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Density Control of MDT Gas

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Abstract

The electron drift properties of MDT gases depend particularly on the mean free path which is determined by the gas density and the cross section for collisions between electrons and gas molecules. If the temperature dependence of the cross section is negligible, the mean free path and hence the r - t relationship can be kept stable by maintaining a constant gas density. This requires the compensation of temperature variations by pressure adjustment.

We present a Garfield-based study of two gas mixtures showing that the r - t relationship is indeed insensitive to temperature variations provided a constant density is maintained.

1 Introduction

For the operation of ATLAS MDTs stable drift properties and hence gas conditions are necessary to avoid too frequent recalibration of the space to drift-time relationship. In ATLAS as well as in test beams it is much easier to control the pressure than the temperature which in a day varies up to ± 2 K in ATLAS and ± 5 K in the testbeam areas. The pressure can be regulated to 1 mbar, so its relative variation is 1 mbar / 3000 mbar which is small compared to 5 K / 300 K for the temperature.

Because of this fact it was proposed [5] not to try keeping both temperature T and pressure p constant, but rather to compensate for temperature variations by adjusting the pressure such that the gas density ρ remains constant. Based on this idea a density control according to the ideal gas equation

$$p = \rho \cdot k \cdot T \quad (1)$$

was employed in the test beams M2 and H8 [1].

However, the question arises [6] whether this effectively keeps the r-t relationship stable. The drift velocity and hence $t(r)$ depends in particular on the mean free path λ , which is a function not only of the gas density, but also of the electron/gas-molecule cross-sections σ :

$$\lambda = \frac{1}{\rho(p, T) \sigma(T)}. \quad (2)$$

σ however is temperature-dependent via the c.m. energy of the electron/gas system. Thus keeping the density constant may not achieve the goal.

We have investigated this question using Magboltz/Garfield [2]. Magboltz has as input the electron/gas cross-sections and energy transfer functions. We considered the linear “Datcha” gas Ar(91)/N₂(4)/CH₄(5) and the highly nonlinear gas Ar(90)/CO₂(10) under different conditions:

- $T = 300$ K, $p = 3$ bar (base condition)
- $T = 300$ K + ΔT , p corrected according to the Van-der-Waals equation for real gases (cf. section 2)
- $T = 300$ K + ΔT , $p = 3$ bar (uncompensated)

Our studies were done with $\Delta T = 5$ K and 10 K. For all cases the r-t relationships were calculated at a gas gain of $2 \cdot 10^4$ and compared with each other (section 3).

2 Density Control for Real Gases

Consider a gas mixture consisting of n components with the molar fractions c_i ($i = 1, \dots, n$). Each component can be described by the Van-der-Waals equation

$$(p_i + A_i \rho_i^2) (1 - B_i \rho_i) = \rho_i kT, \quad (3)$$

where p_i is the partial pressure and ρ_i the particle density of the i 'th component. The constants A_i and B_i are given by the Van-der-Waals coefficients a_i and b_i of the i 'th component (cf. table 1) and Avogadro's constant N_A :

$$A_i = \frac{a_i}{N_A^2} \quad (4)$$

$$B_i = \frac{b_i}{N_A} \quad (5)$$

Gas Component	a [$10^3 \frac{\text{N m}^4}{\text{kmol}^2}$]	b [$\frac{\text{m}^3}{\text{kmol}}$]
Ar	136	0.0322
N ₂	136	0.0385
CH ₄	229	0.0427
CO ₂	362	0.0425

Table 1: Van-der-Waals coefficients for various gas components [3]

Resolving (3) for p_i yields

$$p_i = \frac{\rho_i kT}{1 - B_i \rho_i} - A_i \rho_i^2. \quad (6)$$

Using the identities

$$\sum_i c_i = 1, \quad (7)$$

$$\sum_i p_i = p \quad (\text{Dalton's law}), \quad (8)$$

$$c_i \cdot \rho = \rho_i \quad (9)$$

we can sum over the components in (6) and get

$$p = \rho kT \sum_i \frac{c_i}{1 - B_i \rho c_i} - \rho^2 \sum_i A_i c_i^2. \quad (10)$$

The ρ_0 at which we want to keep the density constant, has to be calculated numerically from (10) for the standard conditions $p_0 = 3$ bar and $T_0 = 300$ K. If then the temperature changes from T_0 to $T = T_0 + \Delta T$, (10) tells us how to vary the pressure in order to maintain the density $\rho = \rho_0$.

3 Garfield Study

Garfield/Magboltz calculations of the r-t relationship were performed for the gases Ar(91)/N₂(4)/CH₄(5) (“Datcha gas”) and Ar(90)/CO₂(10) (a possible fall-back solution for the case of ageing problems with “Datcha”). Table 2 gives the density ρ_0 at p_0 and T_0 for both gases. The high voltage corresponding to the nominal gain of $2 \cdot 10^4$ is displayed as well.

Gas Mixture	Density ρ_0 [10^{25} m^{-3}]	High Voltage [V]
Ar(91)/N ₂ (4)/CH ₄ (5)	7.2627	3280
Ar(90)/CO ₂ (10)	7.2631	3180

Table 2: Density and High Voltage for the gases under study

Figure 1 shows the r-t relationships of both gases for the base conditions.

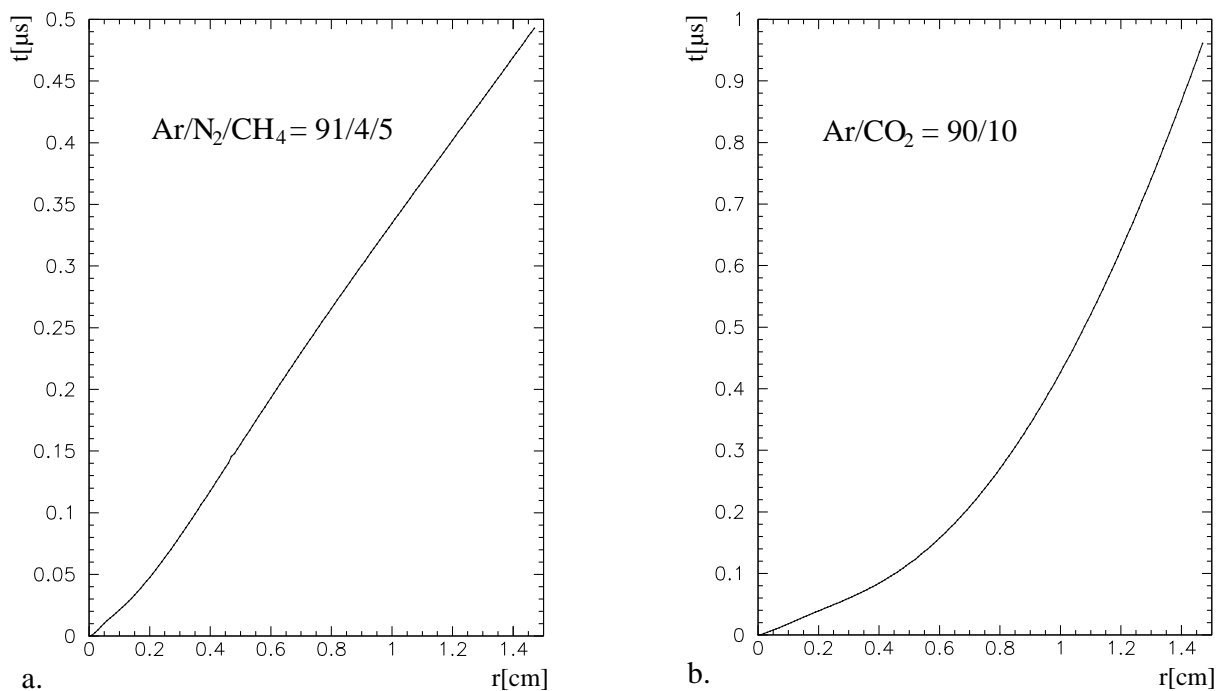


Figure 1: r-t relationships for (a) Ar(91)/N₂(4)/CH₄(5) and (b) Ar(90)/CO₂(10) at the base conditions (3 bar, 300 K)

Figure 2a shows the difference between the r-t relationships of the Ar(91)/N₂(4)/CH₄(5) mixture for $T = 305 \text{ K}$ and for 300 K , if the pressure is kept constant at 3 bar (no compensation). Figure 2b shows the same difference if the temperature variation is compensated by keeping the density constant (i.e. by raising the pressure to 3.0503 bar).

The big deviation of a few points in figures 2 to 4 is due to Garfield calculating in single precision [4].

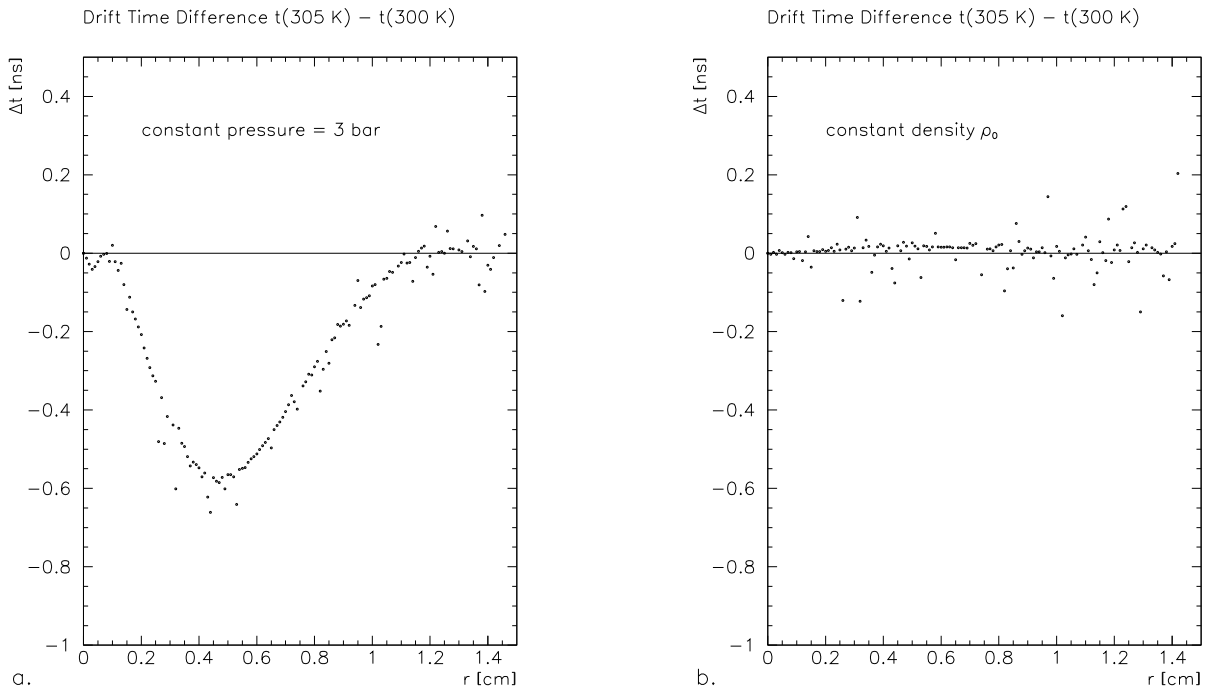


Figure 2: Difference between the r - t relationships for Ar(91)/N₂(4)/CH₄(5) at 300 K and 305 K without (a) and with (b) pressure compensation

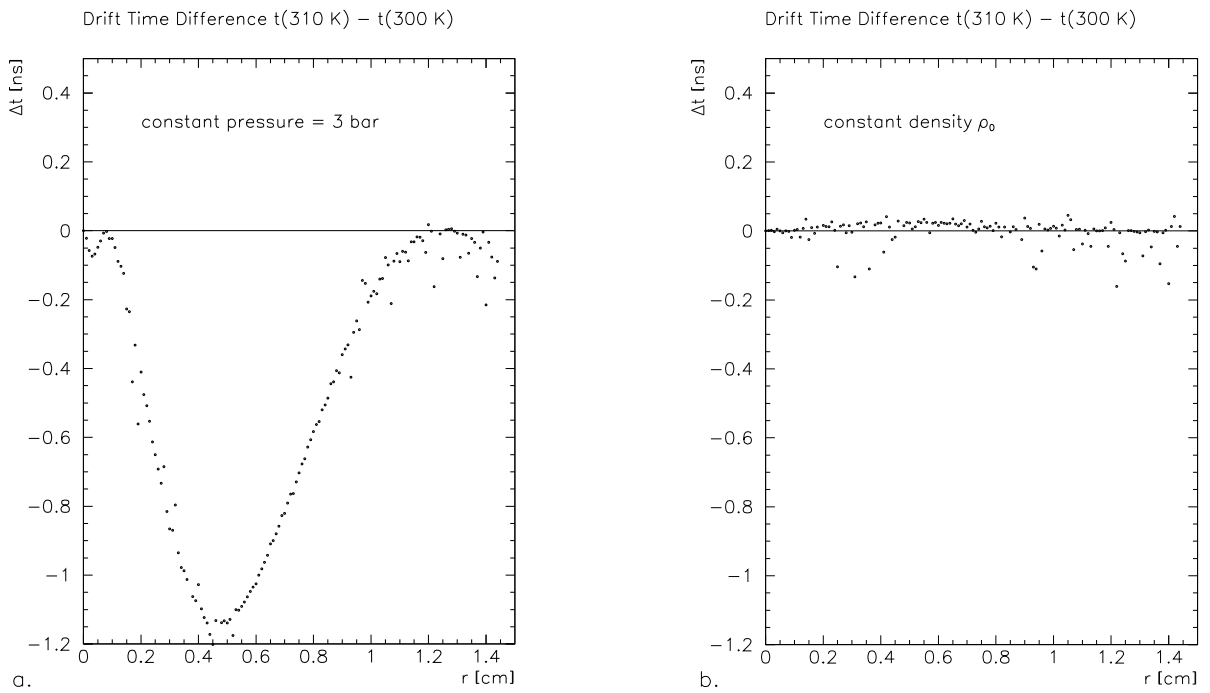


Figure 3: Difference between the r - t relationships for Ar(91)/N₂(4)/CH₄(5) at 300 K and 310 K without (a) and with (b) pressure compensation

Comparing figures 2a and 2b demonstrates that the density control is much better than ignoring temperature variations. Density control keeps $r(t)$ constant with a maximum systematic deviation of about 30 ps corresponding to a hit radius bias of only $1 \mu\text{m}$.

For figure 3 the temperature was even raised by 10 K, and the compensation still keeps the systematic bias below 50 ps.

Finally we did the same study for the Ar(90)/CO₂(10) mixture. As figure 4a shows, a temperature variation of 5 K has a huge effect on the r-t relationship (up to 18 ns corresponding to a systematic error in the hit radius of about $150 \mu\text{m}$). Again, keeping the density constant maintains a stable r-t relationship (figure 4b). The systematic deviations are confined to 0.3 ns corresponding to about $3 \mu\text{m}$ for this gas.

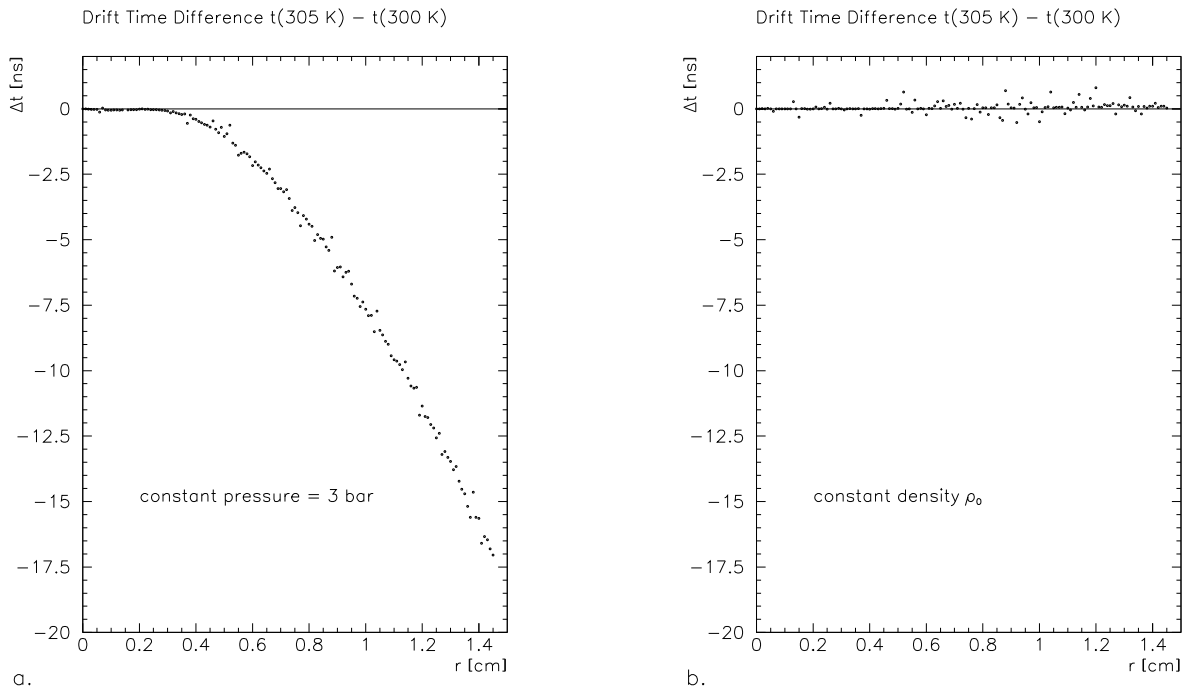


Figure 4: Difference between the r-t relationships for Ar(90)/CO₂(10) at 300 K and 305 K without (a) and with (b) pressure compensation

Note that in the cases presented above the usage of Van-der-Waals' gas equation was not crucial. The difference in pressure correction with respect to the ideal gas equation (1) was at the mbar level and therefore small compared to the applied pressure correction.

4 Conclusions

We have shown that maintaining constant gas density by pressure correction is sufficient to keep the r-t relationship stable under temperature variations. This is a cheap way of significantly reducing the need of MDT recalibration. The compensation has been demonstrated to work for two very different gases, one of which is highly nonlinear and thus very sensitive to variations of the operation conditions.

This result also implies that the temperature dependence of the electron/gas molecule cross-section is not crucial for the gases considered in our study.

References

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