Chapter 6

Jill Pinter

2. As a fast charged particle passes through a gas, the particle can create both excited molecules and ionized molecules along its path. When a neutral molecule is ionized, a positive ion and free electron result, an ion pair. Sometimes, the free electron attaches to a neutral gas molecule and a negative ion is formed. So, why is air widely used as a fill gas for ionization chambers but seldom in proportional counters?

Short answer:

An ion chamber operated in direct current mode can collect either the free electrons or electrons that combine with neutral gas molecules to form negative ions. Either way, the electrons get counted. Oxygen in Air has a rather high electron attachment coefficient, and readily forms negative ions. This is not a problem in ion chambers but *is* a problem in proportional counters. In proportional counters, gas multiplication is critically dependent on the migration of free electrons rather than the much slower negative ions. Thus, ✓ the fill gas in a proportional counter cannot have a high electron attachment coefficient, which air has.

For more information, read on:

In ionization chambers, air is actually required in chambers designed to detect γ-ray exposure. Air-filled ion chambers are well suited for this application because exposure is defined in terms of the amount of ionization charge created in air. On the other hand, if one wants to use a pulse type ion chamber in electron sensitive mode, the fill gas should be such that the electrons remain as free electrons and do not form negative ions. This is because the amplitude of the pulse reflects only the drift of the electrons. The time constant is chosen so this is true. It is an intermediate between the electron collection time and the ion collection time.

In proportional counters, adding a small amount of polyatomic gas, like methane, to the common fill gas will suppress the photon-induced effects by absorbing the photons in a mode that does not lead to further ionization. This gas is called a quench gas. Air can be used in proportional counters under special circumstances. If the distance that the electrons must travel is only ~1-2 mm and the electric field is ~~big~~ kept high in the drift region, enough electrons escape attachment to form small but detectable avalanches.

4. We have:

windowless flow proportional counter

fully stopped 5 MeV α

$a = 0.005$ cm (anode radius)

$b = 5.0$ cm (cathode radius)

P-10 gas at 1 atm

applied voltage = 2000 V

$C = 500$ pF

From Table 6.1, for P-10 gas (90% Ar, 10% CH_4)

$K = 4.8 \times 10^4 \ \frac{V}{cm\ atm}$

$\Delta V = 23.6$ V

First calculate the gas multiplication factor, M.

$$\ln M = \frac{V}{\ln(b/a)} \cdot \frac{\ln 2}{\Delta V} \left(\ln \frac{V}{paK \ln(b/a)} \right)$$

$$= \frac{2000\ V}{\ln(5\,cm/0.005\,cm)} \cdot \frac{\ln 2}{23.6\ V} \left(\ln \frac{2000\ V}{(1\,atm)(0.005\,cm)} \frac{cm\ atm}{4.8 \times 10^4\ V \cdot \ln(5\,cm/0.005\,cm)} \right.$$

$\ln M = 1.595$ (notice all units cancel!)

$\boxed{M = 4.93}$ ✓

The maximum pulse amplitude is:

$V_R = \frac{Q}{C}$ where $Q = n_0 e M$

First we need n_0. $n_0 = \frac{E_\alpha}{W_{P\text{-}10}}$

for α particles,

$W_{Ar} = 26.3$ eV/ion pair

$W_{CH_4} = 29.1$ eV/ion pair

} from Table 5.1

$W_{P\text{-}10} = 0.9(26.3\ \text{eV/ion pair}) + 0.1(29.1\ \text{eV/ion pair}) = 26.58$ eV/ion pair so, $W_{P\text{-}10} = 26.58$ eV/ion pair

$$n_0 = 5 \times 10^6 \text{ eV} \cdot \frac{\text{ion pair}}{26.58 \text{ eV}}$$

$n_0 = 188{,}111$ ion pairs
(that is, 1.88×10^5 ion pairs)

Thus,

$$V_R = \frac{n_0 e M}{C}$$

$$= \frac{1.88 \times 10^5 \cdot 1.6 \times 10^{-19} \text{ C} \cdot 4.93}{500 \times 10^{-12} \text{ F}}$$

$\uparrow$ C/V units: $\frac{\cancel{C}\,V}{\cancel{C}} = V$

$V_R = 2.97 \times 10^{-4}$ V

$\boxed{V_R = 0.30 \text{ mV}}$ ✓

6. In a windowless proportional counter, the output pulse height from an α source will increase with increasing particle energy, but the opposite is true for β particles.

This is because the range of α particles is much less than the range of β particles. Specifically, α particles have a range in the counter gas that is less than the dimensions of the chamber so it is easy for proportional counters to record each particle that enters the active volume with almost 100% efficiency. Since the output pulse height is dependent on the number of ion pairs that are formed, a higher energy α will create more ion pairs as it comes to rest within the chamber and thus a higher pulse height. →

6. cont: For β particles, the particle range greatly exceeds the chamber dimensions, and almost all of the β particles hit the walls of the chamber, depositing their energy there. Thus, the number of ion pairs formed in the gas is proportional to only that small fraction of the particle energy lost in the gas before reaching the opposite wall. Also as the energy of the beta increases the dE/dx in gas will go down and more energy will be deposited in wall.

7. We have:

voltage sensitive preamplifier
min. input pulse amplitude = 10 mV
Ar filled counter
$C = 200$ pF
50 keV X-rays

From Table 5.1 for Ar,
$W = 26.4$ eV/ion pair for fast e^-
$W = 26.3$ eV/ion pair for α particles
W will be ≥ 26.4 eV/ion pair for X-rays

$$n_0 = \frac{E_{x\text{-ray}}}{W}$$

$$n_0 \leq 50 \times 10^3\, eV \cdot \frac{\text{ion pair}}{26.4\, eV}$$

$$n_0 \leq 1893.94 \text{ ion pairs}$$

From before, $Q = n_0 e M$

$$M = \frac{Q}{n_0 e} = \frac{CV}{n_0 e} \qquad M \geq \frac{200 \times 10^{-12}\, \overset{\frac{C}{V}}{F} \cdot 10 \times 10^{-3}\, V}{1893.94 \cdot 1.6 \times 10^{-19}\, C}$$

units cancel!

$$\boxed{M \geq 6625} \checkmark$$

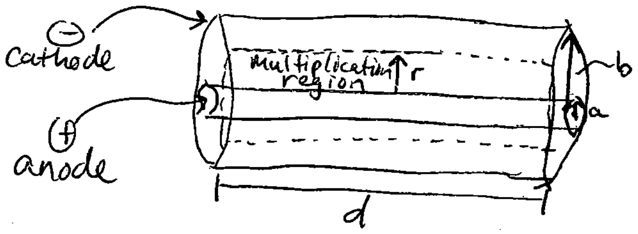
8. We have:

a cylindrical proportional tube
$a = 0.003$ cm (anode)
$b = 2.0$ cm (cathode)
applied $V = 2000$ V
minimum $\mathcal{E} = 1.0$ MV/m (that's 1.0×10^6 V/m)
to initiate gas multiplication

We want the fraction of the volume of the tube that corresponds to the multiplication region.

The multiplication region will extend, or start at, the r of the minimum $\mathcal{E}$ to initiate multiplication:

$$\mathcal{E}(r) = \frac{V}{r\ln(b/a)}$$



at the minimum $\mathcal{E}$ to initiate multiplication,

$$r = \frac{V}{\mathcal{E}\ln(b/a)}$$

$$= \frac{2000\,\text{V} \quad \text{m}}{\cancel{1.6\times10}\; 1\times10^6\ \text{V} \quad \ln(2\,\text{cm}/0.003\,\text{cm})}$$

$$r = 0.3076\ \text{mm}$$ ✓

Take a ratio of the volume of the multiplication region to the total volume of the cylinder:

$$\frac{V_{MR}}{V_{TOT}} = \frac{\pi r^2 d}{\pi b^2 d}$$ where d is the length of the tube

$$\frac{V_{MR}}{V_{TOT}} = \frac{r^2}{b^2} = \frac{(0.3076\ \text{mm})^2}{(20\ \text{mm})^2} \cancel{= 0.}$$

$$\boxed{\frac{V_{MR}}{V_{TOT}} = 2.37\times10^{-4} = 0.024\,\%}$$ ✓