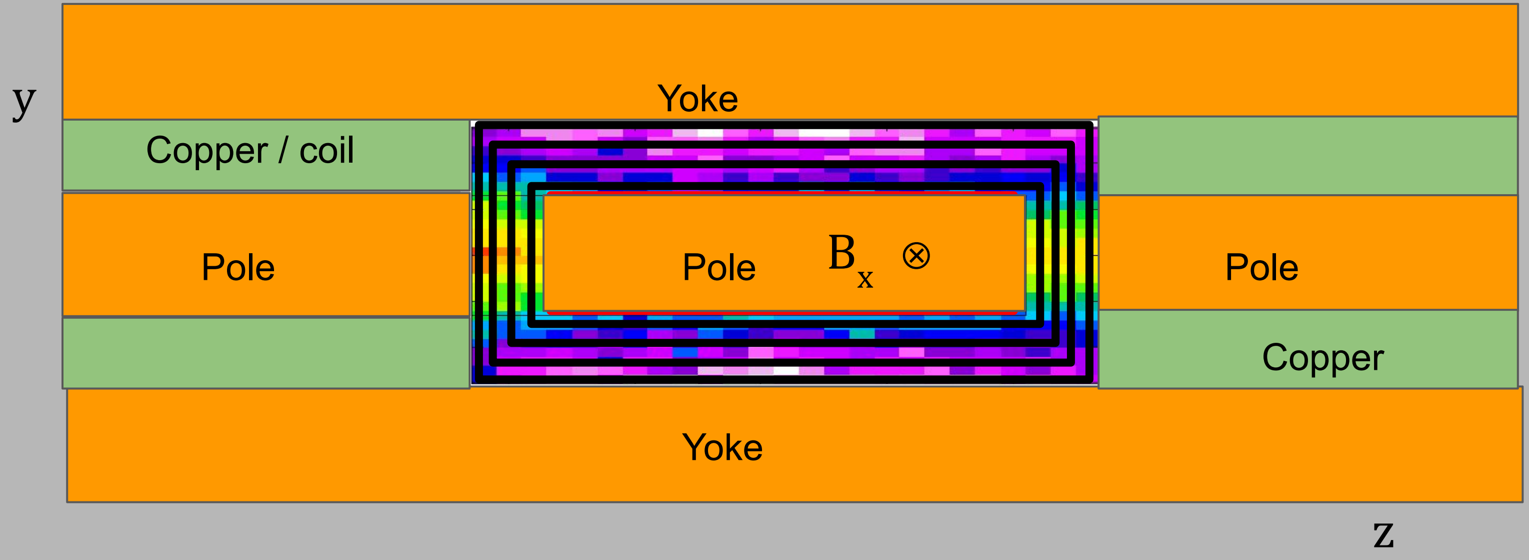
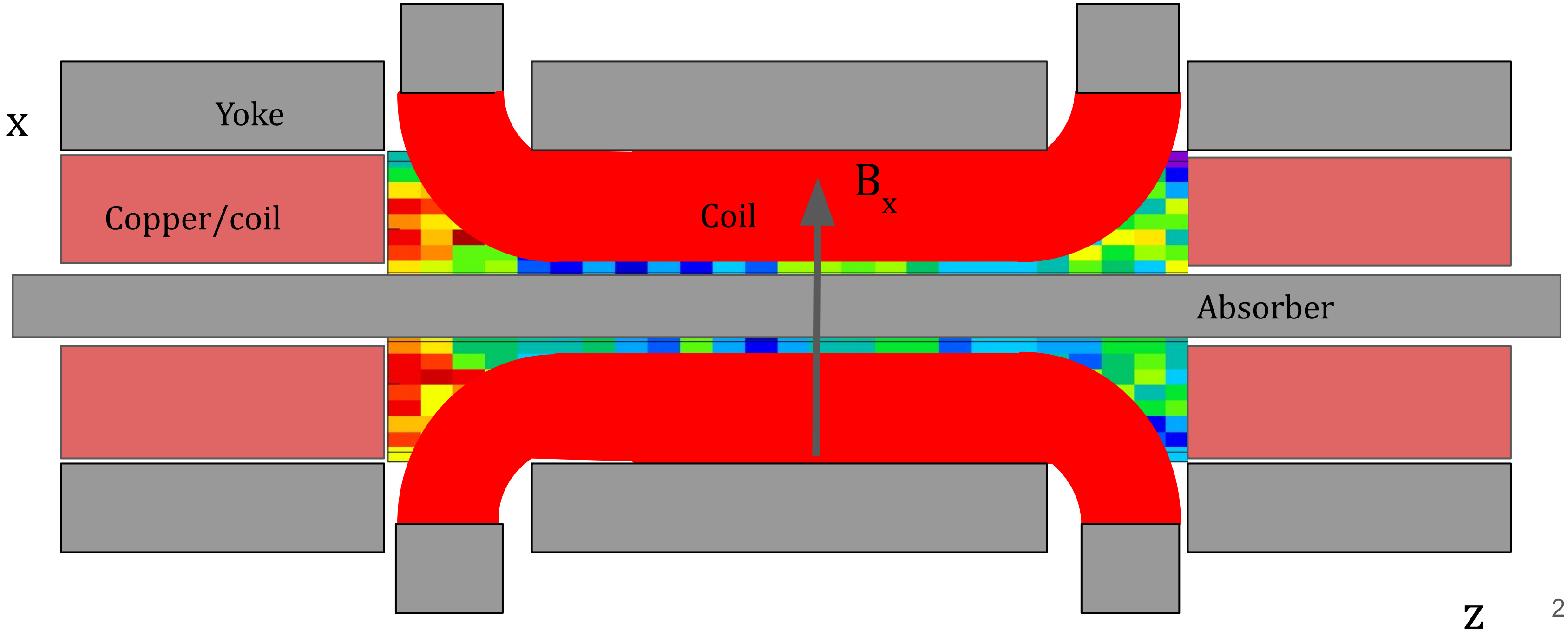
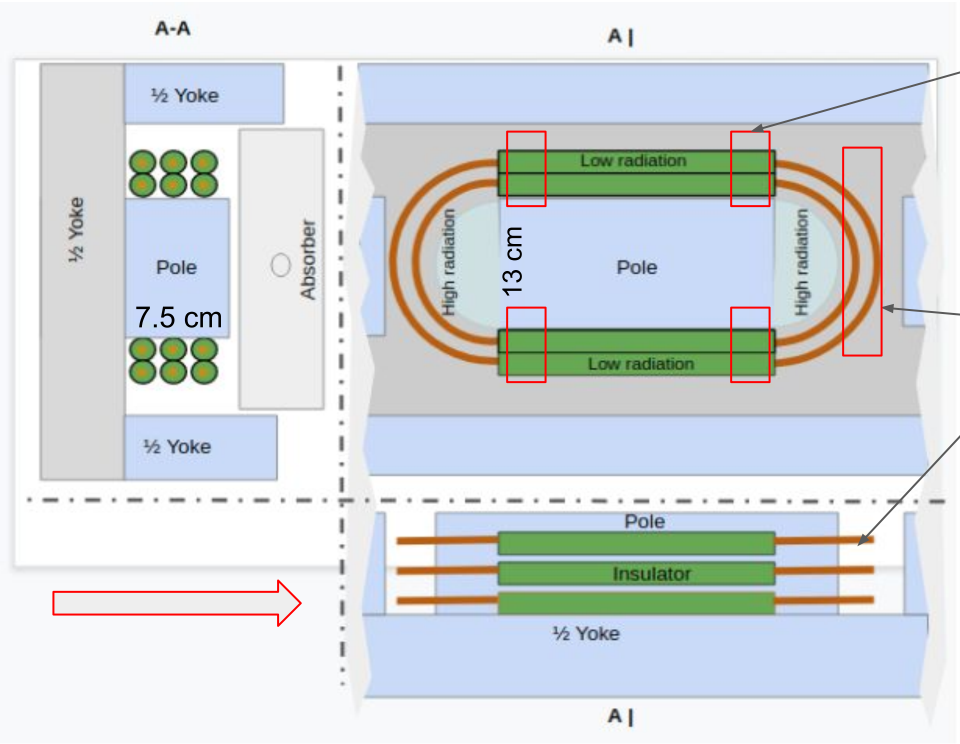
Problem of High radiation in return part of Coils.



Tim Whitlatch's solution.



Coil Design and Insulation Exposure to Radiation.



Hot area for insulation.

Very hot area,

Air insulation,

Gap between wires

~8 mm.

Ampere's force law:

$dF/dl = (\mu_o/2\pi)(I^2/d) = \sim 25$ N/m

at I=1800 A ; d=2.5 cm; $\mu_o = 4\pi E\text{-}7$ N/A^2

- Attractive force of bent parts F = 25 N/m* 0.3 m = 7.5 N.
- Copper 1.7 cm -wires (tubes) will not touch .

Leakage Current between wires.

Current through gas :

$$dI/ds\ [A/cm^2] = n\ [e/cm^3] \times \upsilon\ [cm/s] \times e\ [C]$$

1. What is concentration of electrons n?
2. What is the drift velocity of electrons υ?

Drift velocity of electrons and ions in dry and humid air and in water vapour H. RYZKO Institutet for Hogspbningsforskg vid Uppsala Universitet, Uppsala, Sweden MS. received 7th Septembw 1964 https://journals.aps.org/pr/abstract/10.1103/PhysRev.32.624#:~:text=From%20the%20measured%20rate%20of,because%20of%20several%20unavoidable%20errors.

1. What is n and Ionisation in Magnet Coil.

$$\color{red}{dI/ds\ [A/cm^2]} = n\ [e/cm^3] \times v\ [cm/s] \times e$$

Assume **maximum dose D in space between coil winding**s is D= **1.E-5 [GeV/g/e]** (~10 × of **FLUKA** estimate).

Assume **10 eV** is required to produce one electron -ion pair .

Dose D translate to ion **pair production ~1.E+3[pair/g/e]** = 1.E-5 [GeV/g/e] / 1.E-8 [GeV]).

Ion pair production rate **per unit of mass** is at beam intensity 3.E+13 [e/s] :

$dN/dt = \mathbf{3.E{+}16\ [pair/g/s]} = 1.E{+}3\ [pairs/g/e] \times 3.E{+}13\ [e/s]$.

Assume we have **1 cm of argon** between windings ($\boldsymbol{\varrho_A}$**=1.7E-3 [g cm**$^{-3}$**] = ~2.E-3**). Air – 1.3E-3 ; He – 0.17E-3

So we find the ion **production rate between coil wires** :

$$dn_p/dt = (dN/dt)\, \varrho_A = 3.E{+}16\ [pairs\ g^{-1}\ s^{-1}] \times 2.E{-}3\ [g\ cm^{-3}] = \mathbf{6.E{+}13\ [pair\ cm^{-3}\ s^{-1}]}$$

This rate is **balanced by recombination** of argon ions and electrons.

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1. What is n. Ionisation in Magnet Coil and Leakage Current.

$$dI/ds\,[A/cm^2] = n\,[e/cm^3] \times v\,[cm/s] \times e$$

dn_p/dt =6.E+13 [pairs cm^{-3} s^{-1}] is balanced **by recombination** of argon ions and electrons defined as:

$dn_r/dt = \alpha\, n_+ n_-$, where α = 2.E-10 [cm^3 i^{-1} s^{-1}] recombination coeff. for Argon.

(α = ~1.E-8 [cm^3 i^{-1} s^{-1}] for He, and α = 1.E-6 — 1.e-7 for Air.)

Assuming equal densities $n_+ = n_- = n$ for the equilibrium density of electrons **n** we write:

$\alpha n^2 = dn_p/dt$ =6.E+13 [pairs cm^{-3} s^{-1}] from the previous slide and

$n^2 = \alpha^{-1} dn_i/dt$ = 0.5E+10 [pairs s cm^{-3}]×6.E+13 [pairs cm^{-3} s^{-1}] = 3.E+23 (pairs/cm^3)^2.

- The equilibrium **density of electrons** yields **n = 6.E+11 (pairs/cm^3).**
- **Density of electrons** is **proportional** to the gas specific factor $(\alpha^{-1}\varrho_A)^{1/2}$.

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2. What is v and Electric Field between Wires at 2 kA current.

What is Voltage between windings?

Copper resistivity $\varkappa$=**1.7E-6** [Ohm·cm]; L_w/S_w= 100 cm/3 cm^2 =25 cm^{-1}

=> Voltage between windings ($V = I \times R_w$ where $R_w = \varkappa \times L_w/S_w$)

V = 2000 [A]× 1.7E-6 [Ohm·cm] ×25 [cm^{-1}] = 2.E-6 ×5.E+4 [Ohm·A]

V = 0.1 V.

From **Top Plot** [1] we see **drift velocity as v=v(E/P)** where

E -electric field, P=gas pressure.

In our case **E=0.1 [V cm^{-1}]** ; **P=~1000 [mmHg]** =>

E/P=1.E-4 [V cm^{-1}/mmHg]

From Top Plot we read **v(0.1)=2.E+6 [cm/s]** and linear interpolation yields:

v(1.E-4)=2.E+3 [cm/s].

From Bottom Plot for air we find v(1.E-4)=5.E+1 cm/s.

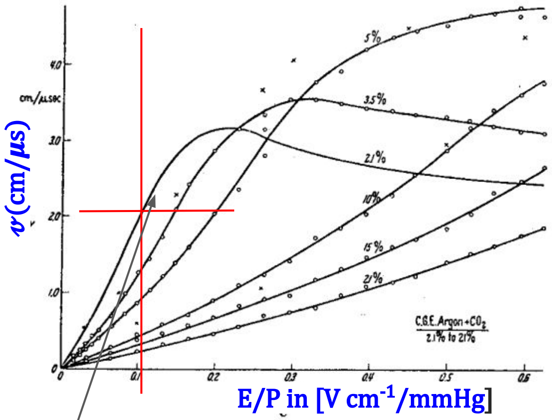

Fig. 29 Drift velocity of electrons in several argon-carbon dioxide mixtures12)

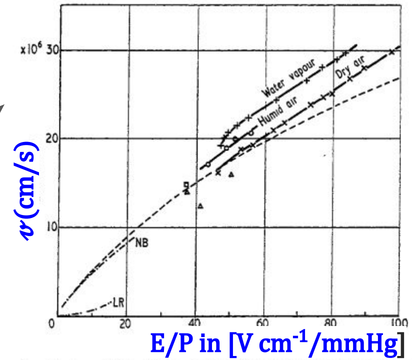

Figure 5. Electron drift velocity in dry air, humid air and water vapour as a function of reduced electrical field. Pressure readings reduced to temperature of 20 °C; humid air, p_w/p = 16%. Broken line, Townsend and Tizard 1913; △, Raether; □, Rieman 1944; NB, Nielson and Bradbury 1937; LR, Lowke and Rees 1963.

- (1) F. Sauli, "PRINCIPLES OF OPERATION OF MULTIWIRE PROPORTIONAL AND DRIFT CHAMBERS",

https://journals.aps.org/pr/abstract/10.1103/PhysRev.32.624#:~:text=From%20the%20measured%20rate%20of,because%20of%20several%20unavoidable%20errors.

2. What is leakage current between wires .

Current density between windings:

$$dI/ds\ [A/cm^2] = n\ [e/cm^3] \times \mathcal{v}\ [cm/s] \times 1.6E\text{-}19\ [C/e] \qquad \propto \qquad \mathcal{v}\ (\alpha^{-1}\varrho_A)^{1/2}$$

Where $n=6.E+11\ [e/cm^3]$.

$\mathcal{v}=2.E+3\ [cm/s]$.

For the current density we find **:**

$$dI/ds\ [A/cm^2] = 6.E+11[e/cm^3] \times 2.E+3\ [cm/s] \times 1.6E\text{-}19\ [C/e] = 12 \times 1.6\ E(+11+3-19) =$$

$$= 20.E\text{-}5\ [A/cm^2].$$

Wire area S=2 cm×100 cm =**2.E+2 cm²** , and the maximum possible current yields:

$$I\ [A] = 20.E\text{-}5\ [A/cm^2] \times 2.E+2\ [cm^2] = 40.E\text{-}3\ [A] = 40\ [mA].$$ Compare to 2 kA !

The voltage between entry lead of coil and ground will be 1 V!

Hence leak current form the first winding may be **I =400 mA.**

- **Leakage is of 2.E-5 of the wire current. It does not affects the coil performance.**
- **For Helium the leakage is ~10 times lower - due to the gas specific factor $\mathcal{v}\ (\alpha^{-1}\varrho_{He})^{1/2}$.**

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