JUAS 2025
Vacuum Practical session

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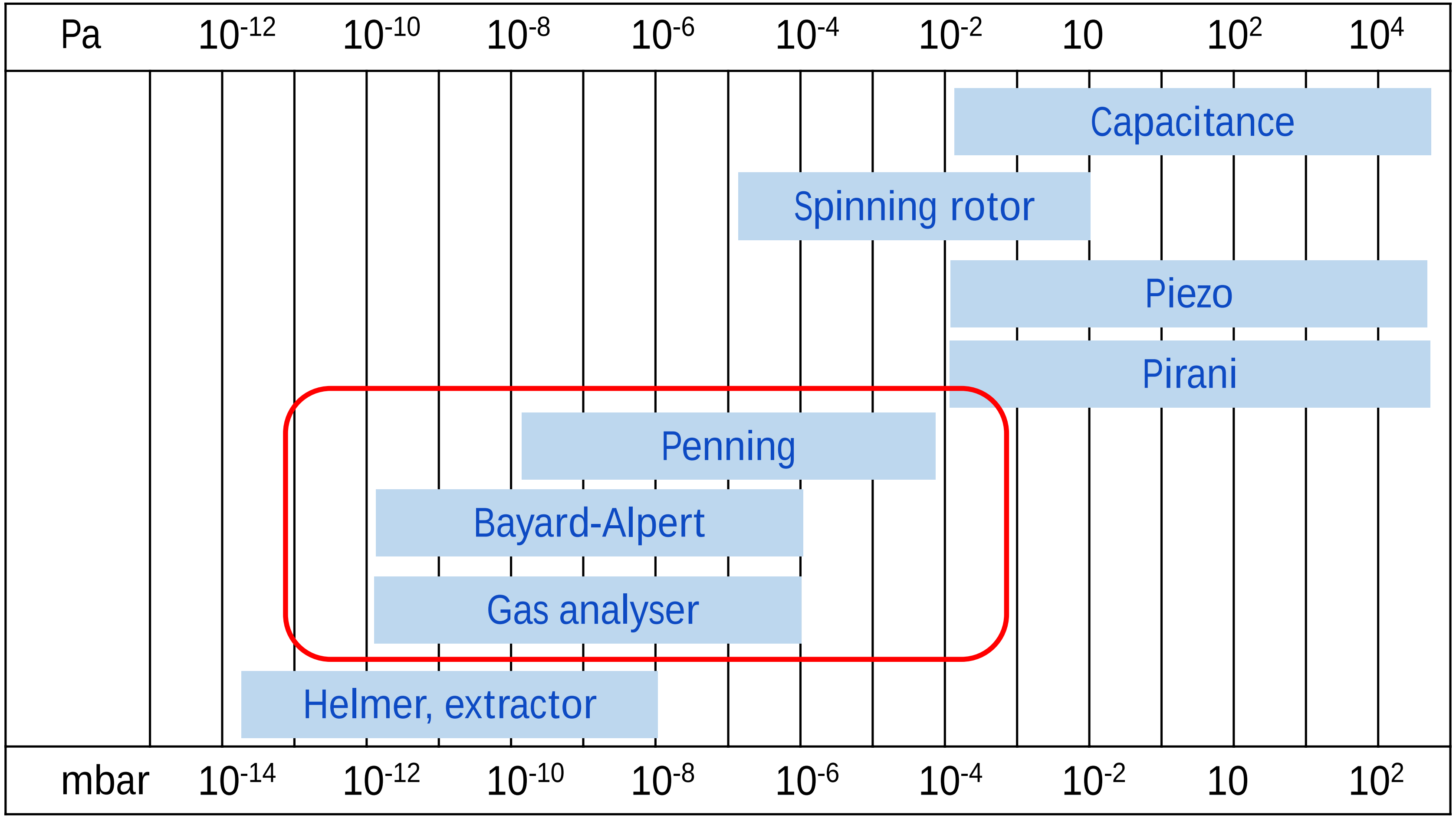
Outline

1. Introduction
2. Pumping speed measurement
3. Partial pressure gauges calibration(RGA)
4. Summary

Vacuum pressure range

16 orders of magnitude !



Gauges used at CERN for UHV measurements

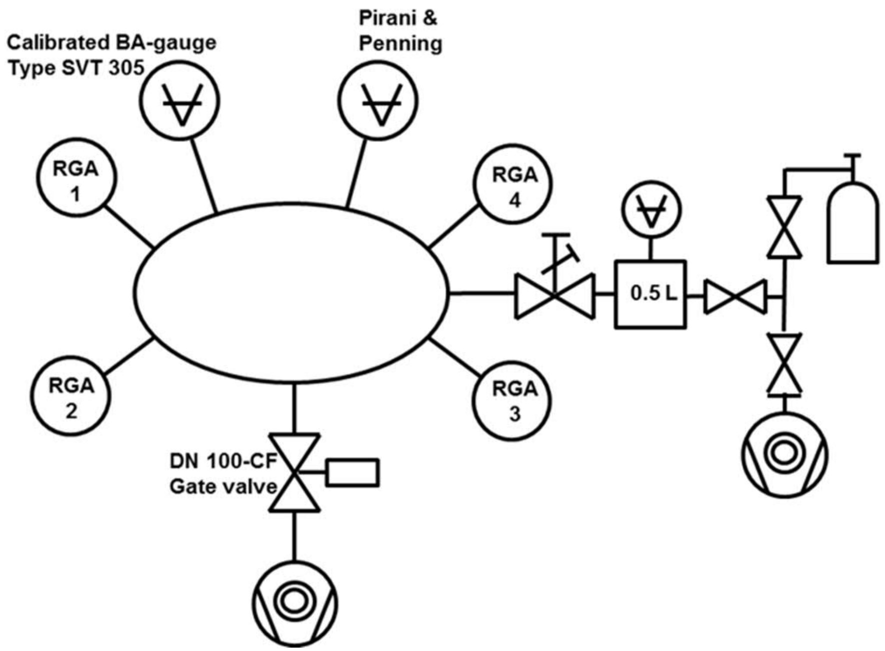
Type	Pirani/ Bayard-Alpert	Penning	Pirani/ Penning
Supplier/Model	PFEIFFER/ PBR260	PFEIFFER/ IKR070	PFEIFFER/ PKR
Type	Active gauge	Passive gauge	Active gauge
Measurement range	1000- $1x10^{-9}$ mbar	$1x10^{-4}$ à $1x10^{-11}$ mbar	1000 à $1x10^{-9}$ mbar
Temp. bakeout	150°C (electronics removed)	200°C	150°C (electronics removed)
Temp. operating	55°C	150°C	55°C

Gauges used at CERN
For UHV/ XHV measurements

Type	Bayard-Alpert	Bayard-Alpert	Extractor
Pressure range	10^{-6} à 2.10^{-12} mbar	1.10^{-2} à 2.10^{-12} mbar	10^{-6} à 2.10^{-12} mbar
Temp. Bakeout.	350°C	350°C	350°C
Temp. operating	150°C	150°C	150°C
Supplier/Model	Spécial CERN /SVT 305	VACOM Barion Ext	LEYBOLD/ IE514

Part 1:
Pumping speed measurement

CERN Test stand for the practical session



CHARACTERISTICS

System baked

Pressure limit: range E-10 mbar (H2 eq.)

Injection volume: 0.6 l

Concepts:

- Effective pumping speed: $Seff = \frac{\Delta Q}{\Delta P}$ l/s

- Flux injected: $Q = V \frac{\Delta P \text{inj}}{\Delta t}$ mbar·l/s

JUAS practical session

Exercise: Determine effective pumping speed of the turbomolecular pump for two different type of gases (Ar, He)

- Fill injection volume to 200 mbar (capacitance gauge 1000mbar FS)
- Inject to about 7×10^{-6} mbar (P_dome)
- Determine flux injected (at least 4 points)
- Reduce injection volume to 1 mbar (capacitance gauge 1mbar FS), determine flux injected (4 points). Pressure drops to about 5×10^{-8} mbar
- Determine apparent flux (zero)
- Stop injection

Gauge used for the pressure measurement: Penning Gauge

Measurement equipment:

•Vacuum system: Penning gauge (gas type dependent)

Gauge correction factor

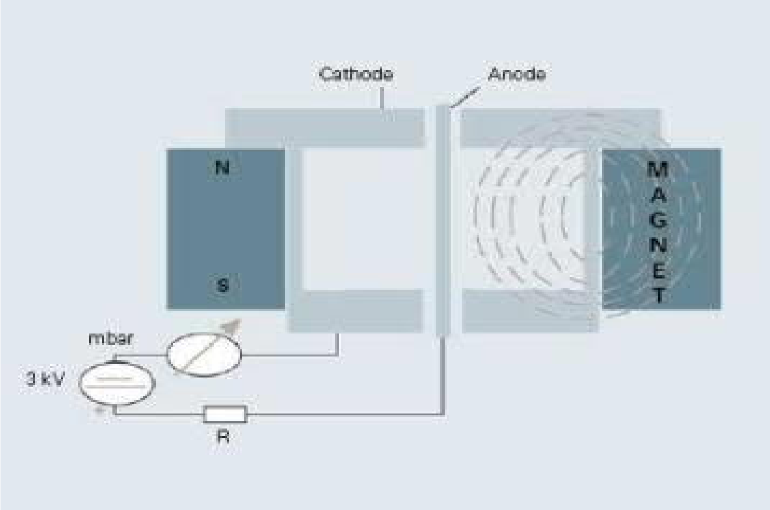
Gas type	C
Air (N_2, O_2, CO)	1.0
Xe	0.4
Kr	0.5
Ar	0.8
H_2	2.4
Ne	4.1
He	5.9

IKR070 Penning gauge

Penning gauge:
Operating principle

Cold cathode ionization gauge consists of two electrodes, a cathode and an anode, between which a high voltage (2-4 kV) is applied.
A permanent ring magnet is placed around the cathode to generate a magnetic field within the chamber.
The electrons travel through the magnetic field on spiral trajectories. They ionize neutral gas molecules which ignite and maintain a gas discharge. The measured gas discharge current is proportional to the pressure.

Pressure range: 10^{-4} à 10^{-11} mbar



Advantages:
- Low outgassing rate
- The gauge head is not broken by an air inrush (no filament)

Disadvantages:
Gauge can be easily contaminated
- If gauge is activated at P>10^{-1} mbar
- If it is regularly used in Argon atmosphere
- If it is used in residual gas atmospheres containing hydrocarbons …

=> wrong pressure measurements

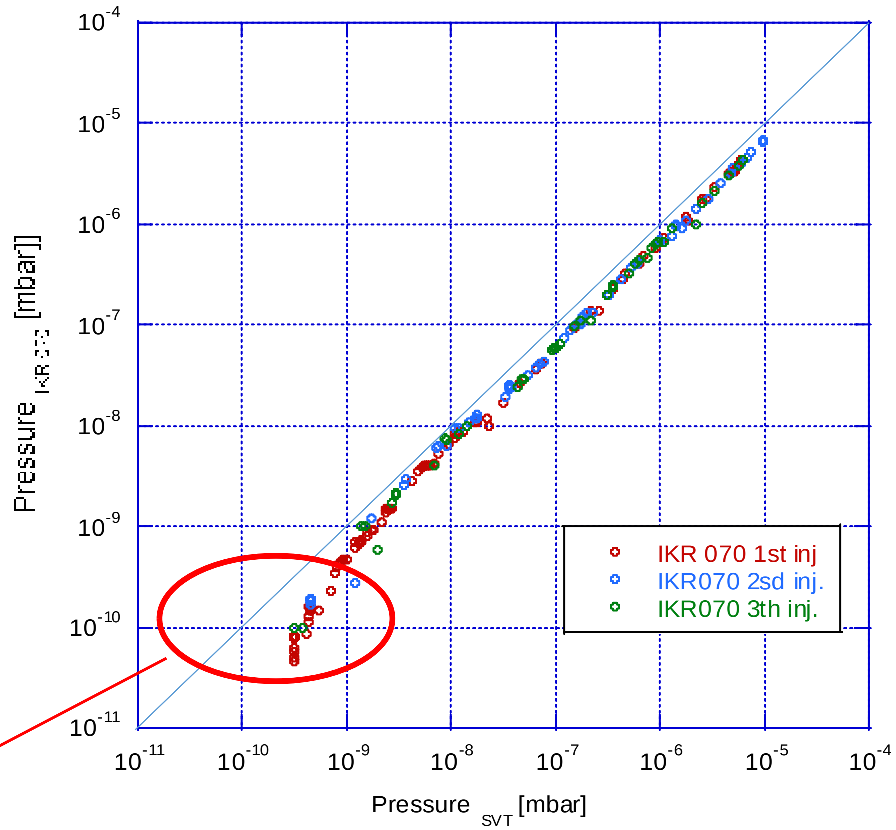
Penning gauges accuracy

Nitrogen injection (N2)

% d'erreur	Penning A	IKR 070	Penning C
Range E-6	41%	11%	13%
Range E-7	58%	14%	29%
Range E-8	63%	13%	56%
Range E-9	73%	18%	46%
Range E-10	63%	44%	

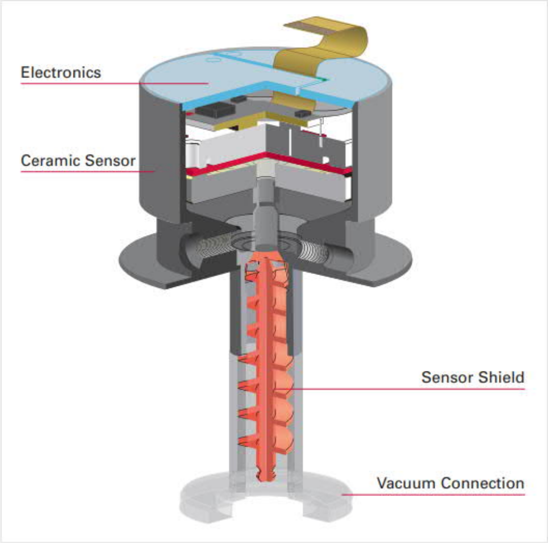
Hydrogen injection (H2)

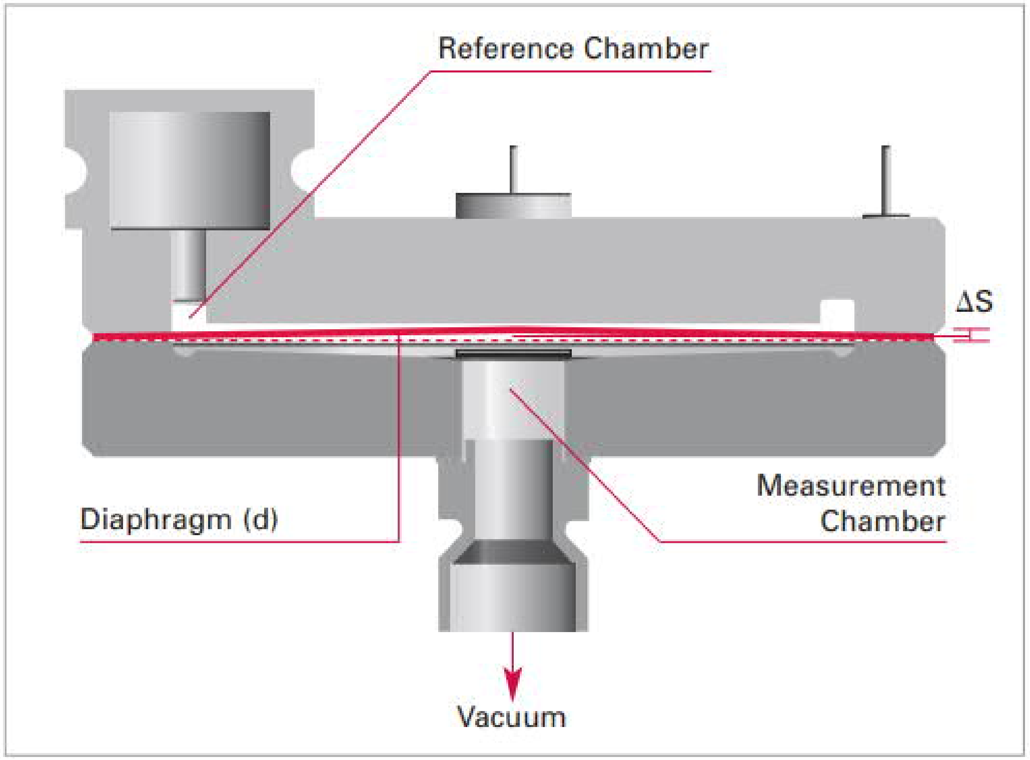
% d'erreur	Penning A	IKR070	Penning C
Range E-6	60%	33%	14%
Range E-7	66%	35%	26%
Range E-8	74%	36%	56%
Range E-9	81%	28%	63%
Range E-10	85%	59%	



Pressure of the IKR070 Pfeiffer as function of the SVT reference gauge for different hydrogen injections

Gauges used for the Injection volume measurement: Capacitance gauge

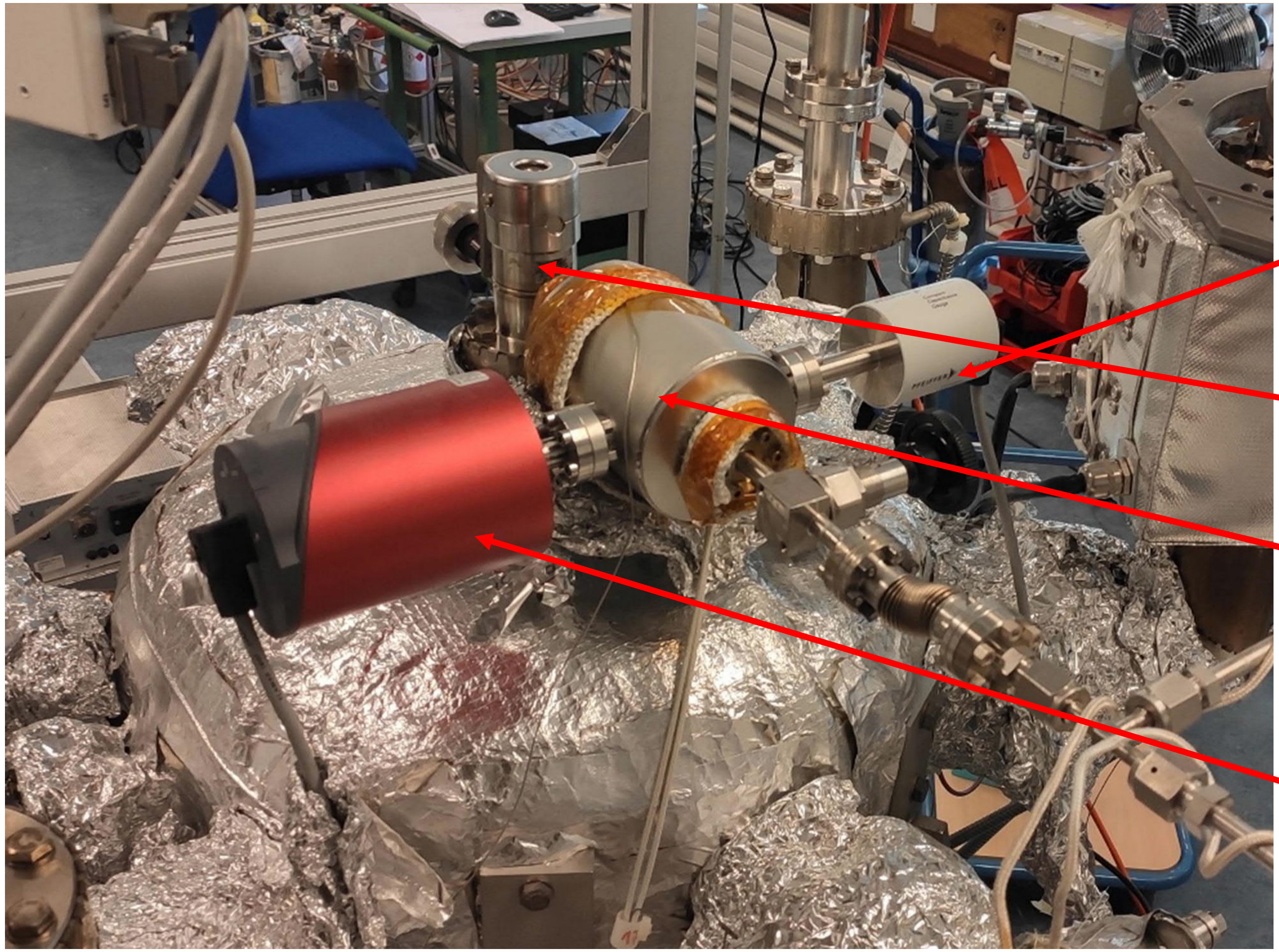




Our transmitters measure the deflection of the diaphragm in form of a change in electrical capacitance detected by the conductors that are vapor-deposited on the ceramic diaphragms. By varying the thicknesses (d) of the diaphragms it is possible to provide measurement ranges from 1,100 to 10^{-5} mbar. The thinnest diaphragms are barely as thick as a human hair (0.01 mm), and the measured deflections (ΔS) are a mere 0.001 mm.

Informations from Pfeiffer vacuum website

Injection volume



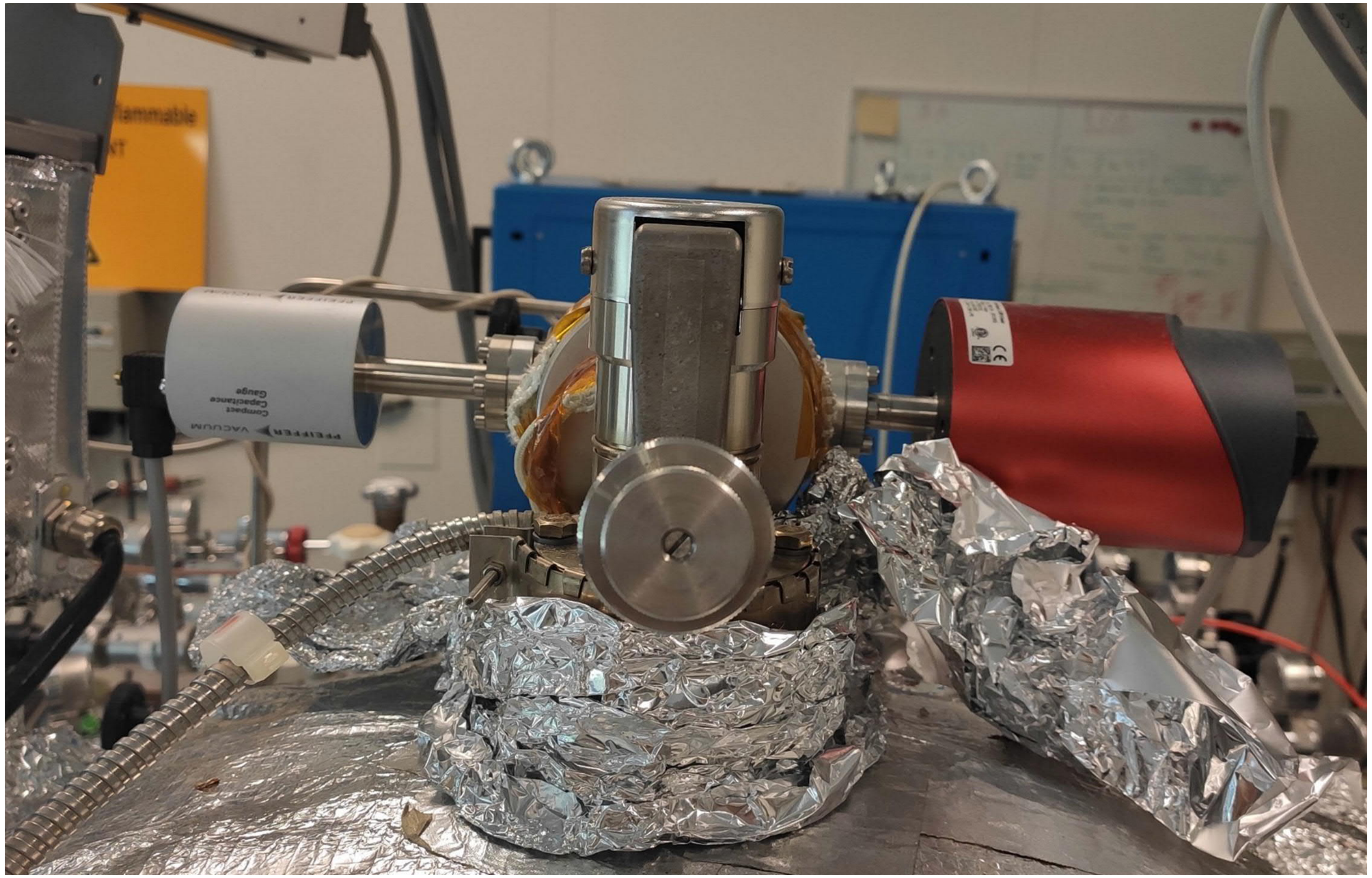
Capacitance gauge CMR261

Variable leak valve

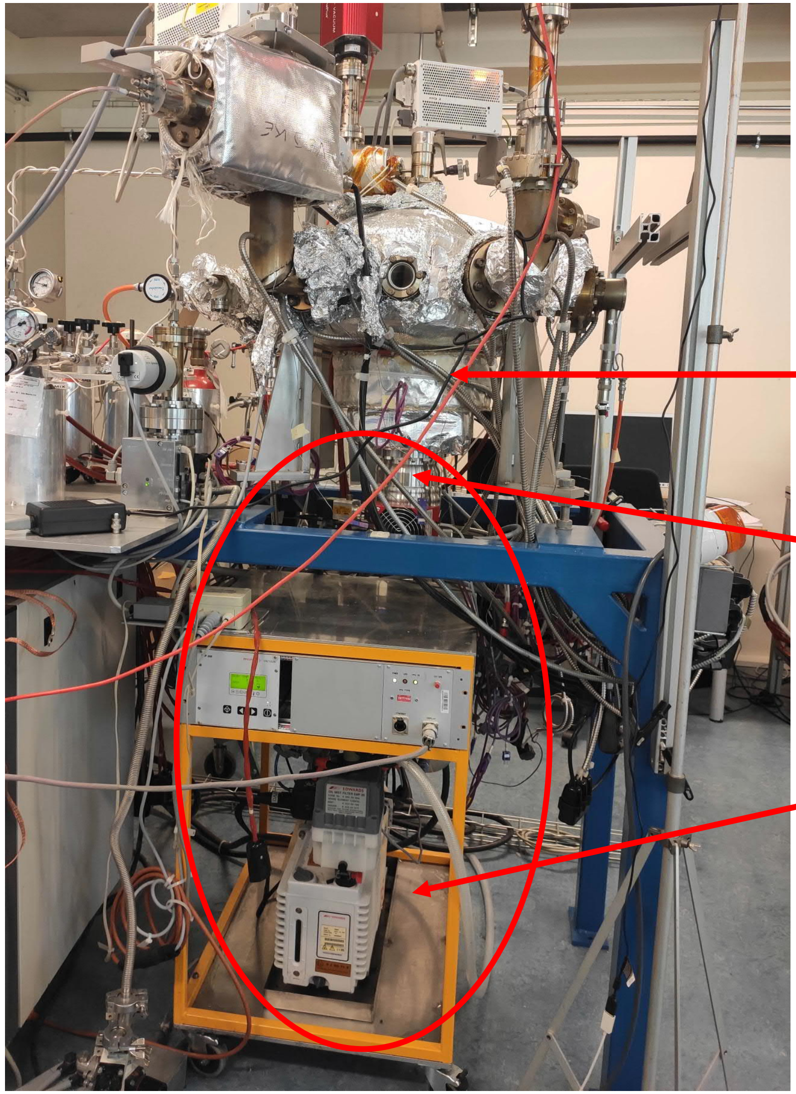
Injection volume 0.6 L

Capacitance gauge CMR374

Injection valve:
Variable leak valve



Dome Pumping group



DN100CF-F all metal gate valve

Turbomolecular pump

Oil roughing pump

Dome pumping group: turbomolecular pump

HiPace® 300 for TCP 350, DN 100 CF-F

Order number: PM P03 994

- Rugged, powerful turbopump with a pumping speed of up to 260 l/s for N_2
- For external TCP 350 drive electronics
- Ideal for applications that require separate installation of pump and drive
- For installation in any orientation
- Extensive accessories expand the range of applications

Pumping speed for Ar	255 l/s
Pumping speed for H_2	220 l/s
Pumping speed for He	255 l/s
Pumping speed for N_2	260 l/s

Pumping speed measurement

Helium

Gauge correction_factor: 5.9

INJ_1

time [hh:mm:ss]	t [s]	P_inj [mbar]	dP_inj/dt [mbar/s]	P_dome [mbar]	P_corr [mbar]	Q [mbar.L/s]	S [L/s]
11:24:51	0	196.300					
11:26:51	120.00	194.900	0.012	6.40E-06	3.78E-05	7.00E-03	185.38
11:28:51	240.00	193.300	0.013	6.30E-06	3.72E-05	8.00E-03	215.23
11:30:51	360.00	191.700	0.013	6.30E-06	3.72E-05	8.00E-03	215.23
							205.28

INJ_2

time [hh:mm:ss]	t [s]	P_inj [mbar]	dP_inj/dt [mbar/s]	P_dome [mbar]	P_corr [mbar]	Q [mbar.L/s]	S [L/s]
11:40:00	0	0.938					
11:42:00	120.00	0.931	5.83333E-05	3.40E-08	2.01E-07	3.50E-05	174.48
11:44:00	240.00	0.925	5.08333E-05	3.30E-08	1.95E-07	3.05E-05	156.65
11:46:00	360.00	0.918	5.41667E-05	3.30E-08	1.95E-07	3.25E-05	166.92
							166.02

Zero (INJ_2 corrected)

time [hh:mm:ss]	t [s]	P_inj [mbar]	dP_inj/dt [mbar/s]		dP_inj/dt_corr		
11:51:50	0	0.919					
11:53:50	120.00	0.921	-1.93333E-05		7.77E-05	4.66E-05	232.30
					7.02E-05	4.21E-05	216.23
					7.35E-05	4.41E-05	226.50
							225.01

Argon

Gauge correction_factor: 0.8

INJ_1

time [hh:mm:ss]	t [s]	P_inj [mbar]	dP_inj/dt [mbar/s]	P_dome [mbar]	P_corr [mbar]	Q [mbar.L/s]	S [L/s]
12:09:30	0	200.138					
12:11:30	120.00	200.018	0.001	5.80E-06	4.64E-06	6.00E-04	129.31
12:13:30	240.00	199.890	0.001	5.70E-06	4.56E-06	6.40E-04	140.35
12:15:30	360.00	199.770	0.001	5.70E-06	4.56E-06	6.00E-04	131.58
							133.75

INJ_2

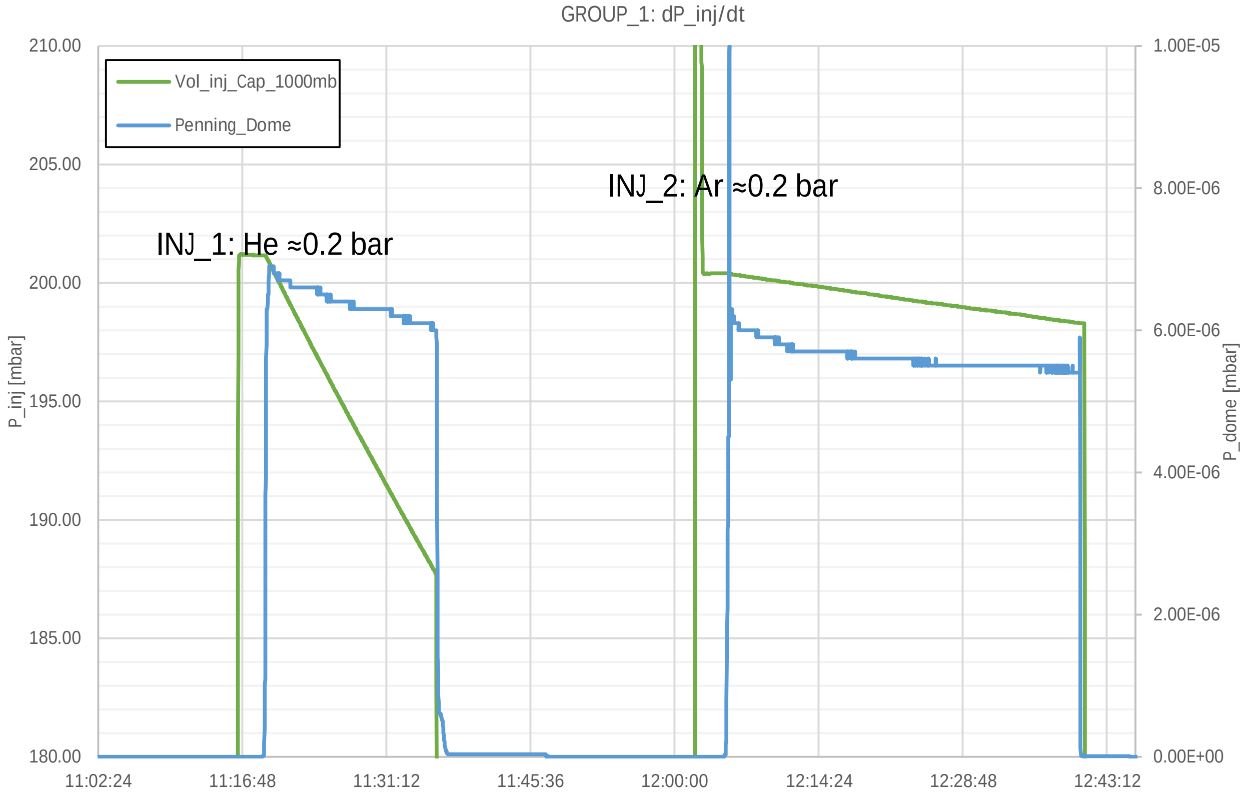
time [hh:mm:ss]	t [s]	P_inj [mbar]	dP_inj/dt [mbar/s]	P_dome [mbar]	P_corr [mbar]	Q [mbar.L/s]	S [L/s]
	0						
	0.00		#DIV/0!		0.00E+00	#DIV/0!	#DIV/0!
	0.00		#DIV/0!		0.00E+00	#DIV/0!	#DIV/0!
	0.00		#DIV/0!		0.00E+00	#DIV/0!	#DIV/0!
							#DIV/0!

Zero (INJ_2 corrected)

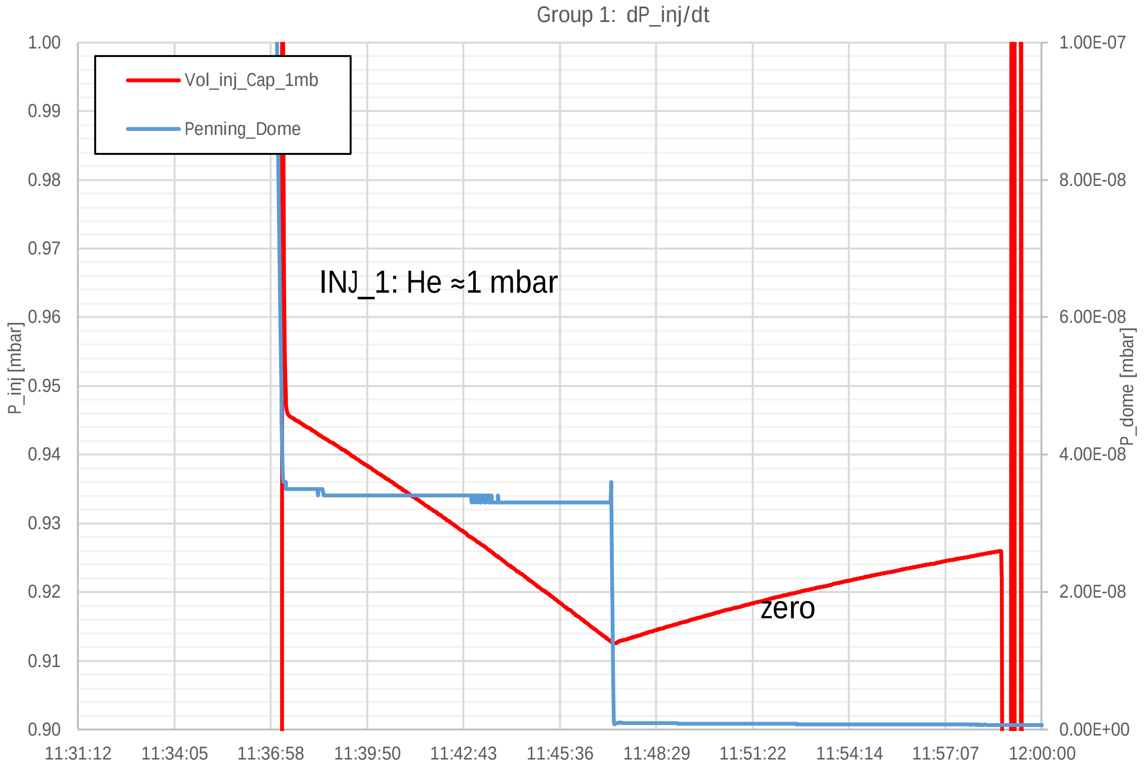
time [hh:mm:ss]	t [s]	P_inj [mbar]	dP_inj/dt [mbar/s]		dP_inj/dt_corr		
	0						
	0.00		#DIV/0!		#DIV/0!	#DIV/0!	#DIV/0!
					#DIV/0!	#DIV/0!	#DIV/0!
					#DIV/0!	#DIV/0!	#DIV/0!
							#DIV/0!

Courtesy Cesar Vazquez

Pumping speed measurement



Plot 1: Pressure drop in injection volume (≈200 mbar) in function of time (primary axis). Pressure in vacuum system in secondary axis.



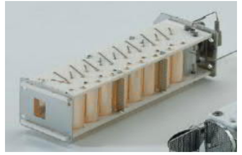
Plot 2: Pressure drop in injection volume (≈1 mbar) in function of time (primary axis). Pressure in vacuum system in secondary axis.

Courtesy Cesar Vazquez

Mass spectrometers at CERN

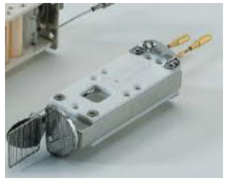
60 units

Grid Ion source/ SEM

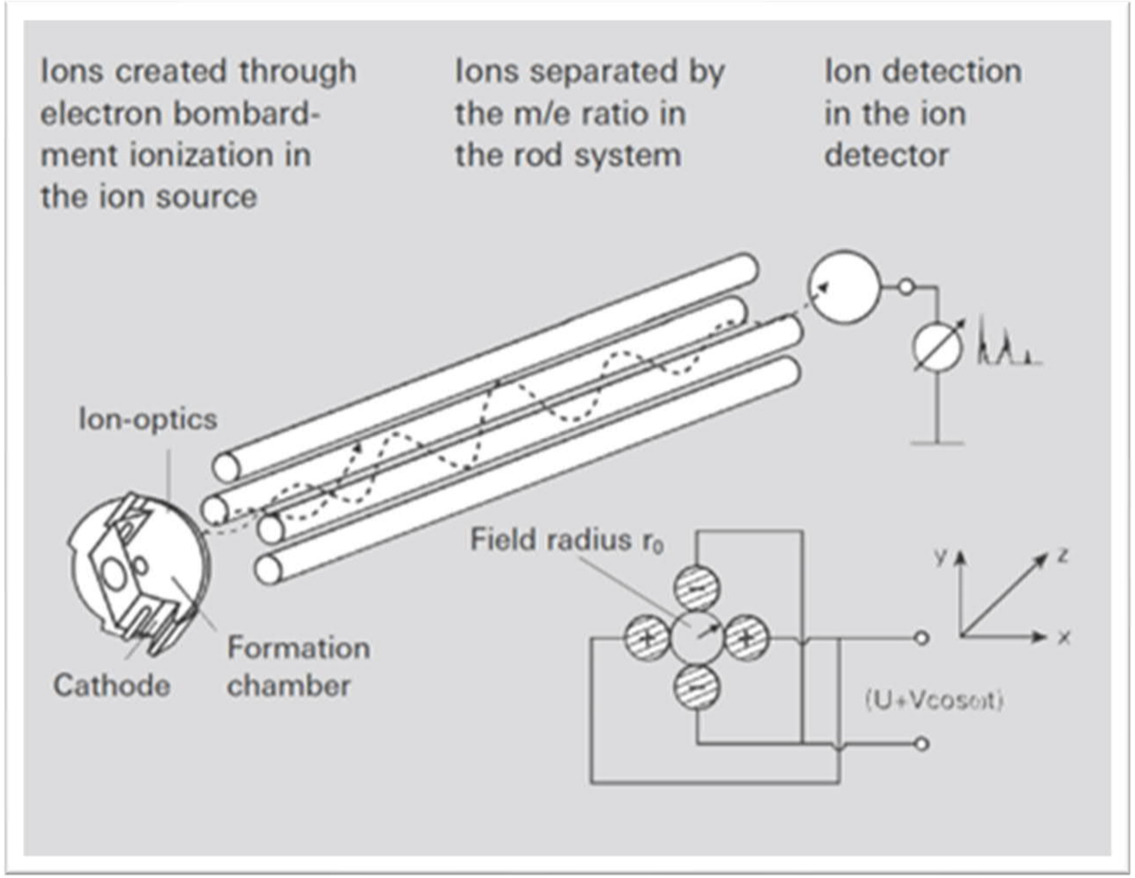


150 units

Open ion source/ Channeltron



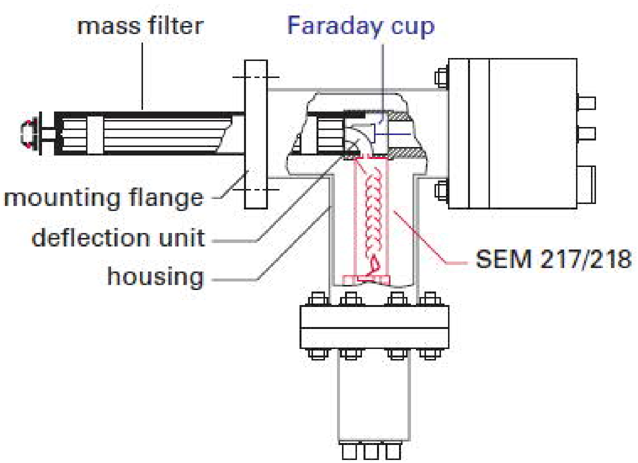
Mass spectrometers
Operating principle



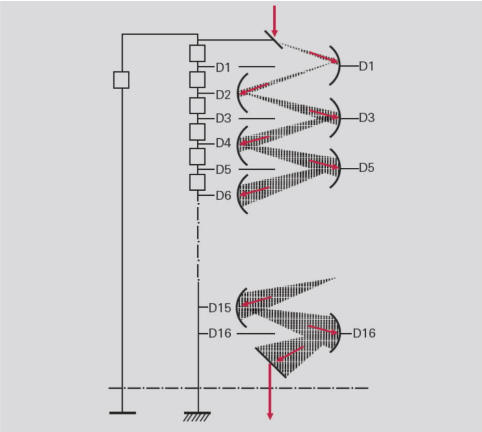
Mass spectrometer operating principle

https://www.pfeiffer-vacuum.com/en/know-how/mass-spectrometers-and-residual-gas-analysis/

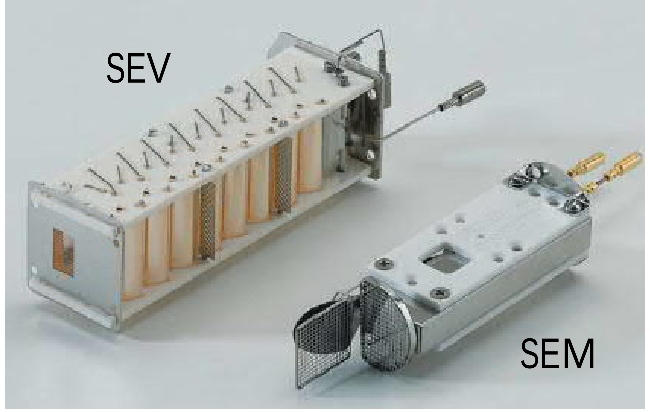
Mass spectrometers
Operating principle



Schematic view of a Pfeiffer QMA125 MS



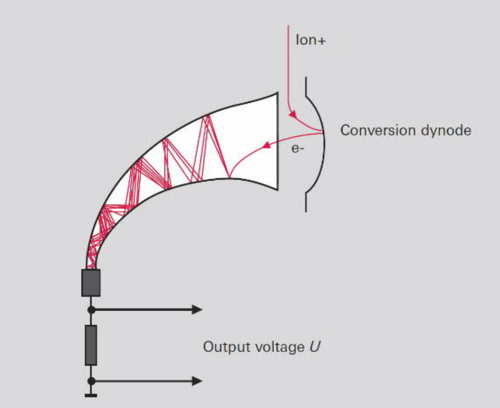
Secondary electron multiplier (SEM) SEV



Secondary electron multipliers

Open ion source

Grid ion source

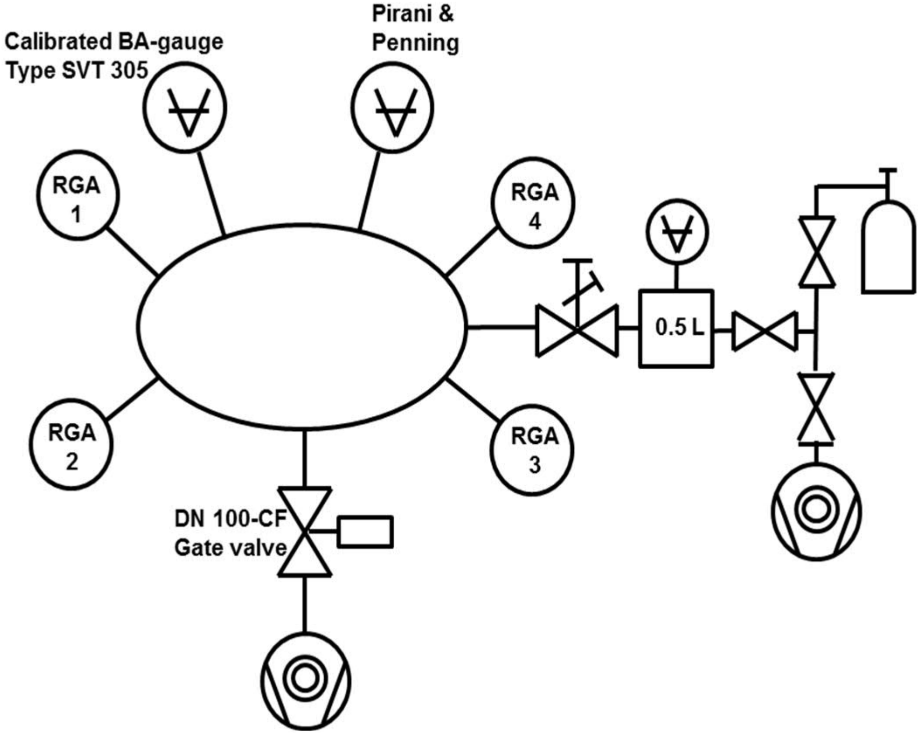


Continuous secondary electron multiplier (C-SEM)

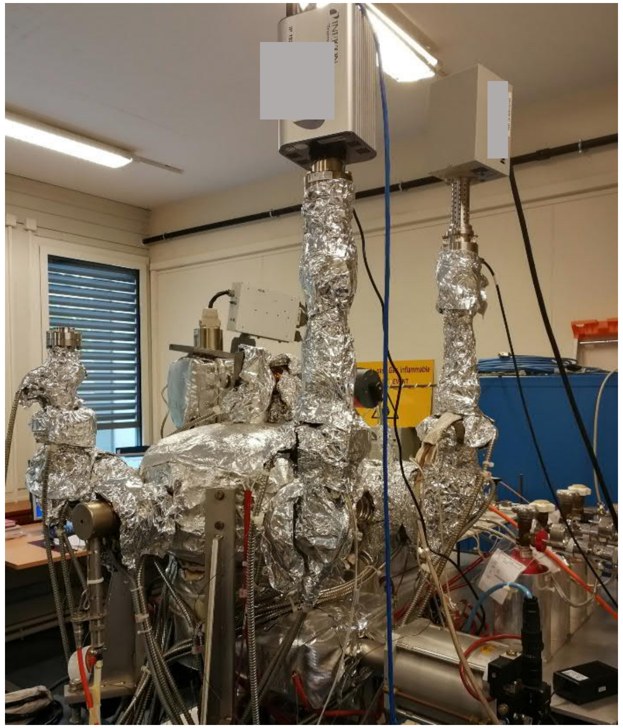
Quadrupole mass filter

Part 2:
Mass spectrometer Evaluation

Mass spectrometer: Characteristics



CERN test stand for RGA calibration



RGA Sensitivity (A/mbar):

$$Sg = \frac{\Delta ion\ current\ RGA\ (A)}{\Delta P\ Partial\ pressure\ (mbar)}$$

Outgassing rate (mbar.l.s^{-1}):

$$Q = Cg(\Delta Pg)$$

Gauge used for RGA calibration measurement: Bayard-Alpert gauge

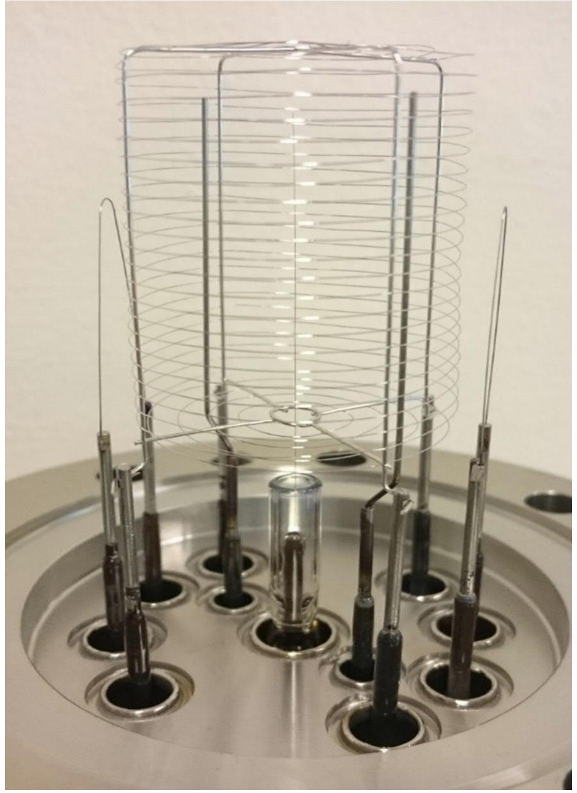
Pressure range: 10^{-6} to 2.10^{-12} mbar

Advantages:

- High measurement accuracy and realibility measurement error (between15% and 30 %)

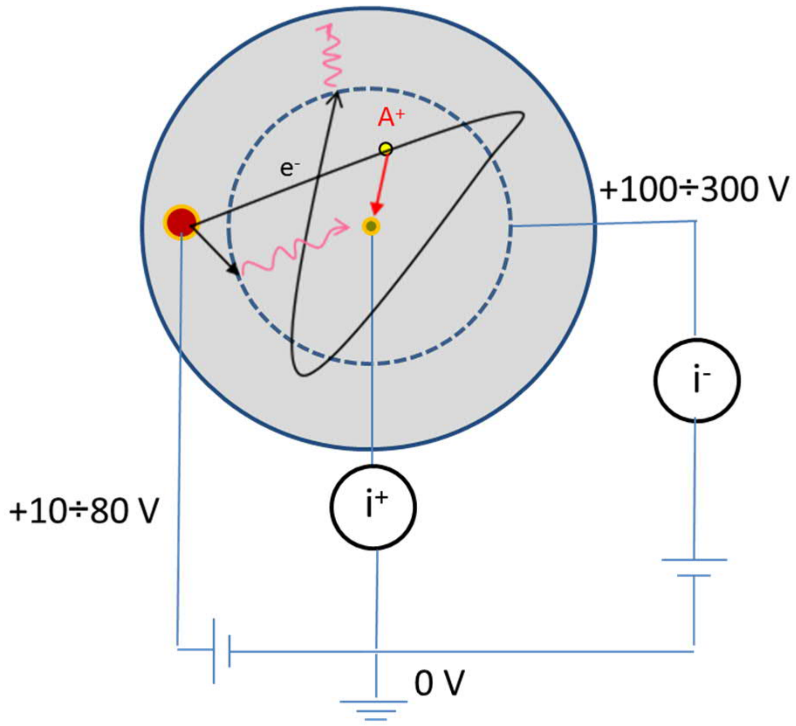
Disadvantages:

- Pressure depends on the main gas
- Fragility of the parts (grid, filament, feedthroughs)
- Highly sensitive gauge to air inrush and contamination
- Limit of the measurement with the X-rays effect(residual current)



SVT 305

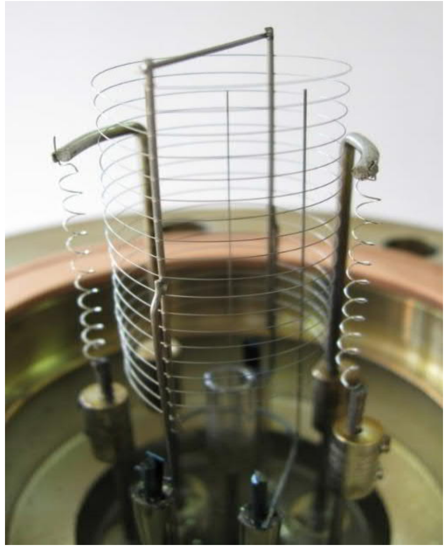
Bayard-Alpert Gauge
Operating Principle



- Hot filament ionisation gauge
- **Electrons emitted by the filament perform oscillations inside the grid and ionise molecules** of the residual gas or hit the grid.
- Ions are eventually collected at the central wire

$$I^{+} = SIeP$$

I^+ is the collected ion current(A)
S is the sensibility ($mbar^{-1}$)
P is the pressure (mbar)
I_e is the emission current(A)



Gauge used for RGA calibration measurement: Bayard-Alpert gauge

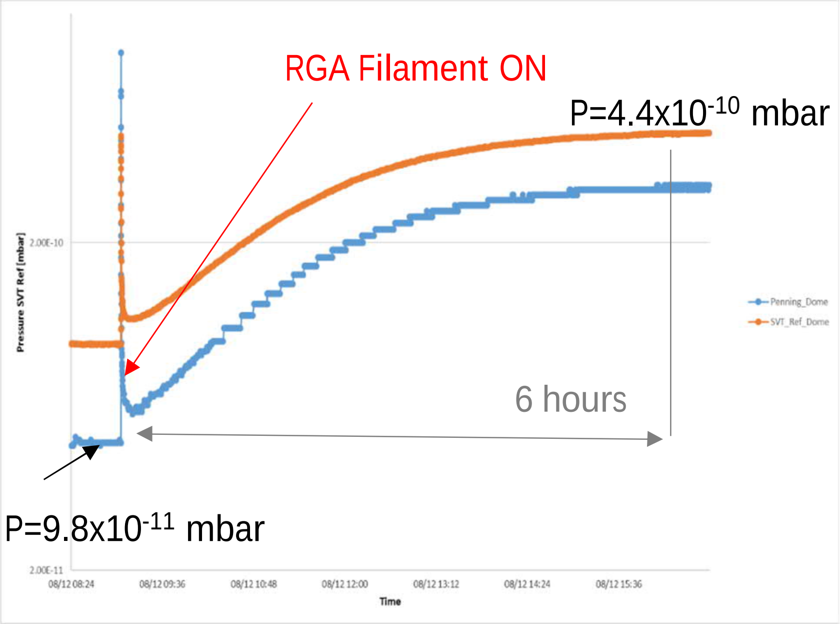
Nominal Gas Correction Factors for Common Gases

(relative to N_2 = 1.00)

Gas	R_g
He	.18
Ne	.30
D_2	.35
H_2	.46
N_2	**1.00**
Air	1.0
O_2	1.01
CO	1.05
H_2O	1.12
NO	1.15
NH_3	1.23
Ar	1.29
CO_2	1.42
CH_4 (methane)	1.4
Kr	1.94
SF_6	2.2
C_2H_6 (ethane)	2.6
Xe	2.87
Hg	3.64
C_3H_8 (Propane)	4.2

1. Mass spectrometer outgassing measurement

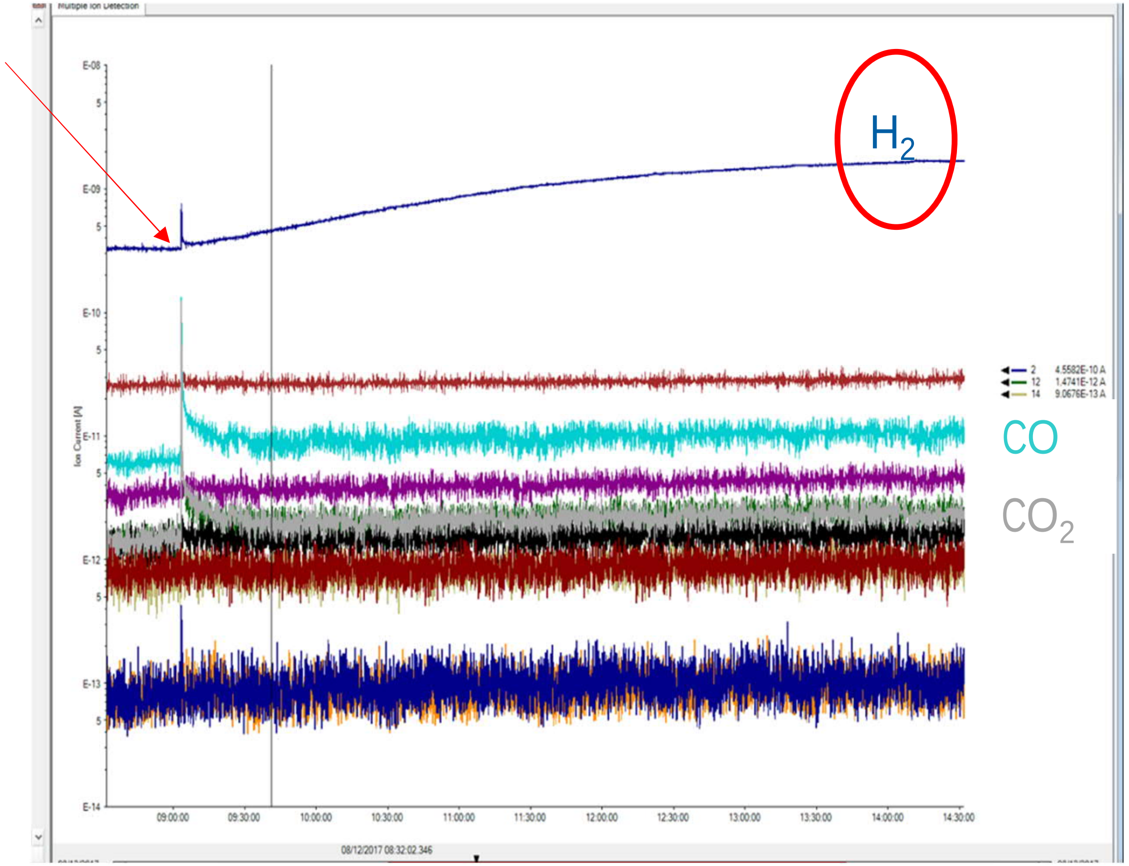
Mass spectrometer: Outgassing measurement



Pressure follow-up when switching ON the filment of theMKS microvision2 RGA

$Q= 1x10^{-7}$ mbar.l.s^{-1}

H_2, CO et CO_2 are the main released species responsible for the outgassing



Partial pressures follow-up when switching ON the filament of the microvision2 MKS RGA

Mass spectrometer:
Outgassing rate as function of the ion source




RGA type	Ion source type	Fil	Q(mbar.l/s)
FAR/SEM	Grid with «vacuum firing»	W	$2x10^{-9}$
FAR/Channeltron	Grid with «vacuum firing»	W	$4x10^{-9}$
FAR/Channeltron	Grid without «vacuum firing»	W	$3.7x10^{-8}$
FAR/Channeltron	Open ion source with «vacuum firing»	Y	$8x10^{-9}$
FAR/Channeltron	Open ion source without «vacuum firing»	Y/W	Min=$2x10^{-8}$ Max= $5x10^{-7}$

Using supplier parameters

2. Mass spectrometer: sensitivity measurement

Mass spectrometer: Sensitivity measurement

In general, to define the sensitivity, one can inject pure gas in the vacuum system following the pressure given by the BAG gauge and the ion current given by the RGA.

Sensitivity is the ratio of change in the spectrum peak height (Ion Current) to the corresponding change in partial pressure (*definition from ISO 14291-Vacuum technology — Vacuum gauges — Definitions and specifications for quadrupole mass spectrometers*).

The calculation for working out sensitivity is:

$$Sensitivity\left(\frac{A}{mbar}\right) = \frac{\boldsymbol{I - I_{\circ}}}{\boldsymbol{(P - P_{\circ})}}$$

I is the Ion Current (A) of the selected test gas during injection.

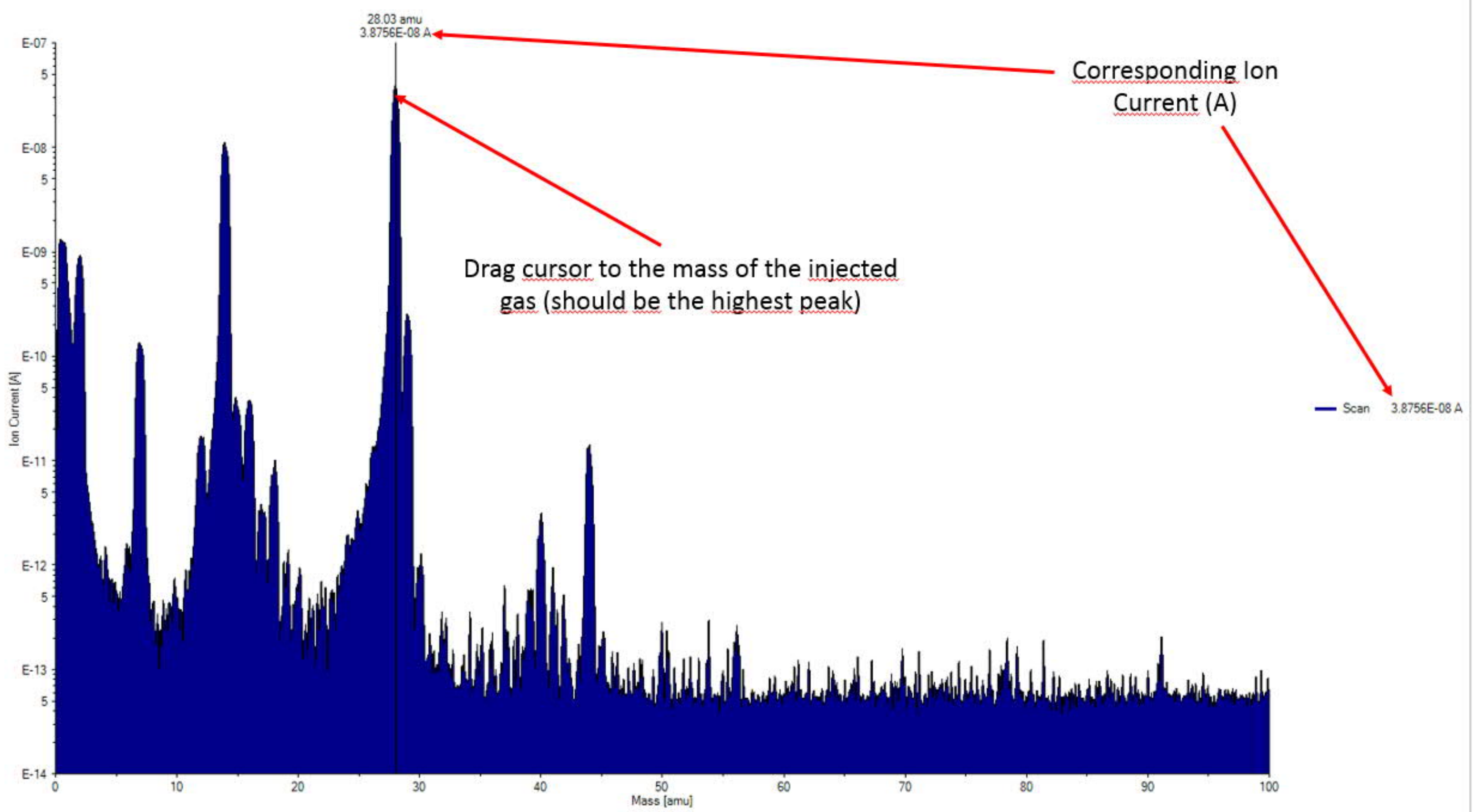
I_o is the Ion Current (A) of the selected test gas before injection.

P is the pressure within the test vessel during injection.

P_o is the pressure in the test vessel before injection.

The pressure measured by a Bayard-Alpert gauge depend on the main gas in the vacuum system and must be corrected according to the majority gas.

Mass spectrometer: Sensitivity measurement for Nitrogen



Analog scan during Nitrogen injection to determine RGA Nitrogen sensitivity

Mass spectrometer: Sensitivity measurement exemple

For example, if an RGA is tested with Nitrogen Gas, a typical sensitivity would look like this.

$$Sensitivity\left(\frac{A}{mbar}\right) = \frac{\boldsymbol{I - I_{\circ}}}{\boldsymbol{(P - P_{\circ})}}$$

If we substitute values in;

$$Sensitivity\left(\frac{A}{mbar}\right) = \frac{\mathbf{(8.51e-09)-(1.96e-11)}}{\mathbf{(5.0e-08)-(5.0e-11)}}$$

$$Sensitivity\left(\frac{A}{mbar}\right) = \frac{\mathbf{8.4904e-09}}{\mathbf{4.995e-08}}$$

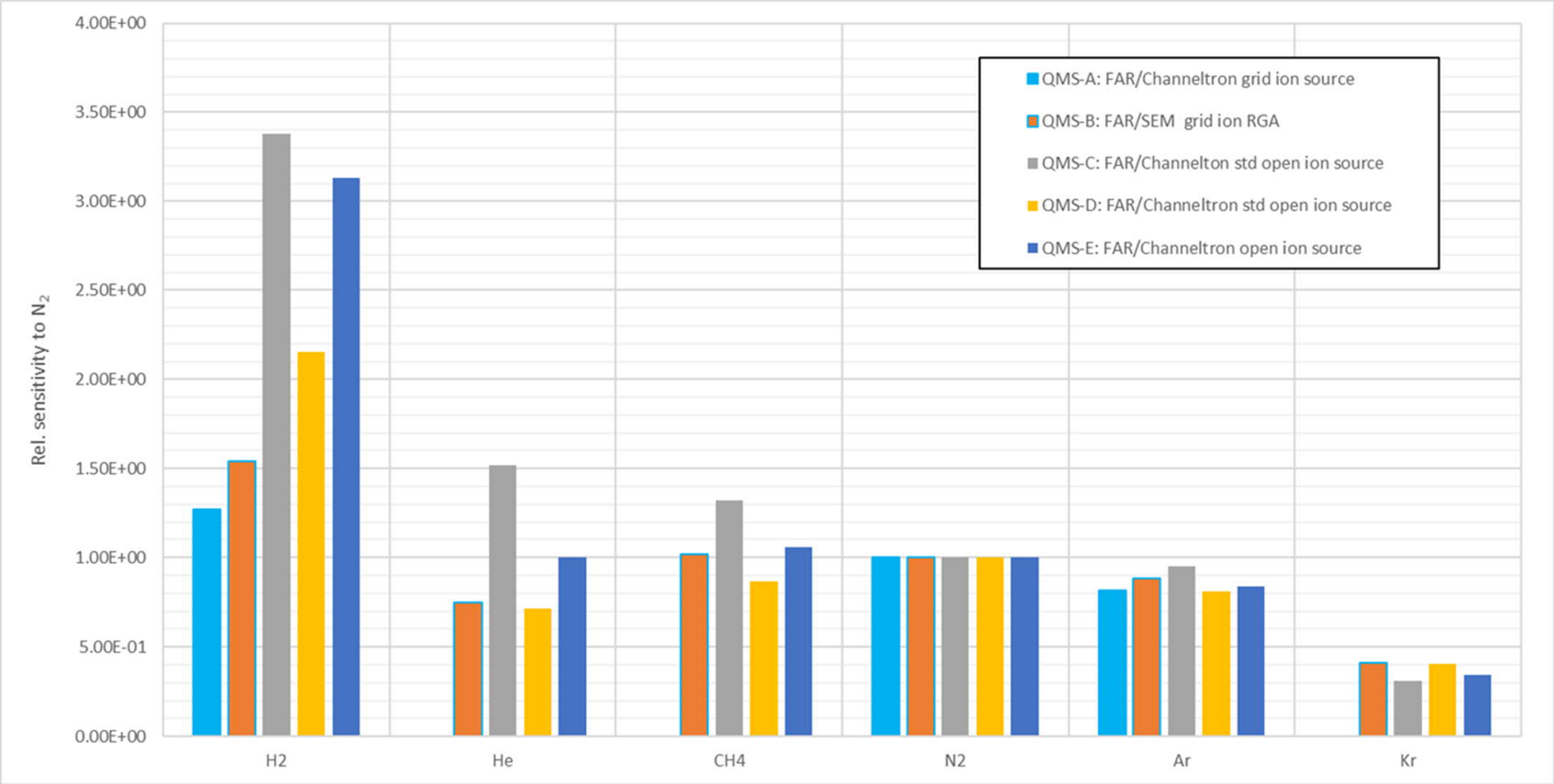
As the correction factor of Nitrogen is 1, the value for the pressure remains the same.

$$Sensitivity\left(\frac{A}{mbar}\right) = 1.70e-01A/mbar$$

Mass spectrometers: Sensitivities (A/mbar)

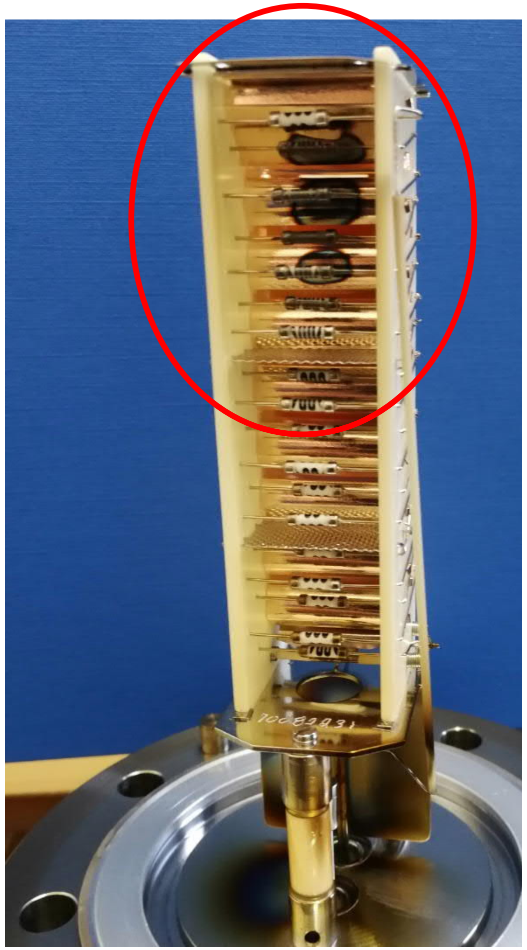
	RGA type	SN_2 (A/mbar) Faraday	SN_2 (A/mbar) SEM
	FAR/SEM Grid ion source	$1x10^{-4}$	min: $5x10^{-1}$ max: 20
	FAR/Channeltron Grid ion source	$6.5x10^{-5}$	$1x10^{-1}$
	FAR/Channeltron Open ion source	min: $5x10^{-5}$ max: $1.5x10^{-4}$	min: $5x10^{-2}$ max: $5x10^{-1}$

Mass spectrometers:
Relative sensitivities to N2 (A/mbar)



Relative sensitivities to nitrogen for different types of RGA *(with supplier parameters)*

Mass spectrometers
User advices



QMA125-PFEIFFER SEM
after few hours at high pressure
in mass follow-up mode

- Degas both filaments during bake-out at 150°C then leave the filament ON
- Switch ON the filament when P< 10^{-6} mbar and wait for 3 hours before any measurement or scan.
- Avoid SEM/ Chaneltron measurements just after the pump-down (oxydation of the SEM by the water vapor).
- Prefer a first measurement in Faraday to check the vacuum system and the absence of contamination
- Avoid prolonged mass follow-up at pressures greater than 10^{-8} mbar in SEM.
- Stop the SEM at the end of a measurement.
- Prohibit the measure in SEM if P > 10^{-6} mbar
- Si la sensibilité en SEM a diminué, vérifier le RGA en Faraday avant d'augmenter le SEM.
- Select the RGA in accordance with measurement to perform