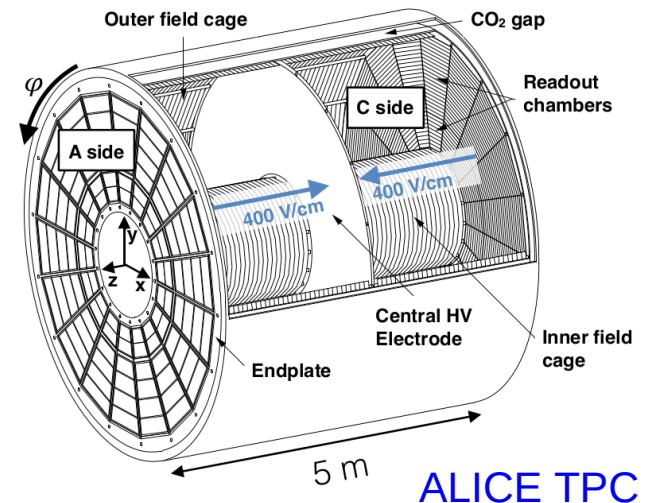
6.1: Gaseous ionization detectors

6.2: Ionization and transport phenomena in gases

6.3: Transport of electrons and ions in gases

6.4: Avalanche multiplication

6.5: The cylindrical proportional counter

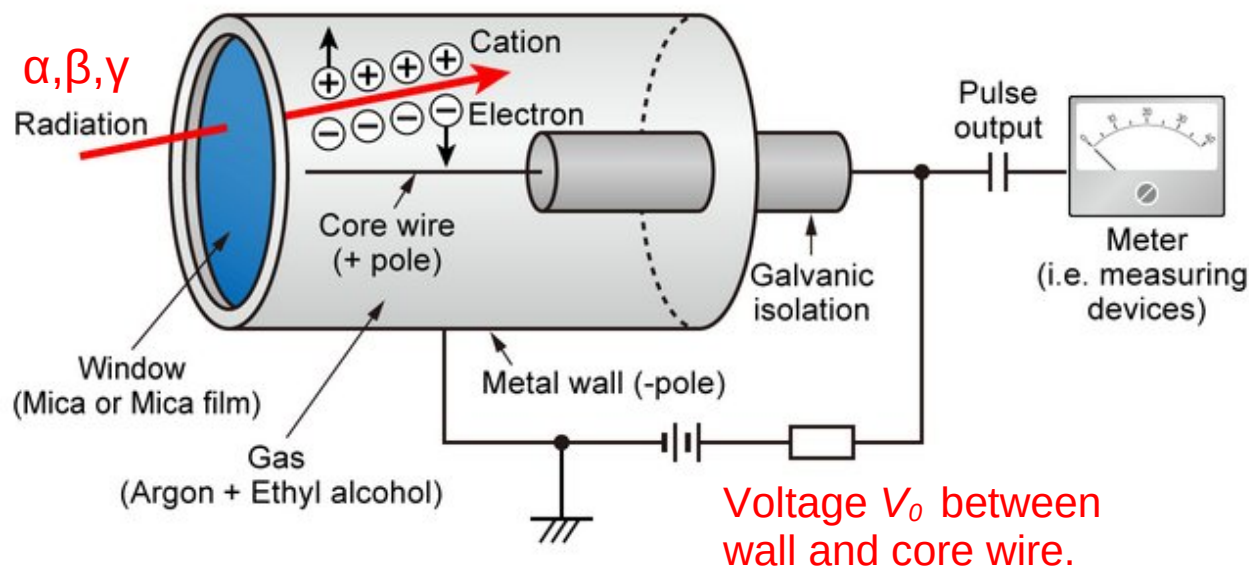
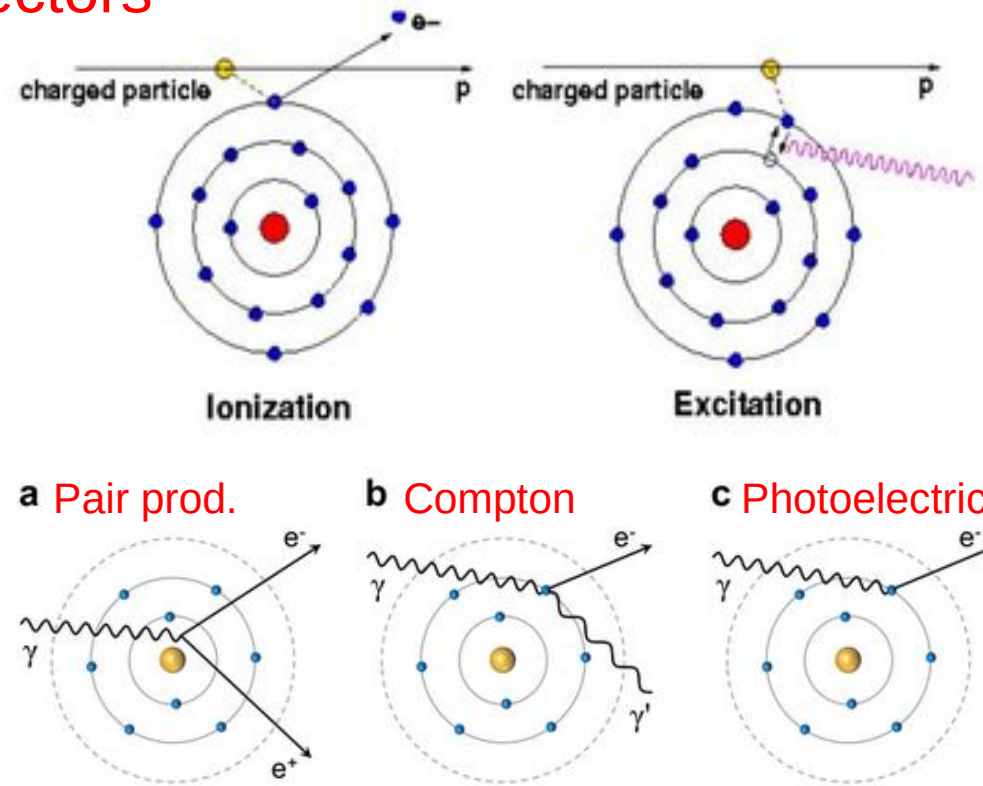


6.1: Gaseous ionization detectors

Ionizing radiation produces electron-ion pairs in matter (e.g. gas).

Charged particles (α -particles, protons, other charged hadrons, charged leptons) lose energy via **ionization** and **excitation** (Bethe-Bloch dE/dx ++).

Photons ionize via photoabsorption, Compton scattering, pair production.



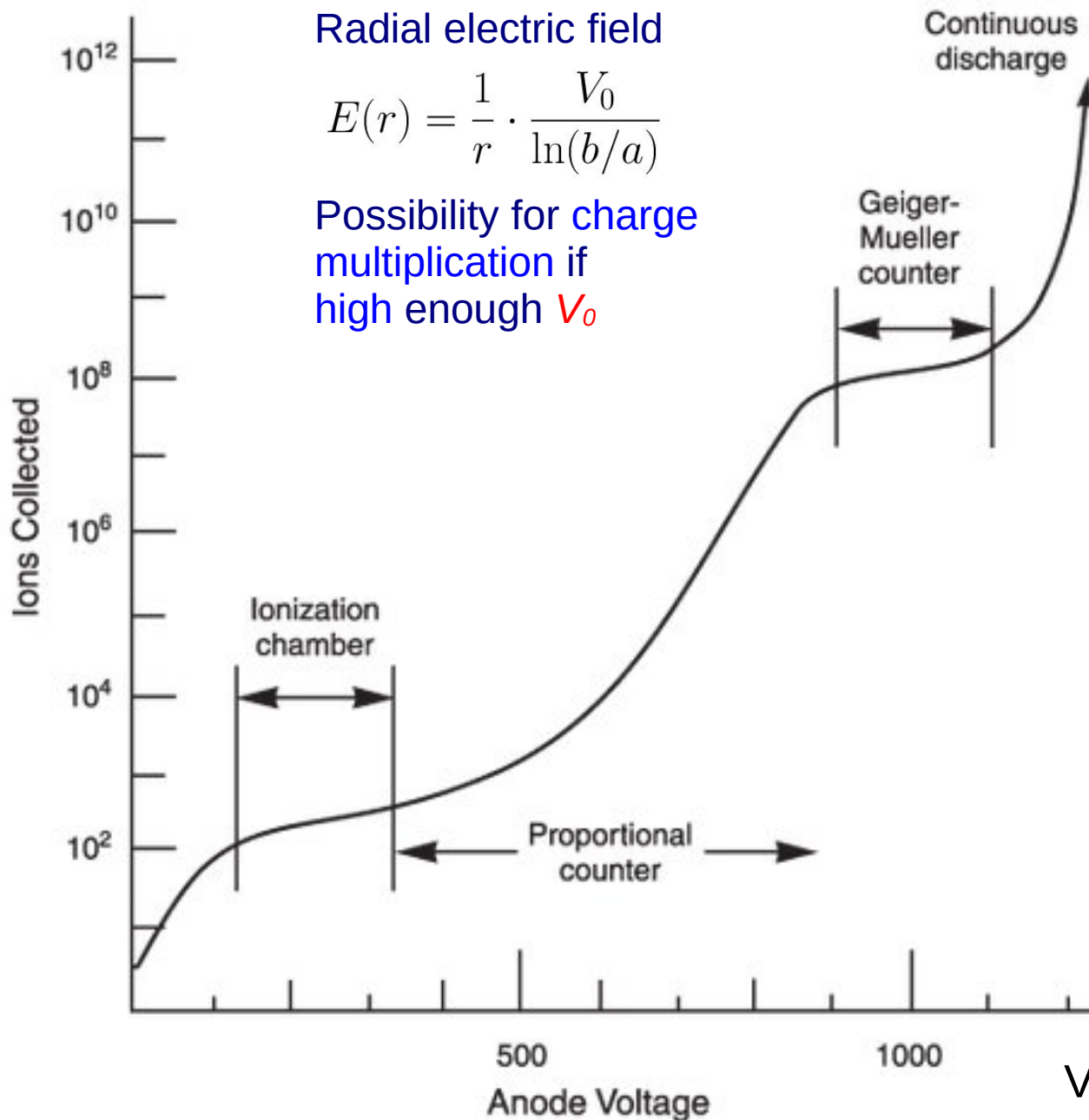
Simple gaseous ionization detectors have a **cylindrical geometry** with **positive core wire (radius a)**, **negative outer wall (radius b)**.

Radial electric field:

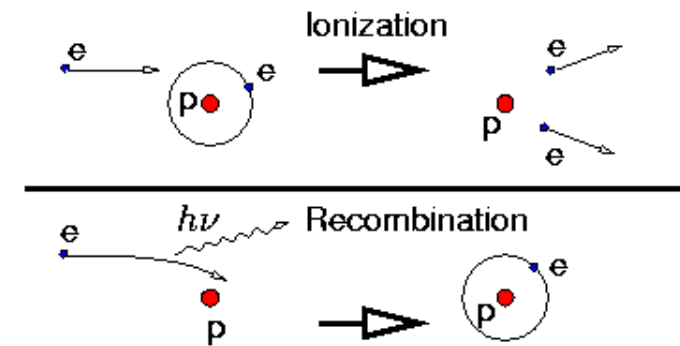
$$E(r) = \frac{1}{r} \cdot \frac{V_0}{\ln(b/a)}$$

separates and collects positive and negative charges.

The output signal depends on the voltage V_0 between core wire (anode) and wall (cathode). Proportional to number of charges collected, but actually caused by motion of charged particles.



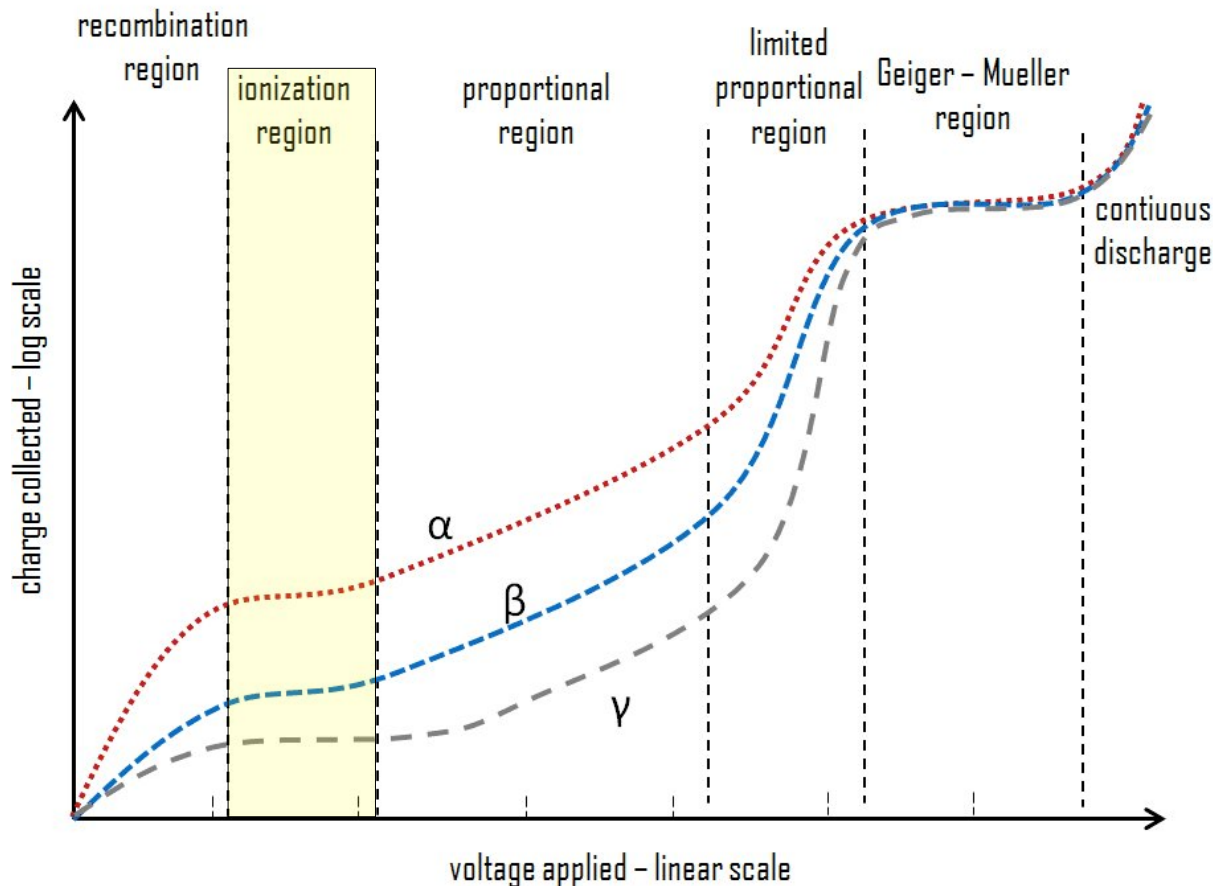
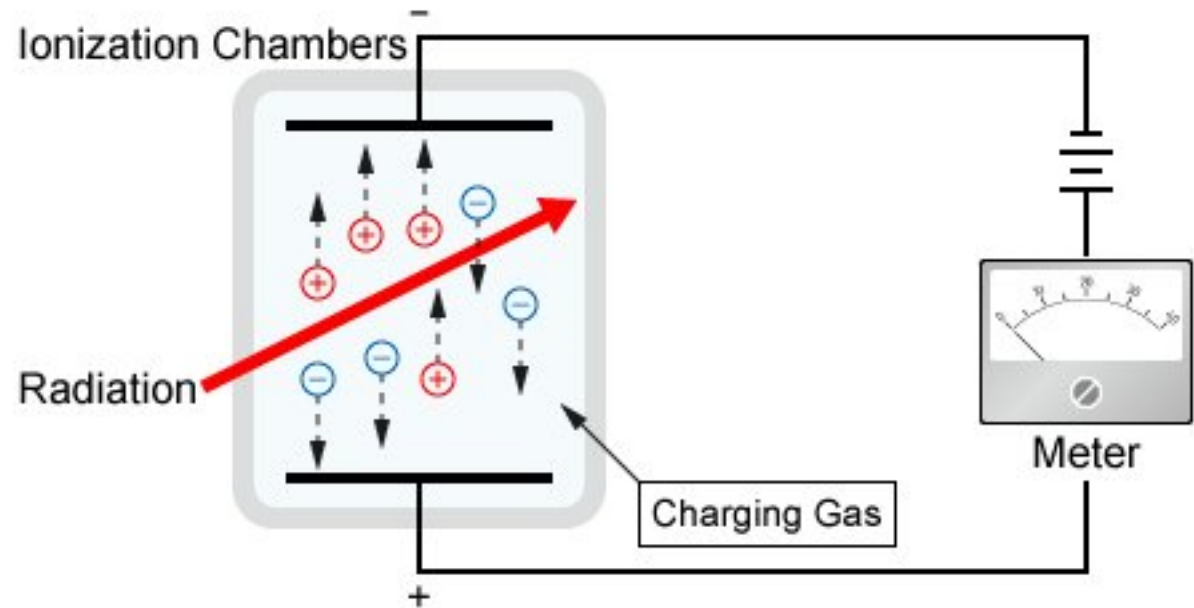
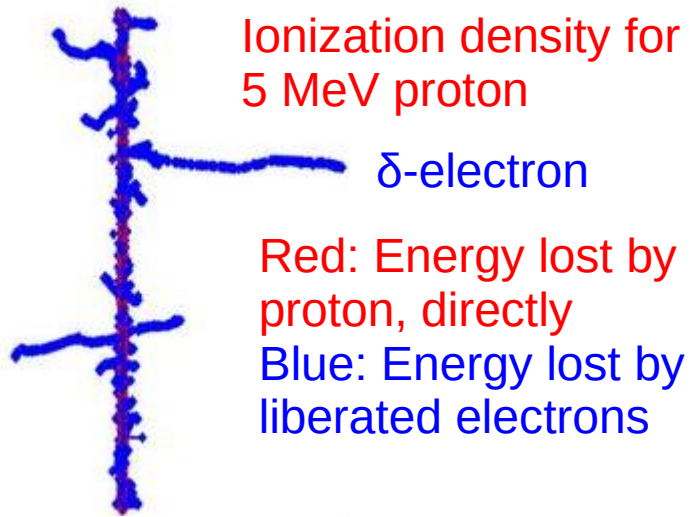
Low V_0 : Recombination of electrons and ions, no charges collected.



Higher V_0 : Regions with various degrees of charge multiplication:

- Ionization chamber region
- Proportional counter region
- Geiger-Müller region

Ionization chamber region



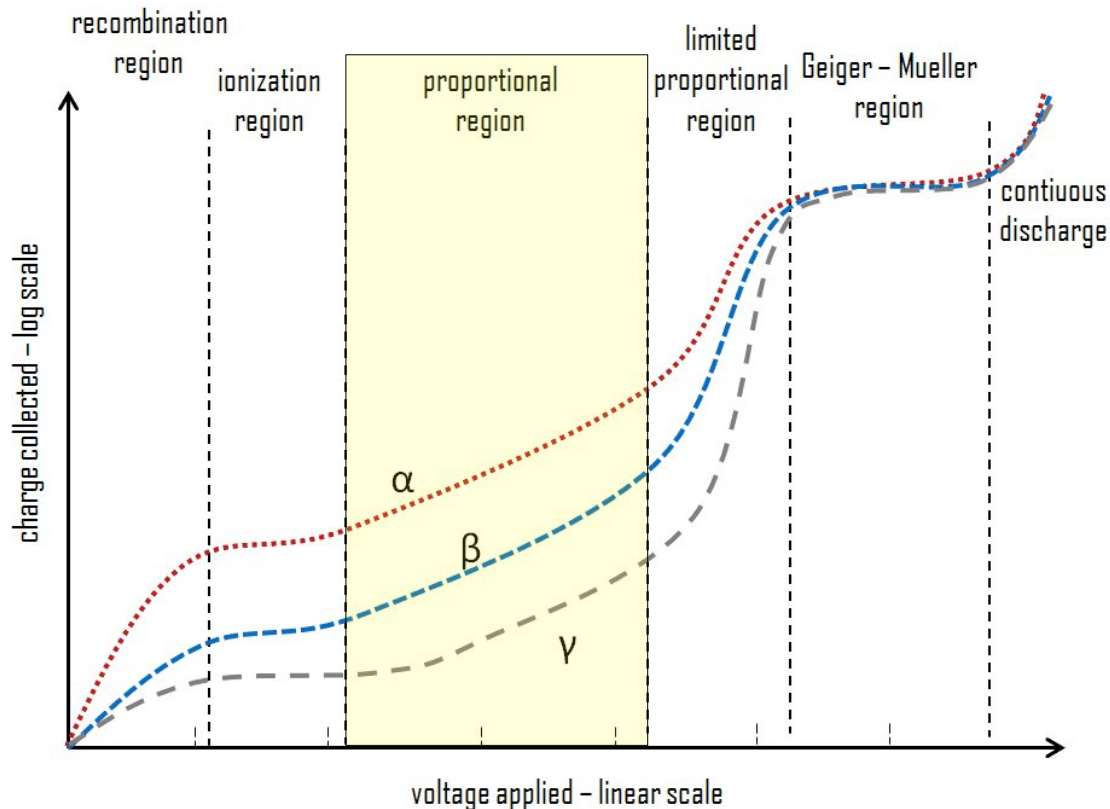
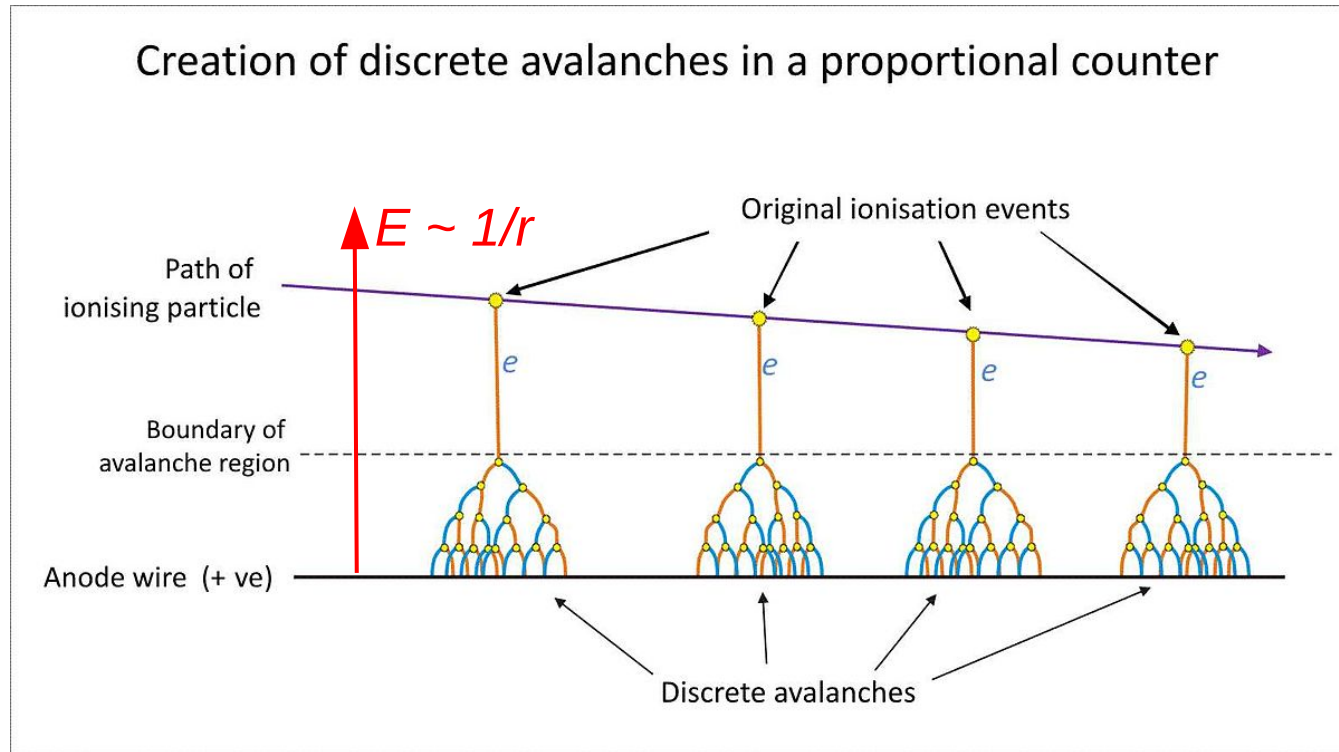
Ionization chamber region:

V_0 large enough to prevent recombination but too small for charge multiplication in gas.

Only charges liberated due to the energy loss ΔE of incident particle are collected (ionization by incident particle and by δ -electrons). Number of electron-ion pairs proportional to ΔE . Small signal.

Proportional counter region

Above a certain V_0 :
Electric field close to anode wire sufficient to accelerate freed (primary) electrons, enabling further ionization followed by acceleration of higher numbers of (secondary) electrons.



Production of avalanches, with energy taken from electric field. Independent avalanches initiated by primary ionizations.

Number of electron-ion pairs collected is proportional to ΔE lost by incident particle, with multiplication factor $\sim 10^2 - 10^4$.

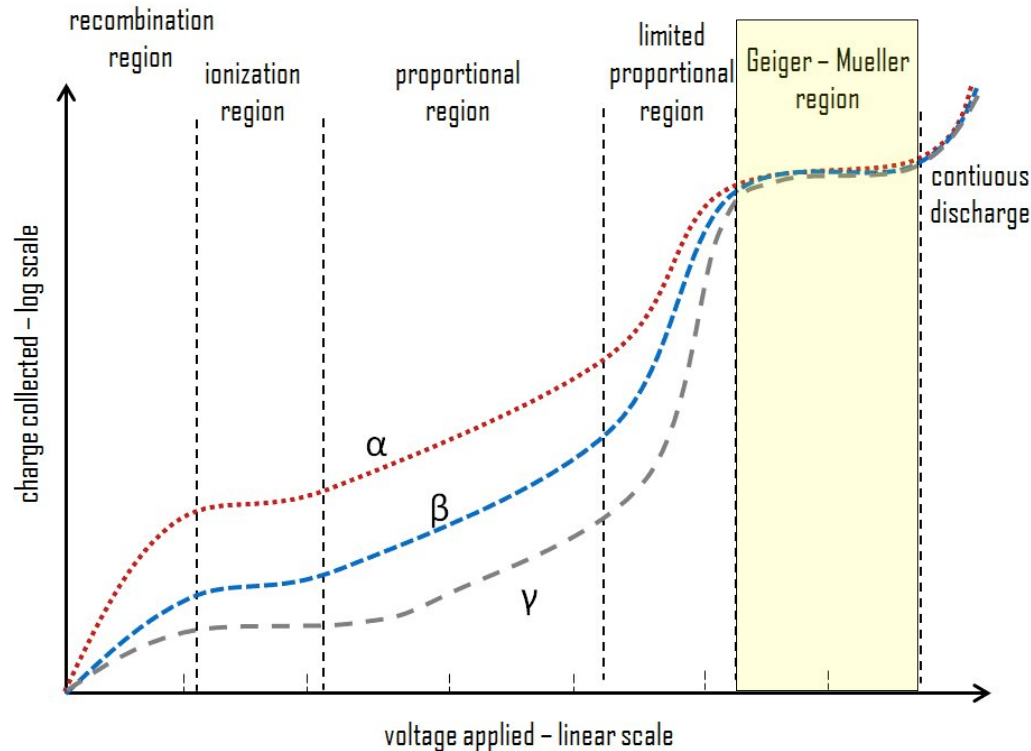
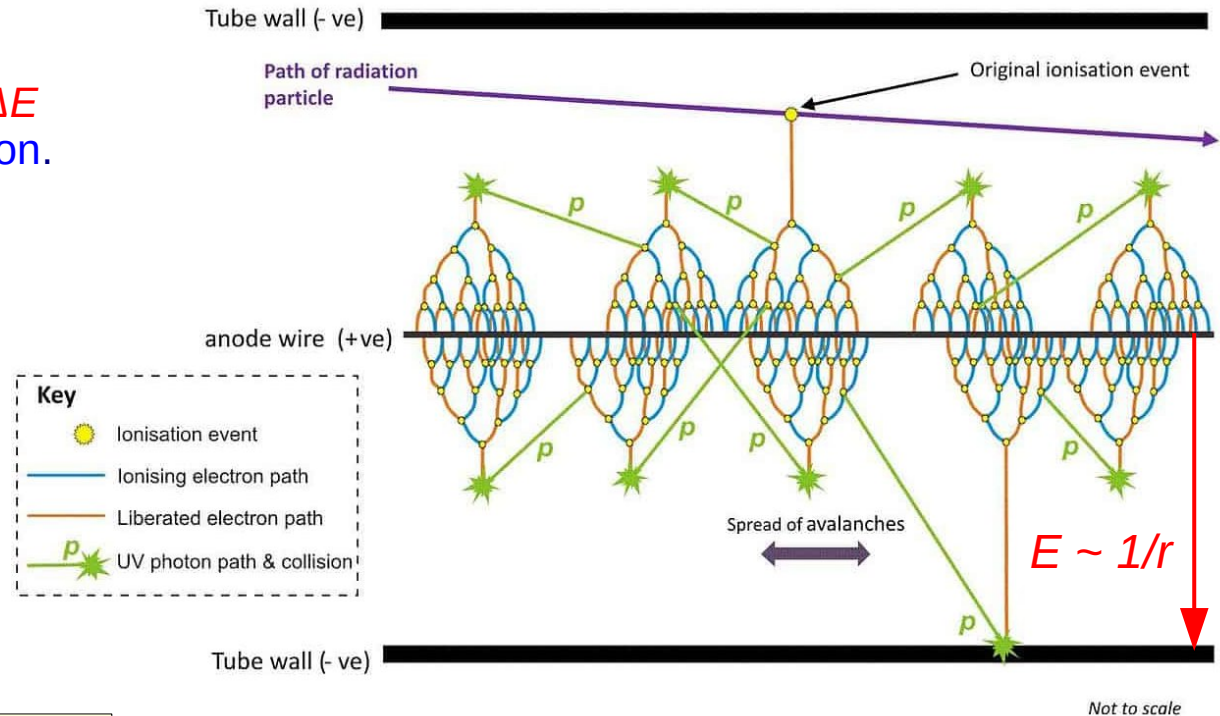
Proportional counters can be used for dE/dx based particle identification. Multiwire proportional chambers, drift chambers and time projection chambers are operated in proportional mode.

Geiger-Müller region

At higher V_0 , liberated space charges distort the E -field $\rightarrow$ proportionality to ΔE gradually lost: Limited proportional region.

Even higher V_0 : Development of detector-wide chain reaction of avalanches (with energy taken from the electric field) – Geiger-Müller region.

Spread of avalanches in a Geiger-Müller tube



Primary ionization $\rightarrow$ avalanche $\rightarrow$ photons from molecular deexcitation trigger secondary avalanches all over detector volume. Full (saturated) response of entire tube for each event, independent of ΔE .

Plateau in collected electron-ion pairs as function of V_0 . Multiplication factor $\sim 10^6 - 10^8$.

Even higher V_0 : Continuous discharge in tube, with and without radiation present.

6.2: Ionization and transport phenomena in gases

Ionization mechanisms:

Bethe-Bloch energy loss takes place via impact processes:

– Excitation of atoms and molecules



Resonant reaction, requires specific energy transfer due to discrete excitation spectrum.

Noble gases: Electronic excitation only, typically with cross section $\sigma_{exc} \sim 10^{-17} \text{ cm}^2$.
Di- (poly-) atomic gases: Also vibrational and rotational states – many excited states.

– Ionization ($X + p \rightarrow X^+ + e^- + p$)

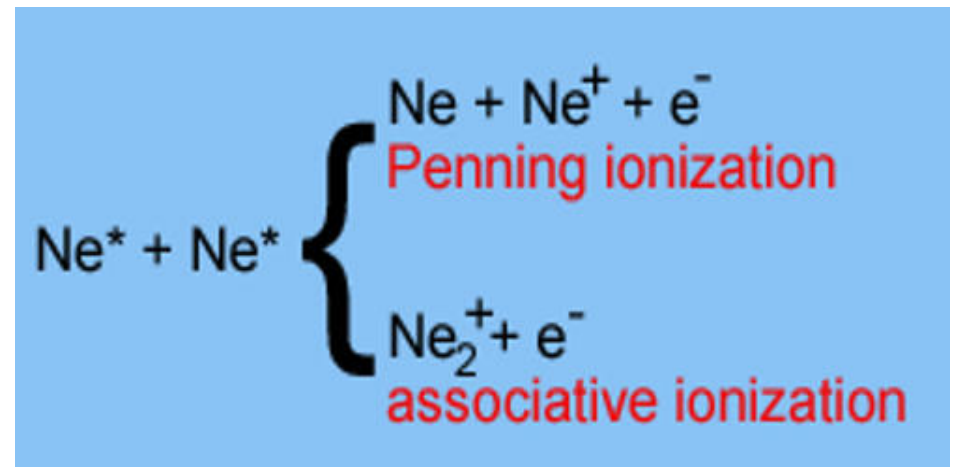
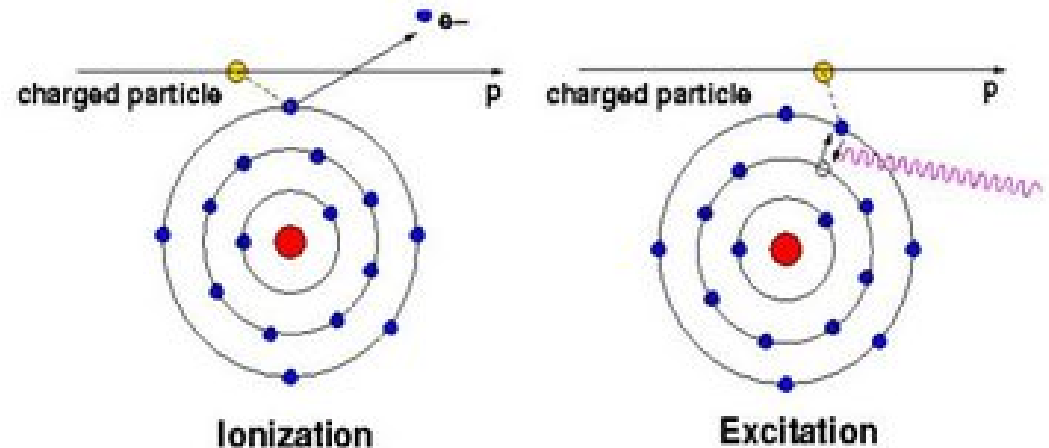
No specific energy transfer required (must be above threshold).

Higher cross section, $\sigma_{ion} \sim 10^{-16} \text{ cm}^2$ but higher threshold energy, $E_{ion}(A) > E_{exc}(A)$

Other ionization mechanisms important in particular in noble gases and mixtures, following excitation of metastable states:

– Penning effect ($A^* + B \rightarrow A + B^+ + e^-$)

– Formation of molecular ions (associative ionization) ($A^* + B^* \rightarrow AB^+ + e^-$)

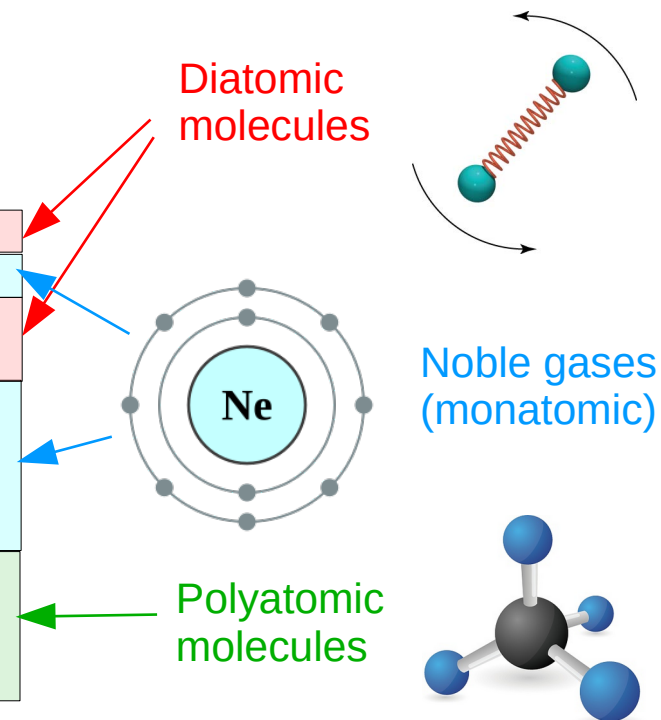


These mechanisms aid ionization by lowering the effective ionization threshold.

Excitation and ionization characteristics of various gases

Table 6.1. Excitation and ionization characteristics of various gases

	Excitation potential [eV] E_{exc}	Ionization potential [eV] E_{ion}	Mean energy for ion-electron pair creation [eV] w
H ₂	10.8	15.4	37
He	19.8	24.6	41
N ₂	8.1	15.5	35
O ₂	7.9	12.2	31
Ne	16.6	21.6	36
Ar	11.6	15.8	26
Kr	10.0	14.0	24
Xe	8.4	12.1	22
CO ₂	10.0	13.7	33
CH ₄		13.1	28
C ₄ H ₁₀		10.8	23



w is mean energy lost by primary particle per electron-ion pair formed.

Always substantially larger than ionization energy E_{ion} . Energy lost both to ionization and excitation (dominant) and to kinetic energy of freed electrons.

w value only weakly dependent on gas species (also on charged particle species / energy).

Excitation (E_{exc}) and ionization (E_{ion}) potential vary significantly with gas species.

Important: w/E_{ion} smaller for noble gases (~ 1.7) than for polyatomic molecules ($\sim 2.1 - 2.5$) (fewer excited states, more of deposited energy goes directly into ionization).

Also note: E_{exc} and E_{ion} decrease with increasing mass in noble gases, such that

$E_{exc}(A_{light}) + \text{small } E_{kin} > E_{ion}(A_{heavy})$ – assists Penning effect in noble gas mixtures.

Resolution in energy measurements

Mean energy w per electron-ion pair created: $w \sim 30$ eV in gases.

Number of electron-ion pairs created: $J = \Delta E / w$ (with ΔE energy lost by incident particle with energy E_0 , $\Delta E = E_0$ if full stopping of particle).

Energy resolution depends on the number of electron-ion pairs J created
(Poisson statistics: Variance $\sigma^2_{Pois} (J) = J$)
and the Fano factor F .
Observed variance $\sigma^2_{obs} (J) = FJ$ where F describes the deviation from Poisson statistics:

$$F = \frac{\text{observed variance } (= FJ)}{\text{Poisson predicted variance } (= J)}$$

Energy resolution often characterised via $FWHM$ (full width half maximum).

Recall: Gaussian distribution $\rightarrow$

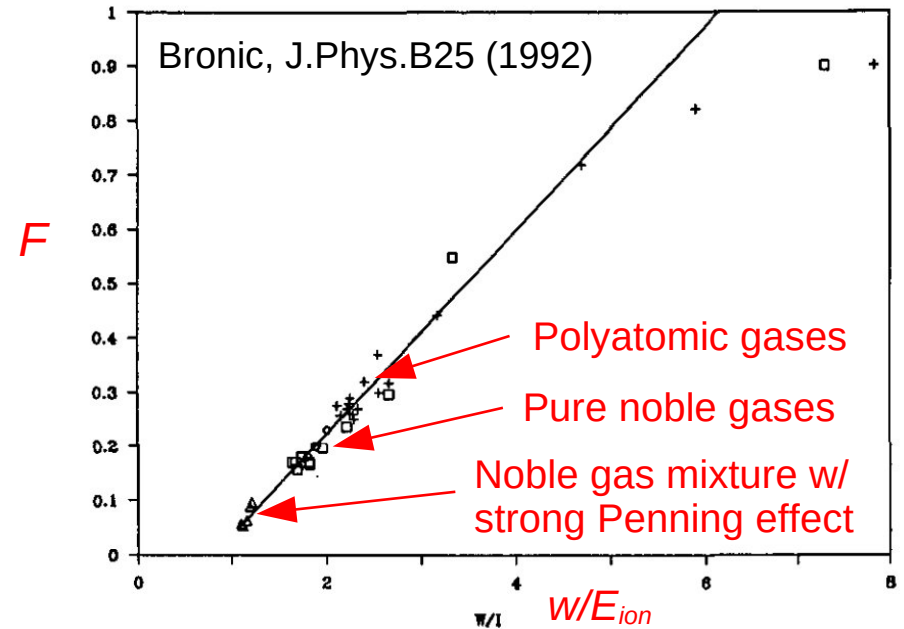
$$FWHM (J) = 2 \sqrt{(2 \ln 2) \sigma_J} = 2.35 \sigma_J$$

where observed $\sigma_J = \sqrt{FJ}$

Relative energy resolution R :

$$R = 2.35 \sqrt{\frac{F}{J}} = 2.35 \sqrt{\frac{Fw}{\Delta E}}$$

where ΔE is total energy deposited by incident particle.



F depends on type of gas / gas mixture (typically ~ 0.2 for pure noble gases).

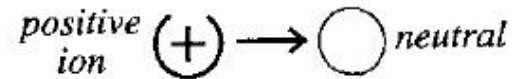
F is a function of all different and partially interdependent processes contributing to energy transfer in a medium (ionization / excitation ...)

F shows a roughly linear dependence on w/E_{ion} . Smaller for high ionization efficiency, particularly small in noble gas mixtures where ionization is aided by the Penning effect ($\sim 0.05 - 0.1$).

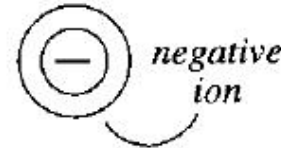
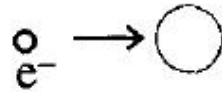
Unwanted processes hampering electron-ion collection: Mostly recombination and electron attachment

Charge transfer between positive ion and neutral gas (important in gas mixtures). Transfer to species with lower E_{ion} .

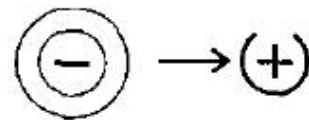
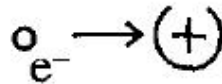
Charge transfer:



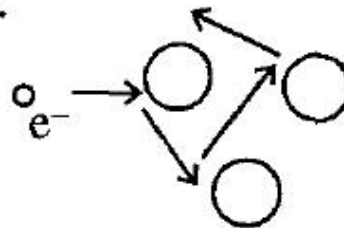
Electron attachment:



Recombination:



Diffusion:



Electron attachment to neutral gas molecules, forming negative ions. Hampers collection of negative charges. Most important for electronegative gases (e.g. O_2 , CF_4). Largely avoided in H_2 , N_2 , noble gases, hydrocarbons.

Recombination takes place between electrons and positive ions, also (quickly) between negative and positive ions in gases with extensive electron attachment. Reduces collected charge $\rightarrow$ poorer energy resolution.

Prevented by sufficiently high voltage $V_0 \rightarrow$ fast charge collection.

Diffusion of electrons (mostly) and positive ions in gas might cause migration away from the region where they are most readily collected, and aid other processes mentioned here. Important effect on spatial resolution.

6.3: Transport of electrons and ions in gases

Thermal diffusion

Liberated electrons and ions diffuse outwards from point of creation.
Multiple collisions lead to random walk and to thermalisation.
Particle velocities described by the Maxwell distribution $f(v)$, with mean value $\langle v \rangle$:

$$f(v) \sim v^2 \exp\left(-\frac{mv^2}{2kT}\right) \quad \langle v \rangle = \sqrt{\frac{8kT}{\pi m}} \quad \begin{array}{l} k: \text{ Boltzmann's constant,} \\ T: \text{ temperature, } m: \text{ particle mass} \end{array}$$

$$T \sim 300 \text{ K: } \langle v_e \rangle \sim 10^4 - 10^5 \text{ m/s, } \langle v_{ion} \rangle \sim 10^2 \text{ m/s}$$

Starting from a δ -function, the 1D distribution of charges (in x) after a time t is given by a Gaussian:

$$\frac{dN}{dx} = \frac{N_0}{\sqrt{4\pi Dt}} \exp\left(-\frac{x^2}{4Dt}\right) \quad \begin{array}{l} D: \text{ diffusion coefficient, } N_0: \text{ total number of charges} \end{array}$$

The rms spread in 1D (x) is: $\sigma(x) = \sqrt{2Dt}$ In 3D (r): $\sigma(r) = \sqrt{6Dt}$

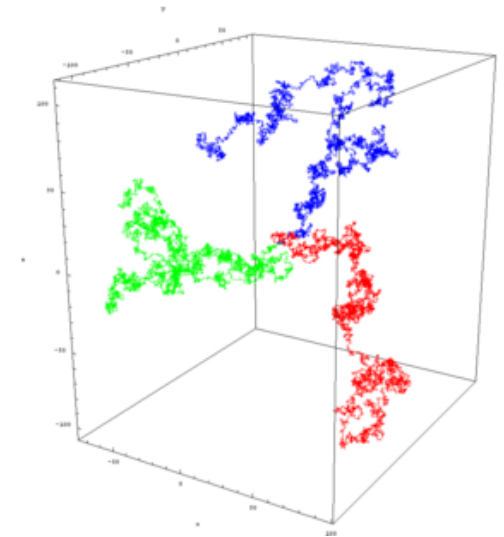
The diffusion constant D is given as: $D = \frac{1}{3} \langle v \rangle \lambda$ $\langle v \rangle$: average velocity
 λ : mean free path in gas

Mean free path λ is: $\lambda = \frac{1}{\sqrt{2}} \cdot \frac{kT}{\sigma_0 p} \quad \left(= \frac{1}{\sqrt{2}} \cdot \frac{1}{n\sigma_0} \right)$ σ_0 : collision cross section
 p : gas pressure
 n : density $N/V = p/kT$

The diffusion constant D can then be expressed:
$$D = \frac{2}{3\sqrt{\pi}} \cdot \frac{1}{\sigma_0 p} \cdot \sqrt{\frac{(kT)^3}{m}}$$

Increases with increasing T

Decreases with increasing m, σ_0, p



Random walk

Drift and mobility in electric field

In the presence of an electric field:
Electrons and ions accelerated by E -field, interrupted by collisions with gas molecules. Average velocity in field direction, drift velocity u , superimposed on random walk, is given as:

$$u = \mu E \sim \frac{eE}{m} \tau \sim \frac{eE}{m} \cdot \frac{\lambda}{\langle v \rangle}$$

μ : mobility of electrons / ions

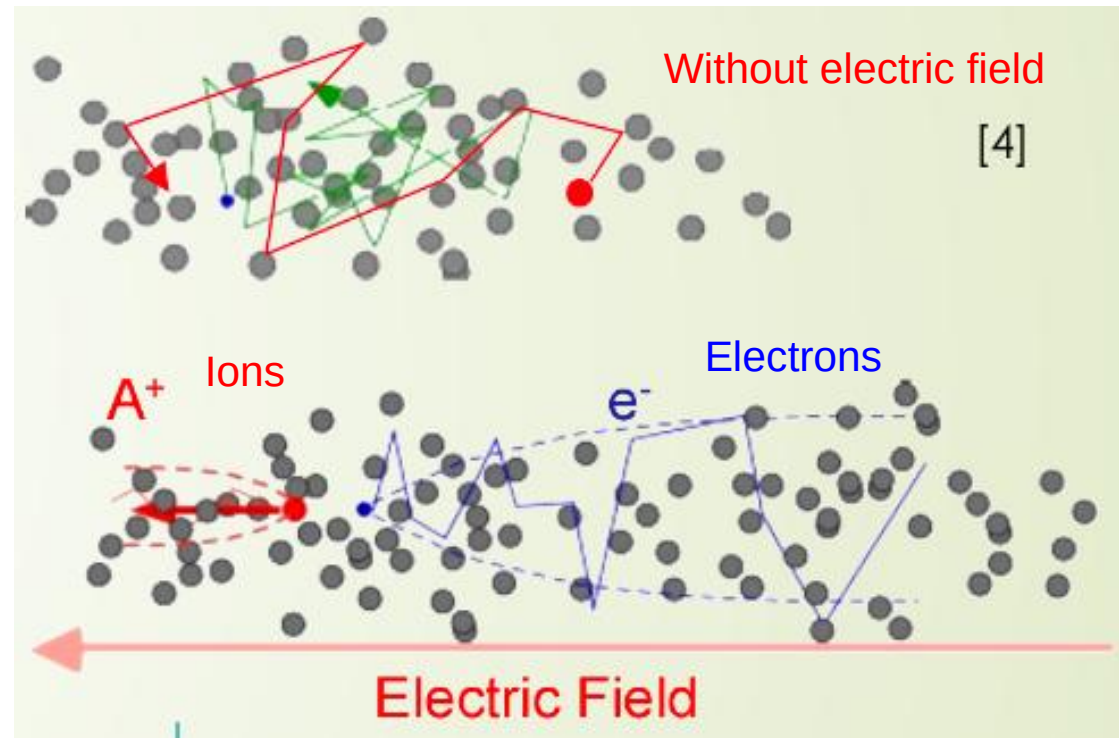
τ : average time between collisions

The mobility μ can be expressed:

$$\mu = \frac{u}{E} \sim \frac{e}{m} \cdot \frac{\lambda}{\langle v \rangle} \sim \frac{e}{m} \cdot \frac{1}{\langle v \rangle} \cdot \frac{kT}{\sigma_0 p}$$

Useful scaling relation for u :

$$u \sim \frac{1}{\sigma_0 \langle v \rangle m} \cdot \frac{E}{p} \quad \begin{array}{l} E/p: \text{reduced field} \\ \text{Note: } \sigma_0 \text{ may be} \\ \text{energy dependent} \end{array}$$



Increasing with increasing T
Decreasing with increasing m, σ_0, p

Positive ions: u grows $\sim$ linearly with reduced electric field E/p (constant collision cross section σ_0) and with $1/m$.

Electrons: u much higher than for ions. Complicated dependence on E/p (σ_0 in general energy dependent)

Ion drift velocities

The drift velocity u for positive ions scales roughly linearly with E/p (reduced field) and with inverse ion mass $1/m$:

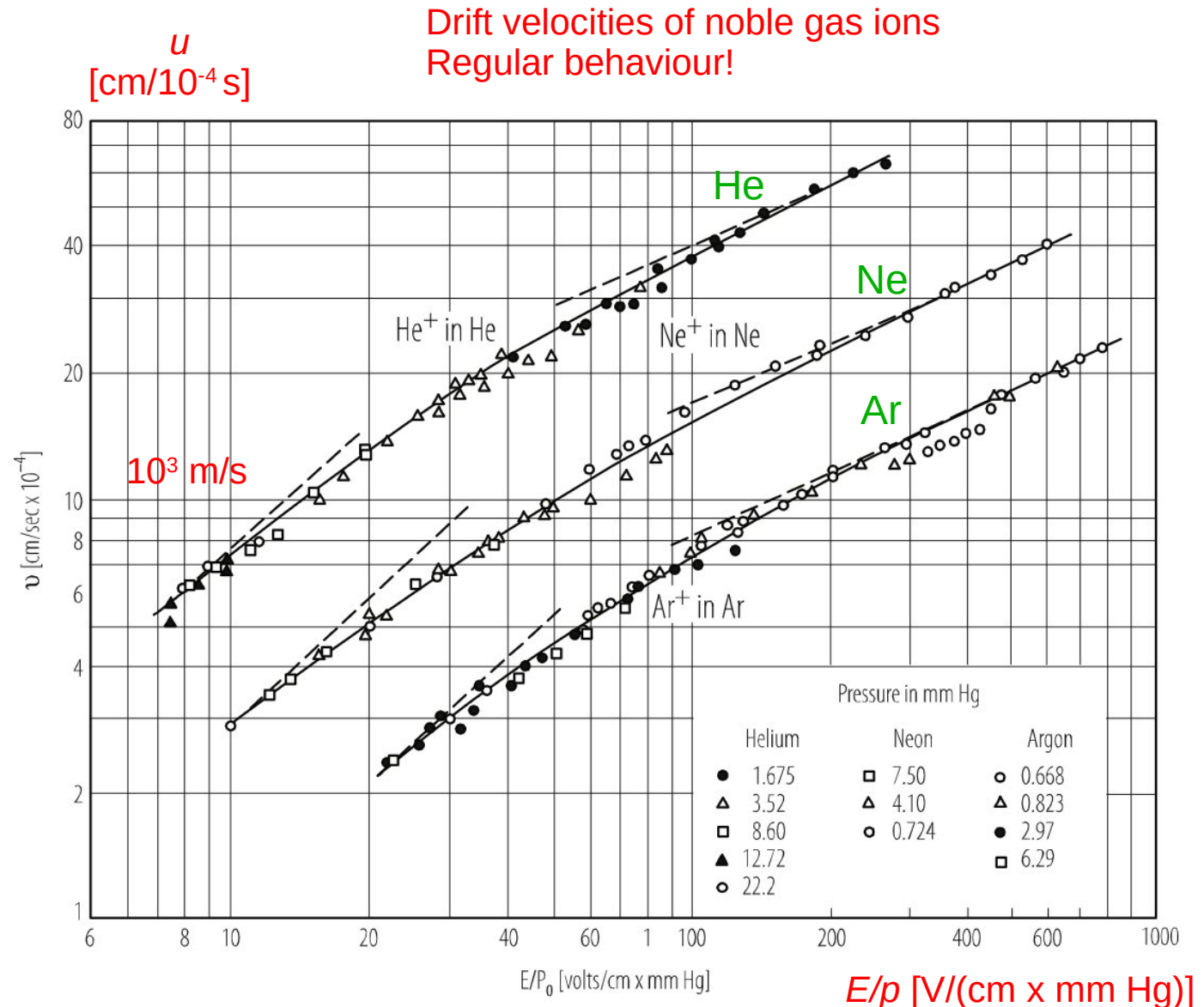
$$u \sim \frac{1}{\sigma_0 \langle v \rangle m} \cdot \frac{E}{p}$$

E/m controls acceleration in electric field.

With $\sigma_0 \sim \text{constant}$, the pressure p controls collision frequency (p is proportional to density n)

Typical ion drift velocities of the order of $\sim 10^3 \text{ m/s}$.

Ion drift velocities are important for rapid dispersal of ion clouds formed in avalanches, which disturb the electric field in the detector and may hamper the counting rate.



Electron drift velocities

Electrons: Much larger drift velocity than ions, found to be a non-trivial function of electric field E and very dependent on gas mixture:

$$u \sim \frac{1}{\sigma_0 \langle v \rangle m} \cdot \frac{E}{p} \quad \sigma_0 = \sigma_0(E_e)!$$

u highly sensitive to collision cross section σ_0 , which depends on instantaneous electron energy E_e .

May have minima (quantum mechanical effect – for certain electron wavelengths the atomic / molecular “obstacles” appear transparent) $\rightarrow$ large $u \sim 1/\sigma_0$ (Ramsauer-Townsend minimum).

Admixtures of polyatomic gases in noble gases may adjust E_e distributions to match dips in $\sigma_0 \rightarrow$ large values of u (gaining drift velocity by lowering instantaneous velocity).

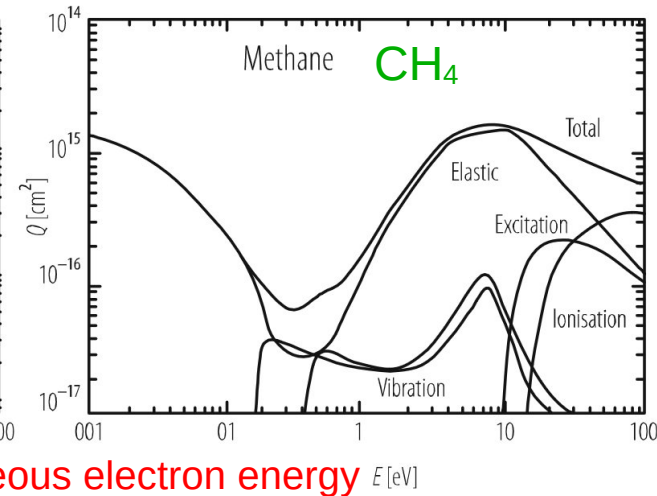
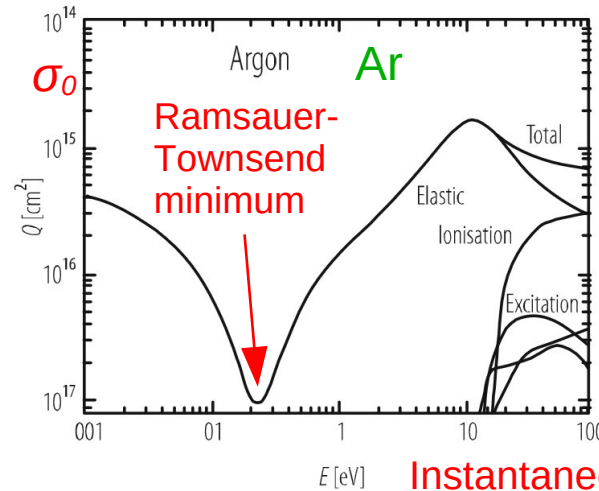
u frequently saturates at not too high E .

Typical electron drift velocities are of the order of a few 10^4 m/s (e.g. Ar-CH₄ mixtures)

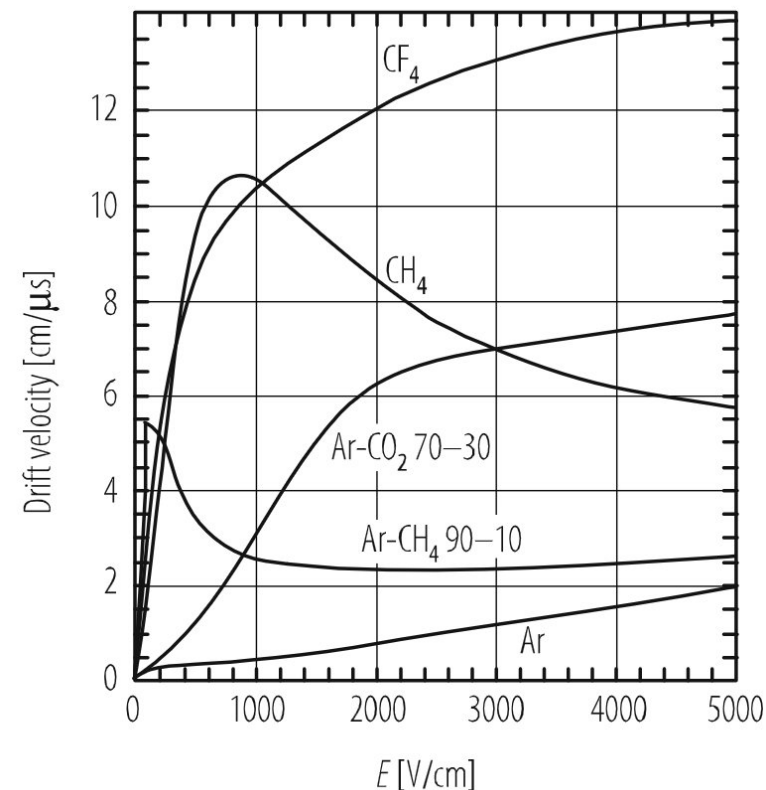
ALICE TPC (90% Ne, 10% CO₂, 5% N₂): $u \sim 2.5 \times 10^4$ m/s

CF₄ (very deep minimum): $u > 10^5$ m/s for high E

Electron collision cross sections



Drift velocities in selected gases



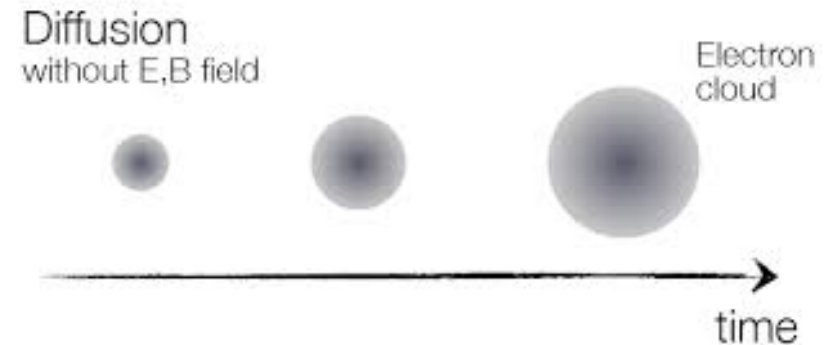
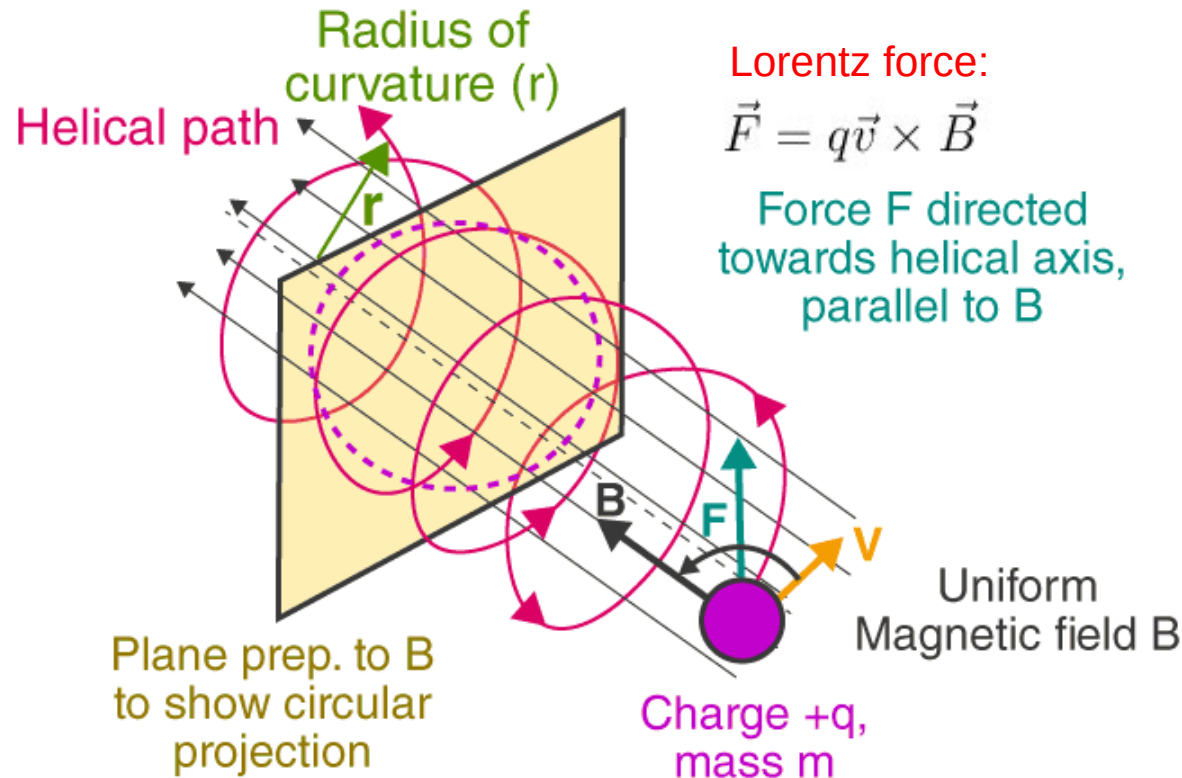
Controlling electron diffusion using a B-field

Electron diffusion can be an issue, compromising spatial resolution of gas detectors, in case of long drift distances (long drift time) or if mean kinetic energy E_e of electrons in E -field exceed thermal value.

We recall spatial spread due to diffusion:

$$\sigma(x) = \sqrt{2Dt} \quad \text{with} \quad D = \frac{2}{3\sqrt{\pi}} \cdot \frac{1}{\sigma_0 p} \cdot \sqrt{\frac{(kT)^3}{m}}$$

Can partially be remedied via a B -field!



Diffusion in parallel electric and magnetic field: Electrons follow helical paths along magnetic field lines $\rightarrow$ reduced transverse diffusion, with spatial spread σ given as:

$$\sigma_{\parallel} = \sqrt{2D_0 t} \quad \sigma_{\perp} = \sqrt{\frac{2D_0 t}{1 + \omega^2 \tau^2}}$$

D_0 : diffusion constant when $B=0$ (same as D)

τ : time between collisions

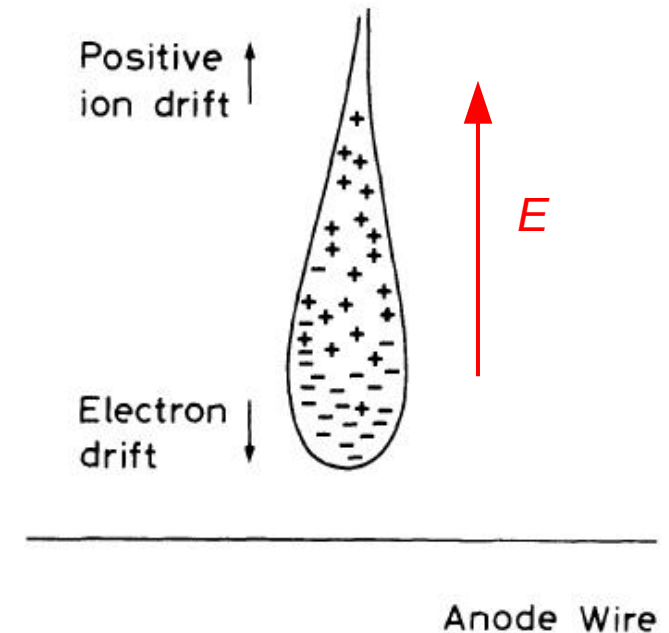
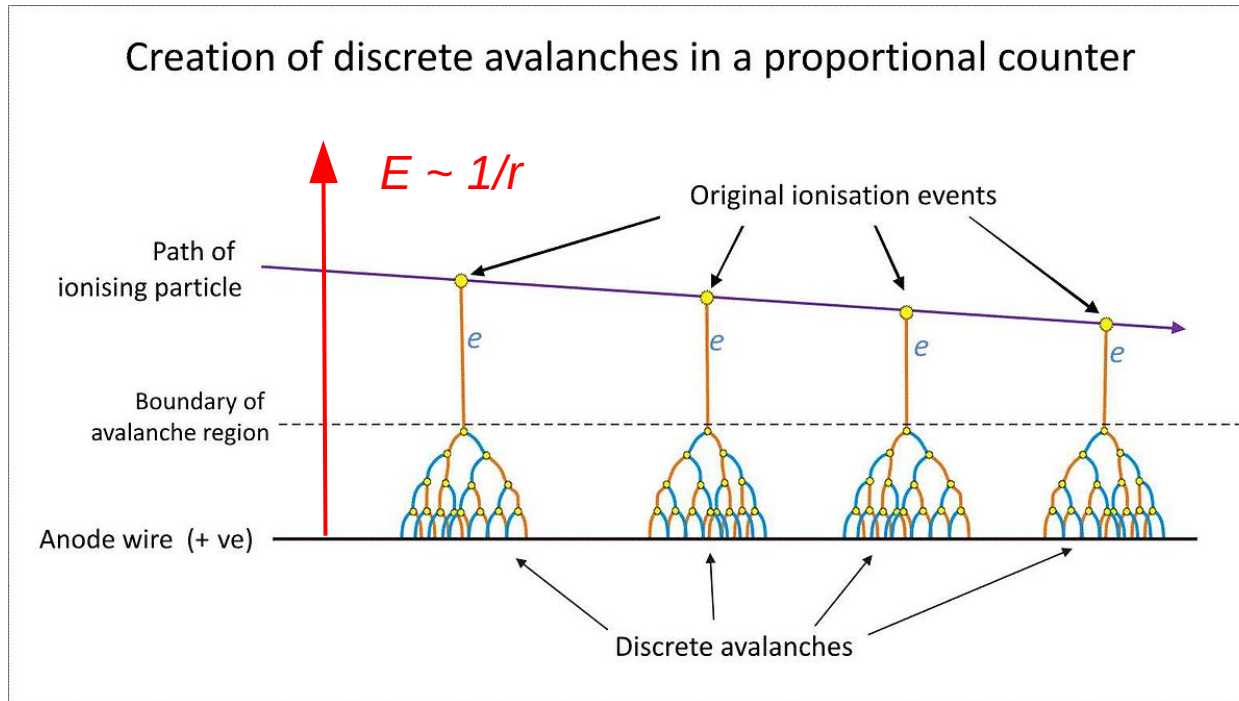
ω : angular spiraling frequency, "cyclotron frequency":

$$\omega = \frac{eB}{m_e}$$

Note: Increasing the pressure p will also reduce diffusion (shorter mean free path).

6.4: Avalanche multiplication

Multiplication in gas detectors: Primary ionization electrons from incident charged particle gain enough energy in E -field to ionize new gas molecules $\rightarrow$ secondary electrons, also accelerated $\rightarrow$ successive steps of ionization $\rightarrow$ development of Townsend avalanche.



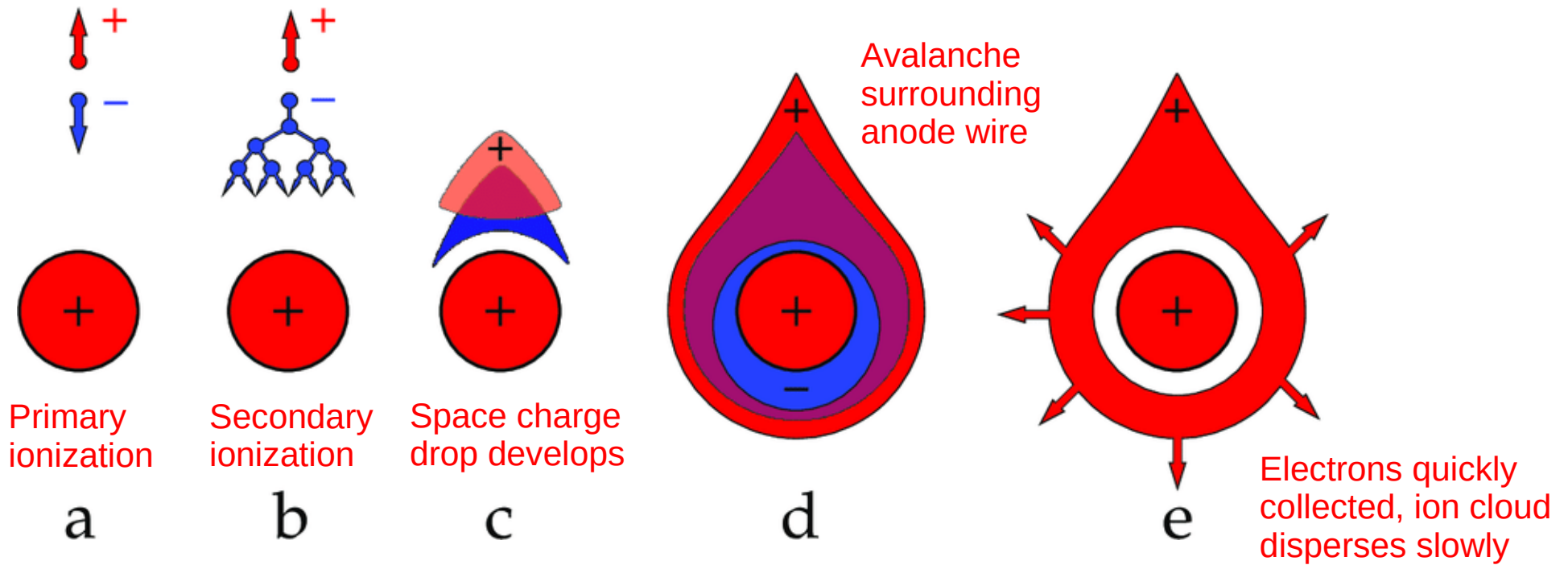
Assuming constant ionization probability α per unit path length, we obtain an exponential development of the avalanche:

$$dn = n\alpha dx \rightarrow n = n_0 \exp(\alpha x)$$

n (n_0): number (initial number) of electrons
 x : path length in gas

The electron multiplication factor M is then given as: $M = n/n_0 = \exp(\alpha x)$

Time development of avalanche close to anode wire (normal Townsend avalanche):



General case – non-constant ionization probability α

Typically α depends on the electric field E , which is position dependent. E.g. cylindrical detector, radial field:
The multiplication factor M is in the general case given as:

$$M = \exp \left[\int_{r_1}^{r_2} \alpha(x) dx \right]$$

The dependence $\alpha(E(r))$ can be modelled:

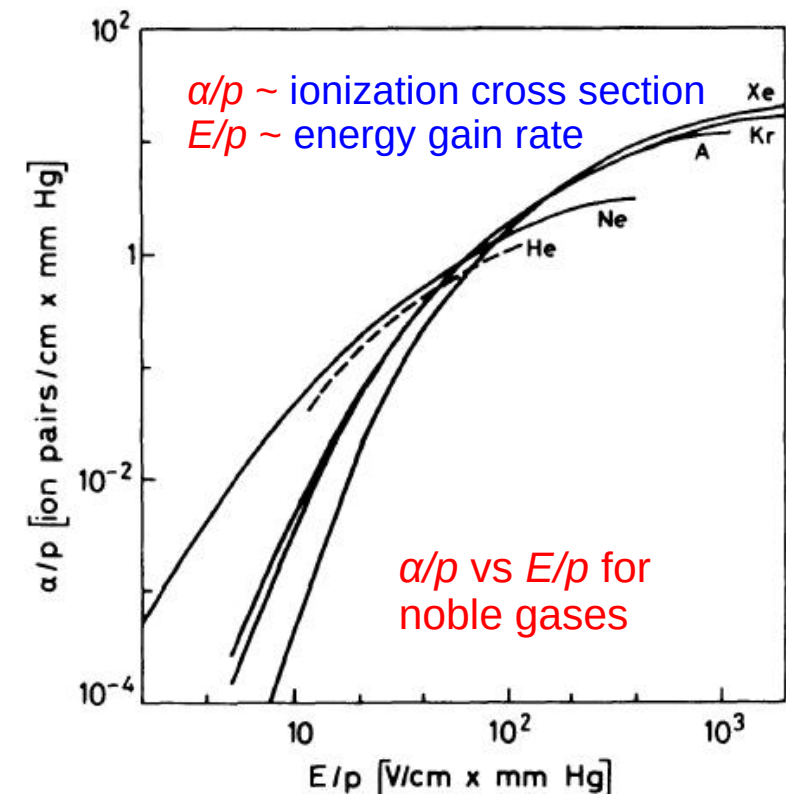
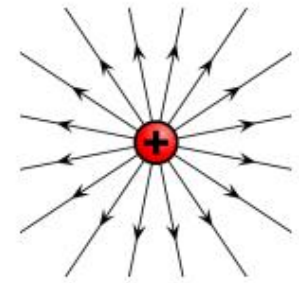
- Electrons need to travel a length Δx_{ion} in the E -field in order to gain sufficient energy (E_{ion}) to ionize: $eE\Delta x_{ion} = E_{ion}$.
- Probability for electron to travel Δx_{ion} without interruption equals $\exp(-\Delta x_{ion} / \lambda) = \exp(-E_{ion} / eE\lambda)$ where λ is mean free path.
- Ionization probability $\alpha \sim$ probability for gaining enough energy times the probability for colliding with a gas molecule, inversely proportional to λ .

We then have $\alpha \sim 1/\lambda \exp(-E_{ion} / eE\lambda)$ where $\lambda \sim 1/(\sigma_0 p)$:

$$\frac{\alpha}{p} = A \exp \left(\frac{-Bp}{E} \right) \quad A, B: \text{constants fitted to experimental data}$$

Expression for $\alpha(E(r))$ can be inserted in integral above to find multiplication factor M .

$$E(r) = \frac{1}{r} \cdot \frac{V_0}{\ln(b/a)}$$



Typical multiplication factors in gases and gas mixtures:

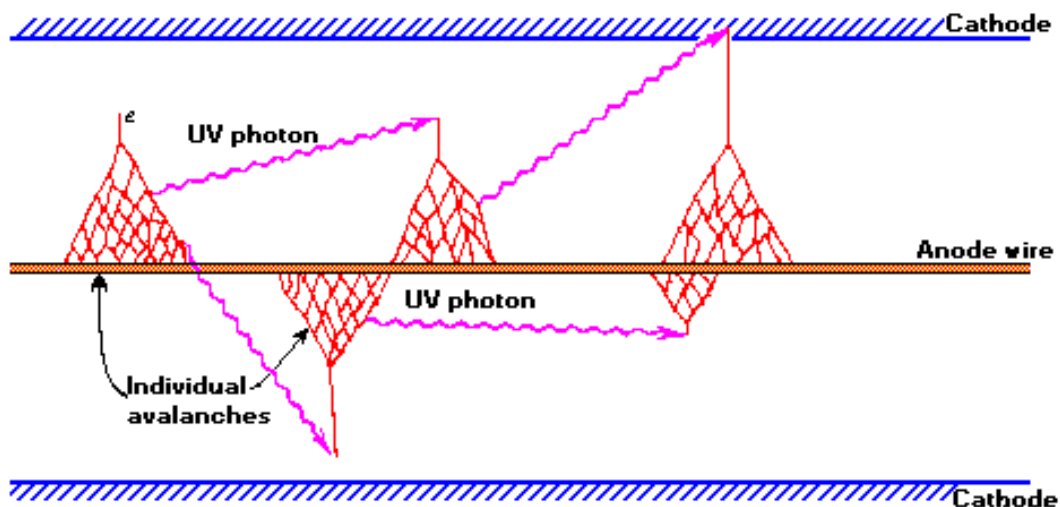
Multiplication factor M (gas gain) depends on gas and on voltage:

$$M = \exp \left[\int_{r_1}^{r_2} \alpha(x) dx \right] \quad \text{where} \quad \frac{\alpha}{p} = A \exp \left(\frac{-Bp}{E} \right)$$

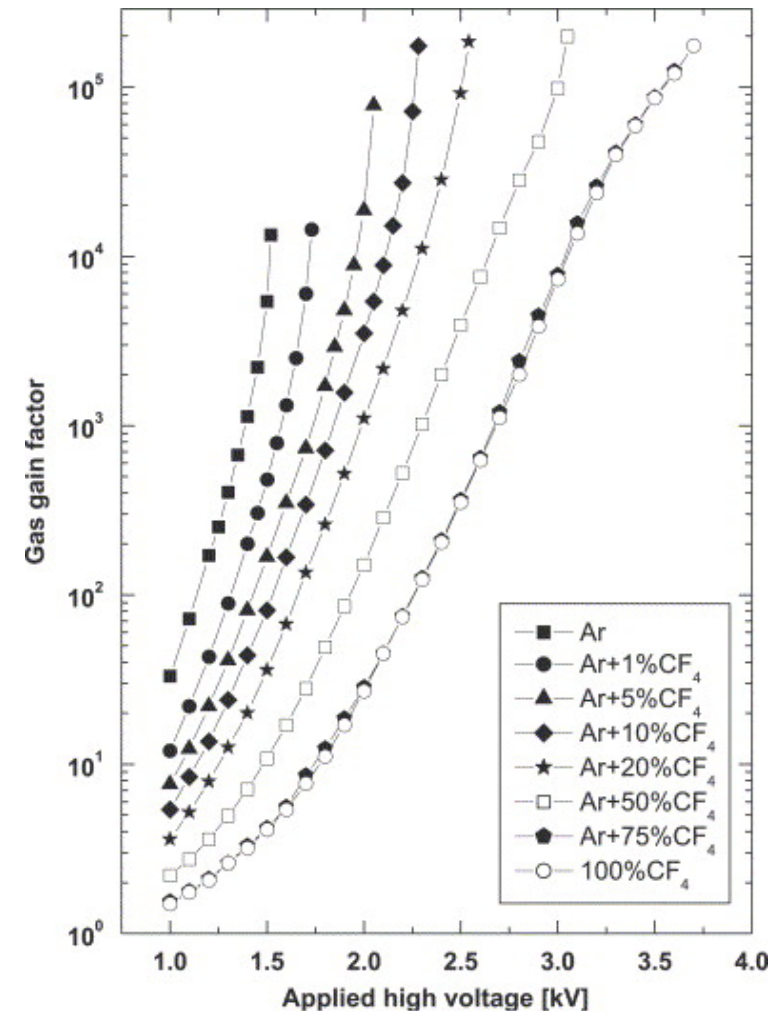
M increases steeply with increasing V_0 .

Typically $M \sim 10^3 - 10^4$ ($< 10^6$) for proportional counter.

Pure noble gases cannot sustain M above $\sim 10^3 - 10^4$.
High excitation energies due to electronic excitation only $\rightarrow$ UV and X-ray photons from deexcitations can trigger new avalanches (GM-like behaviour), in particular by ionizing cathode, already at moderate V_0 .



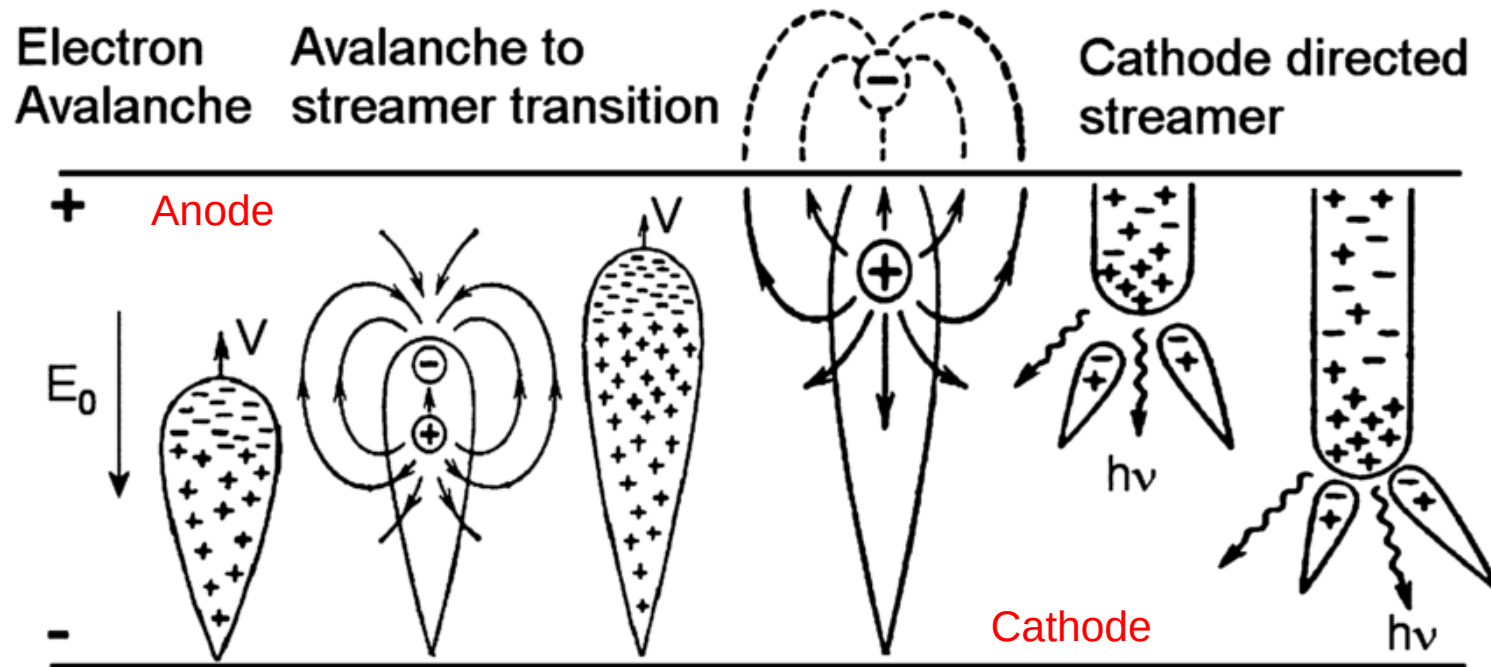
M as function of V_0 for various gas mixtures (Ar – CF₄)



This problem with noble gases can be mitigated by adding polyatomic gases (with rotational and vibrational excitations) as photon absorbers – quenchers.
E.g. Ar – CH₄ or Ar – CF₄ mixtures.

Avalanche breakdown at very high multiplication

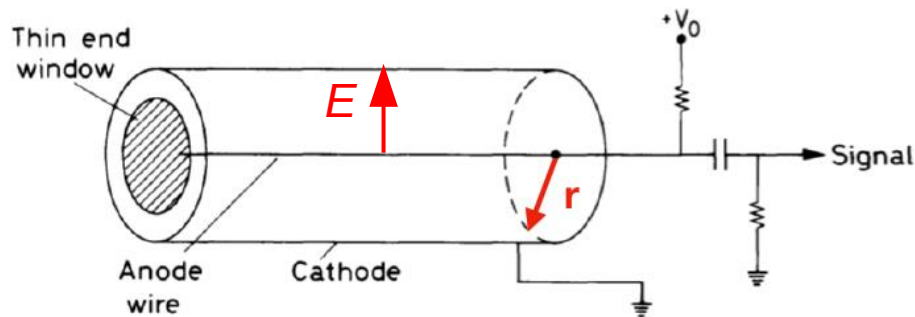
In practice, the multiplication factor M has an upper limit (Raether limit) of $M < 10^8$ ($\alpha x < 20$). For higher M (V_0), avalanche breakdown takes place due to space charge distorting the E -field. Proportionality is then already lost (GM-like behaviour for $M \sim 10^6 - 10^8$).



Very high $M \rightarrow$ high space charge densities distort the applied E -field:

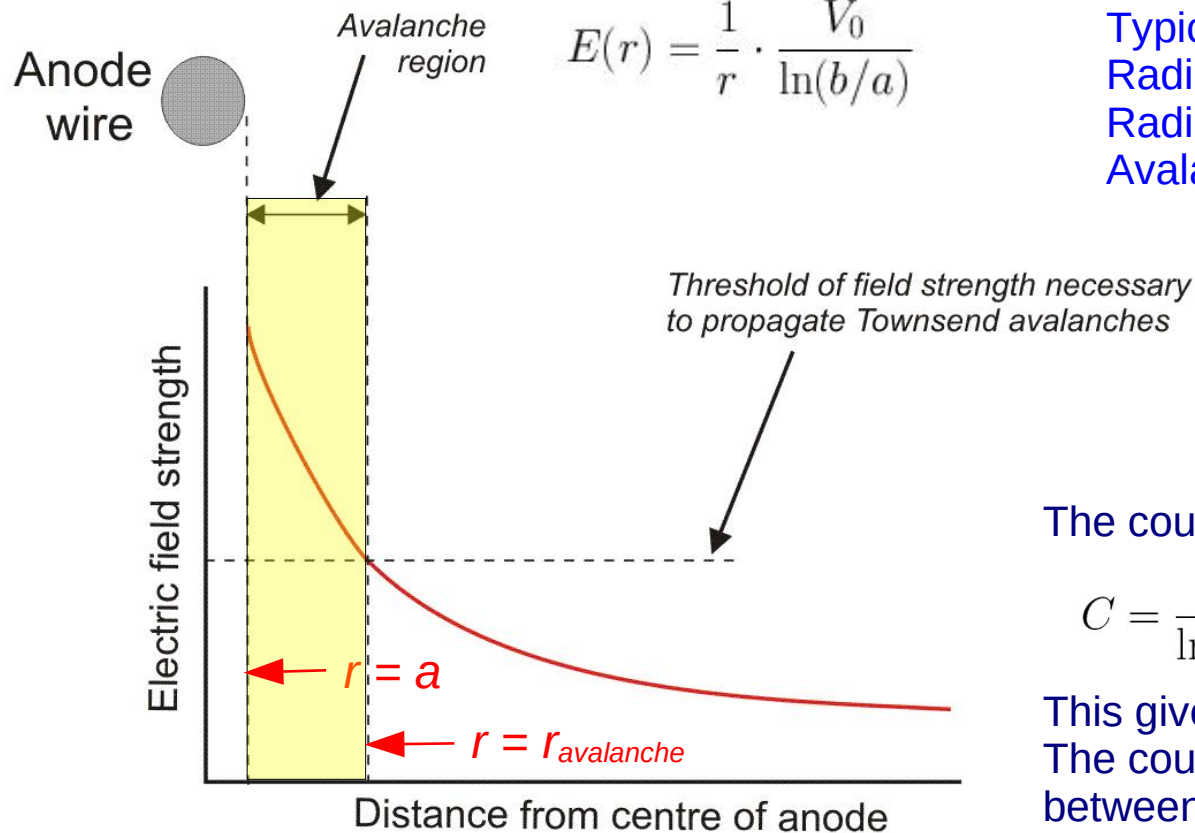
- The liberated charge cloud acts as a dipole, partially cancelling original E in some regions
- E strongly magnified at head and tail of charge cloud
- Photon emission from increased recombination of ions and electrons, can initiate new avalanches which are attracted to existing space charge
- Avalanche converted into streamer (spark) which spans the distance between anode and cathode

6.5: The cylindrical proportional counter



Electric field $E(r)$ in cylindrical geometry:

$$E(r) = \frac{1}{r} \cdot \frac{V_0}{\ln(b/a)}$$



Cylindrical geometry: Almost all the multiplication takes place close to the anode wire. Multiplication M is given as:

$$M \sim \exp \left[\int_{r=r_{\text{avalanche}}}^{r=a} \alpha(r) dr \right]$$

M approximately independent of ionization point $\rightarrow$ total collected charge and electric signal proportional to deposited energy.

Typical dimensions of counter:

Radius of anode wire $a \sim 10 \mu\text{m}$

Radius of cathode tube $b \sim 10 \text{ mm}$

Avalanche region a few μm thick.

Critical reduced field strength E/p needed for avalanche formation depends on gas type but is of the order of $\sim 10^6 \text{ V/(m atm)}$

The counter has a capacitance C :

$$C = \frac{2\pi\epsilon l}{\ln(b/a)} \quad \begin{array}{l} l \text{ is length of tube} \\ \epsilon \text{ is dielectric constant (close to } \epsilon_0) \end{array}$$

This gives a C of typically some pF.

The counter also has a resistance $R \sim$ some $\text{M}\Omega$ between anode and cathode.

Pulse formation in cylindrical proportional counter

Electric signal generated by movement of charges (mostly positive ions), not by electron collection on anode. Moving charges distort the original E -field and induce a small drop ΔV in the voltage between anode and cathode.

Energy conservation – energy ΔW transferred to charged particles taken from field energy:

$$\frac{1}{2}CV^2 = \frac{1}{2}CV_0^2 - \Delta W \quad \begin{array}{l} V_0 \text{ is original voltage, } V = V_0 + \Delta V \\ C \text{ is capacitance of tube} \end{array}$$

ΔW equals work done on charged particles by E -field:

$$\begin{aligned} \Delta W_+ &= \int_{a+r'}^b (+q)E(r)dr = \frac{V_0 q}{\ln(b/a)} \ln\left(\frac{b}{a+r'}\right) && \text{ions} \\ \Delta W_- &= \int_{a+r'}^a (-q)E(r)dr = \frac{V_0 q}{\ln(b/a)} \ln\left(\frac{a+r'}{a}\right) && \text{electrons} \end{aligned}$$

Total energy transfer ΔW proportional to collected charge q :

$$\Delta W = \Delta W_+ + \Delta W_- = \frac{V_0 q}{\ln(b/a)} \ln\left(\frac{b}{a+r'} \cdot \frac{a+r'}{a}\right) = V_0 q$$

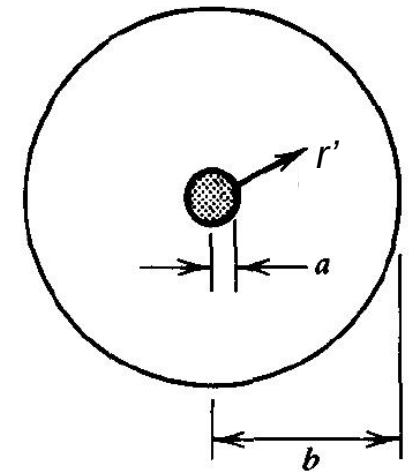
Size of voltage drop $\Delta V = V - V_0$ ($\ll V_0$) is found using energy conservation:

$$\frac{1}{2}CV^2 - \frac{1}{2}CV_0^2 = \frac{1}{2}C(V+V_0)(V-V_0) \approx CV_0\Delta V = -\Delta W \quad \Delta V = \frac{-\Delta W}{CV_0} = -\frac{q}{C}$$

Ratio of contributions from electrons and ions:

$$\frac{\Delta V_-}{\Delta V_+} = \frac{\Delta W_-}{\Delta W_+} = \frac{\ln\left(\frac{a+r'}{a}\right)}{\ln\left(\frac{b}{a+r'}\right)}$$

Some typical dimensions – $a \sim 10 \mu\text{m}$, $b \sim 10 \text{ mm}$, $r' \sim 1 \mu\text{m}$ – give a ratio $\Delta V_-/\Delta V_+$ of less than 1%.



Electrons move from $a+r'$ to a
Ions move from $a+r'$ to b in
electric field $E(r)$:

$$E(r) = \frac{1}{r} \cdot \frac{V_0}{\ln(b/a)}$$

r' is distance of ionization
point from anode surface

Time development of pulse

Assuming ions (created near $r=a$) to dominate the pulse, the time evolution $V(t)$ of the pulse depends on $r(t)$ of the ions:

$$\Delta V(t) = \frac{-\Delta W_+(r(t))}{CV_0} = -\int_a^{r(t)} qE(r(t))dr = -\frac{q}{C \ln(b/a)} \ln\left(\frac{r(t)}{a}\right)$$

The motion is governed by the drift velocity $u(r) = \mu E(r)$ (μ is ion mobility):

$$\frac{dr}{dt} = u = \mu E(r) = \frac{\mu}{r} \frac{V_0}{\ln(b/a)} \rightarrow r dr = \frac{\mu V_0}{\ln(b/a)} dt$$

Integrating this differential equation from a to $r(t)$ and from 0 to t , we can solve for $r(t)$ and obtain $V(t)$:

$$r(t) = a \left[1 + \frac{2\mu V_0}{a^2 \ln(b/a)} t \right]^{1/2} \quad \Delta V(t) = -\frac{q}{C \ln(b/a)} \ln \left[1 + \frac{2\mu V_0}{a^2 \ln(b/a)} t \right]^{1/2}$$

The ions reach the cathode at $r=b$ at time T :

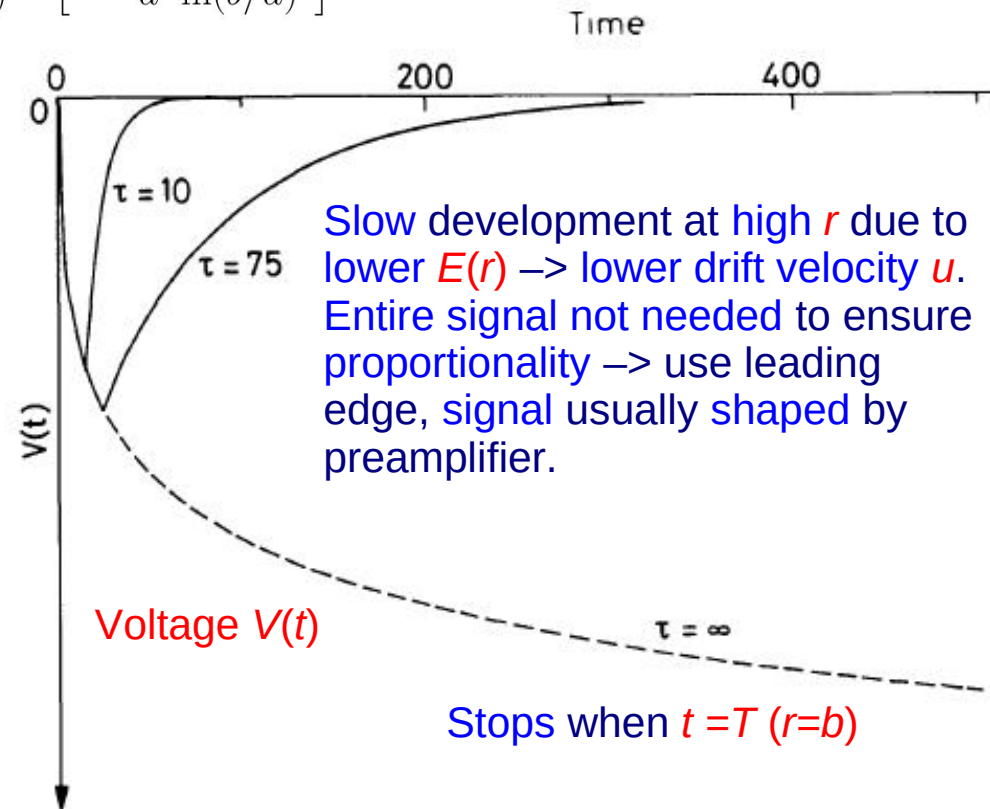
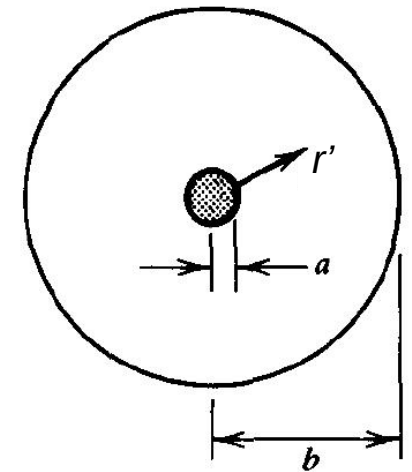
$$r(T) = b \rightarrow T = \frac{\ln(b/a)(b^2 - a^2)}{2\mu V_0}$$

The pulse then reaches its maximum amplitude:

$$\Delta V(T) = -\frac{q}{C}$$

This is the theoretical maximum amplitude for large time constant $\tau = RC$ for the counter.

Assumption of ion domination with creation at $r=a$ can break down if ultraviolet photons extends avalanche to higher $r \rightarrow$ important contribution also from electrons. Gas dependent phenomenon.

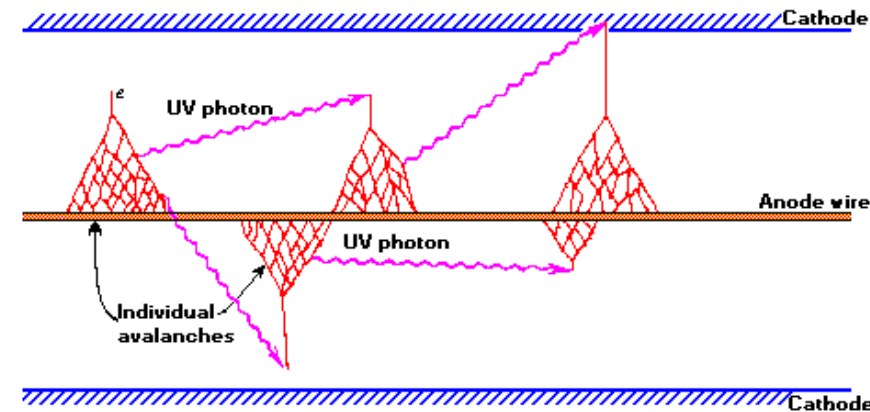


Choice of gas for proportional counter

Many considerations, e.g.:

- Low voltage required for avalanche formation
- High gain (multiplication factor)
- Good energy proportionality
- High rate capability (e.g. for HEP applications)
- Chemical properties (stable, non-toxic)
- Cost

Specific choice depends on desired functionality of detector.



Secondary avalanches triggered by photons liberating electrons from cathode – common problem in noble gases.

Noble gases frequently used (He, Ne, Ar, Kr, Xe).

High ionization probability for given E -field (low competition from excitation).

Also low electron attachment $\rightarrow$ most electrons reach avalanche region.

This ensures low operational voltage, high gain and good proportionality.

All are chemically inert.

Cost considerations favour Ar (0.93% volume fraction in air)

Rate capabilities favour Ne (lighter ions more quickly dispersed due to higher drift velocity u)

Gain increases with voltage, but operational voltage range is limited by secondary avalanche formation due to deexcitation photons (UV, X-rays) $\rightarrow$ GM mode, lost proportionality.

Remedied by addition of quencher – polyatomic gas which absorbs photons (e.g. CO_2 , CH_4).

Additional benefits of polyatomic gas admixture: Can improve gain at low V_0 via Penning effect, can increase u for electrons due to Ramsauer effect.

Frequently used gas mixture: 90% Ar, 10% CH_4 (called P10 gas)

Also: Add electronegative gas (e.g. CF_3Br , N_2) to catch electrons from the cathode.

Possible questions for the FYS4505 examination

- Describe (briefly) the operational modes of gaseous ionization detectors at different voltages between anode and cathode
- Mention some factors important for the number of created electron-ion pairs and for the energy resolution, when a particle deposits a certain amount of energy
- Mention some processes hampering the collection of electron-ion pairs in gases
- Explain some important factors for diffusion and drift of electrons and ions in gases
- Describe the development of an electron-ion avalanche in a gas counter
- Explain (qualitatively) the principle of operation for a cylindrical proportional counter
- Mention some important factors regarding the choice of gas / gas mixture for an ionization detector