Leak Detection

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CAS Vacuum in Accelerators
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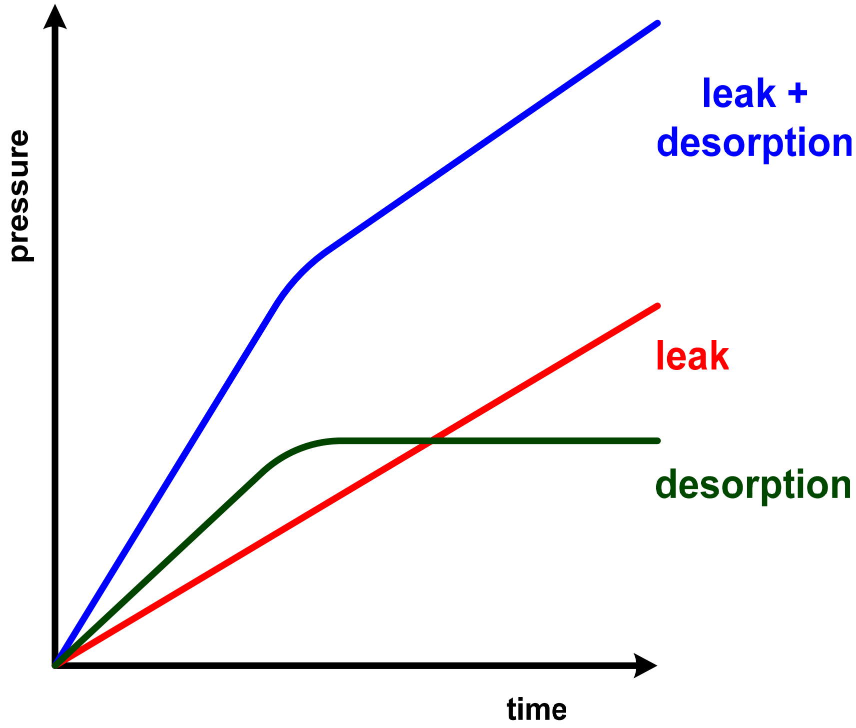
THE CERN ACCELERATOR SCHOOL

Outline

- Introduction
- Leak Rate and Leak Types
- Leak Detection Methods
- Helium Leak Detectors and Leak Detection
- Practical Experience and Examples
- He Leak Detectors - State of the Art
- Concluding Remarks

Introduction

- **Ideal vacuum chamber**
  - ↪ **maintain vacuum pressure forever after switching off pumps**
- **Real vacuum chamber ↪ pressure increase without pumps**
  - outgassing and desorption
  - leaks



Leak Rate

- No vacuum system completely leak tight ↪ even not necessary

specify acceptable leak rate in order to reach required pressure

$$Q_l = V \frac{\Delta p}{\Delta t}$$

	mbar·l/s	Torr·l/s	Pa·m^3/s	cm^3/s
mbar·l/s	1	0.75	0.1	0.99
Torr·l/s	1.33	1	0.133	1.32
Pa·m^3/s	10	7.5	1	~10
cm^3/s	1.01	0.76	0.101	1

Leak Rate

Examples

- high vacuum (HV-) system

  $Q_l < 10^{-6}$ mbar·l/s ↪ very tight
  $Q_l < 10^{-5}$ mbar·l/s ↪ tight
  $Q_l < 10^{-4}$ mbar·l/s ↪ leaky

- small channels

Diameter of hole	Leak rate
0.01 mm (hair)	10^{-2} mbar·l/s
10^{-10} m = 1 Å	10^{-12} mbar·l/s

- $Q_l = 10^{-10}$ mbar·l/s = 10^{-10} cm³/s

  ↪ 1 cm³ gas needs 317 years to flow through leak!

Leak Types

- **Fixed connections**
  - brazed, welded, glued
  - glass-metal, ceramics-metal
- **Pores (mechanical, thermal stress), hair cracks**
  - always present ↪ must be small enough
- **Flanged connections**
- **Cold/warm leaks (reversible) at extreme temperatures**
- **Virtual leaks**
  - excavations, etc. ↪ needs long time to pump
- **Indirect leaks from e.g. supply lines**
  - cooling water
  - gas/liquid supply lines (He, N_2) for cryogenic systems
- ***Permeation* ↪ natural porosity of material**
  - rubber seals
    - Perbunan ($2\cdot10^{-2}$ mbar·l·mm/s/m^2): HERA insulating vacuum tank $2\cdot10^{-5}$ mbar·l/s/m

avoid potential leaks already during design and fabrication!

Leak Detection Methods

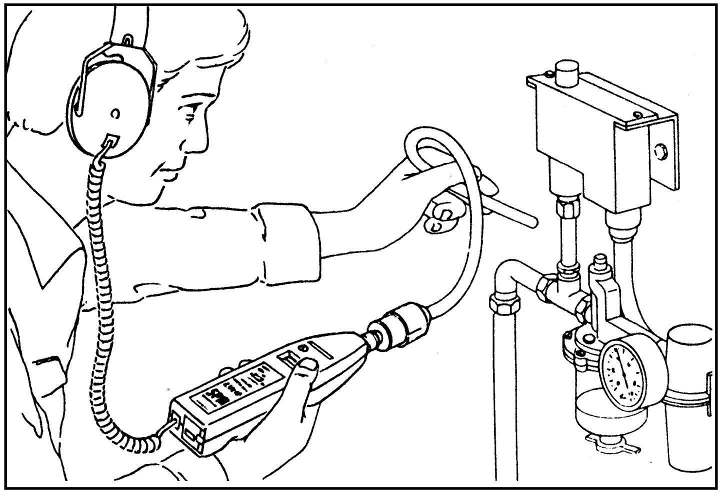
Goals:

localize leak

determine leak rate (locally/total)

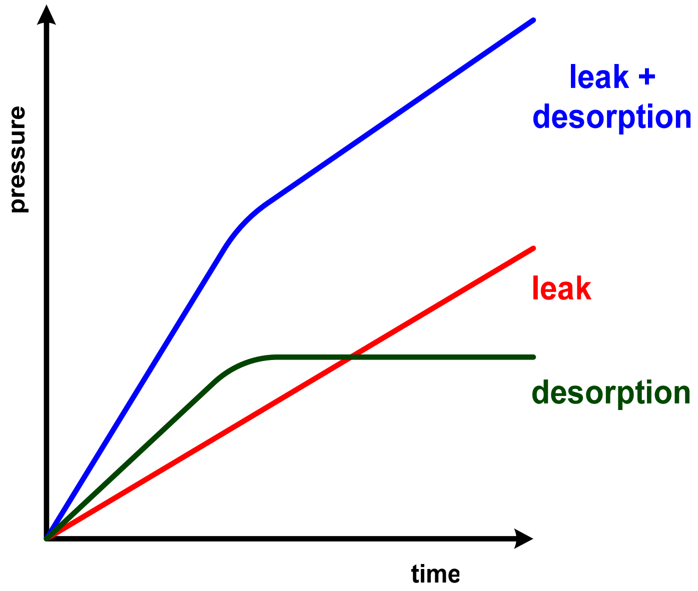
↳ **various methods**

- **Mechanical effects**
  - ultra sound
    - ↳ $Q_l > 10^{-2}$ mbar·l/s
  - bubbles
    - ↳ $Q_l > 10^{-4}$ mbar·l/s



Leak Detection Methods

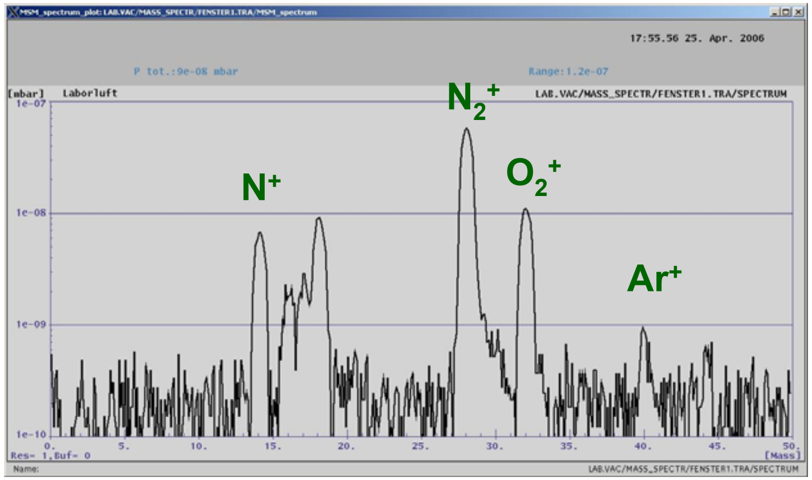
- **Pressure increase**



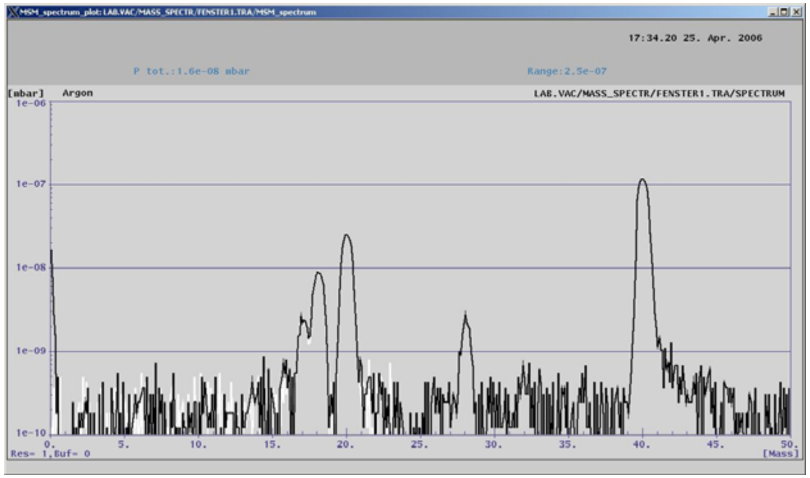
- **Modification of physical properties of residual gas**
  - ↳ **changing gas composition at leak (tracer gas)**
  - heat conductivity (tracer: alcohol/CO_2, detector: Pirani gauge)
  - ionization cross section (tracer: e.g. Ag, detector: ion gauge, sputter ion pump)
  - ….

Leak Detection Methods

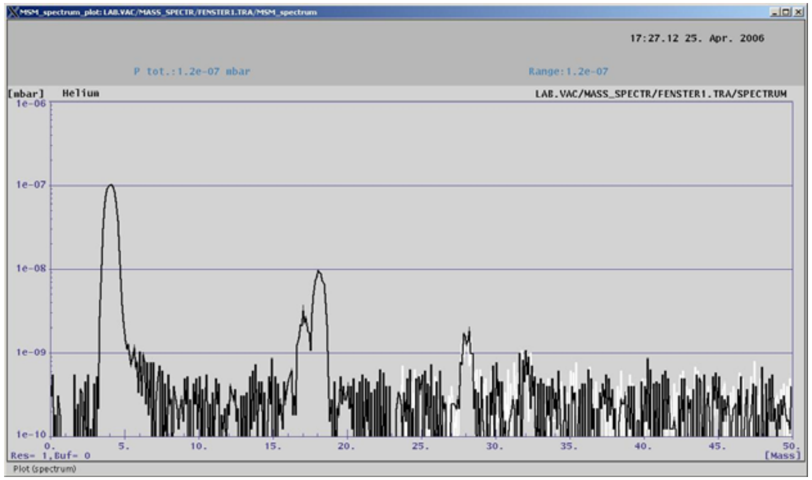
- **Mass of residual gas**
  - ↪ **tracer: He (Ar, air)**
  - ↪ **detector: mass spectrometer**
    - most sensitive method (10^{-12} mbar·l/s)



air



Ar



He

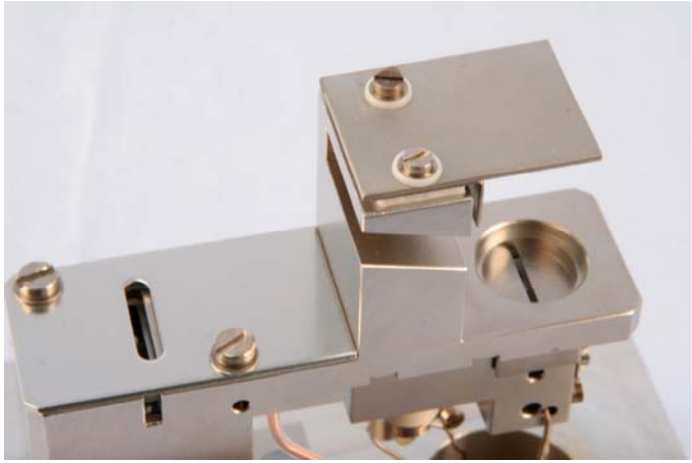
Tracer Gas

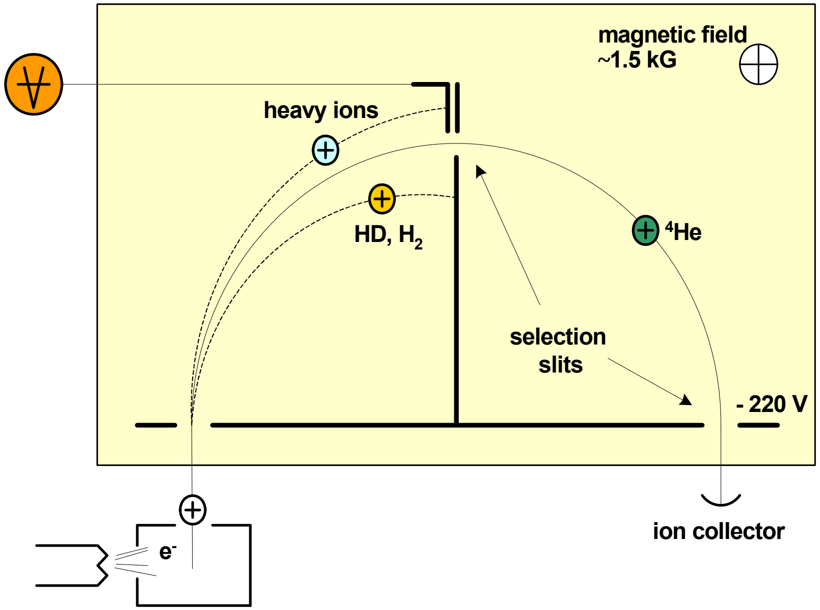
- **Properties**
  - unambiguous signal in RGA
  - inert gas (chemically, physically)
  - non explosive, not harmful
  - cheap
  - low content in air
  - easy to pump/no contamination of vacuum system
- **Helium most commonly used**
  - $v_{He} = 3 \cdot v_{air}$ ↪ 3 times more sensitive than air
  - diameter comparable to lattice constant (1 Å)
- **Argon**
  - larger content in air (1 %)
  - mixed signature in RGA
    - Ar^{+}: mass 40, hydrocarbons
    - Ar^{++}: mass 20, ^{20}Ne, $^{18}OH_2$

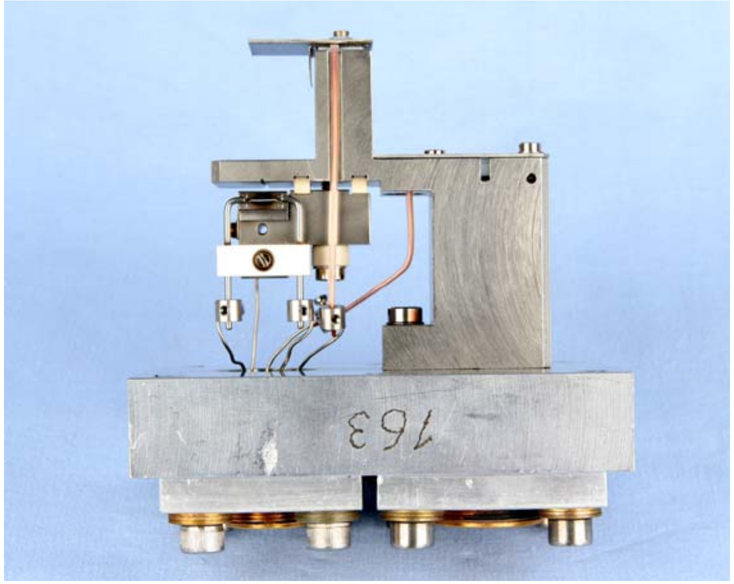
He Standard leak rate
(He Std: Δp = 1 bar)

Helium Leak Detectors

- Operating pressure $p < 10^{-4}$ mbar
- In principle any type of RGA possible
- Most sensitive/safe ↪ mass spectrometer with 180° magnetic sector field
  - optimized for mass 4 (3,2)



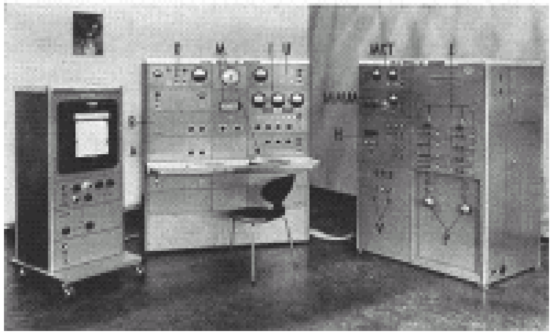




History of Helium Leak Detectors

- **1910 Thomson**
  - first mass spectrometer (Ne)
- **1942/43 Manhatten Project**
  - Uranium enrichment
    - He mass spectrometer leak detector by A.O. Nier (1947)
    - made out of glass ➥ very fragile
- **1950's, 1960's**
  - first metallic version by General Electric (GE)
  - first compact units with pump station (200 kg)
- **~1975**
  - counter-flow method
    - already proposed 1967/68 by Becker (Pfeiffer)
    - Vienna conference 1977 Briggs (Varian)

    ➥ adequate turbomolecular pumps on the market
- **Sensitivity**
  - 1945 ➥ 10^{-6} mbar·l/s
  - 1970 ➥ 10^{-9} mbar·l/s
  - today ➥ 10^{-12} mbar·l/s



1960/Atlas MAT CH-4

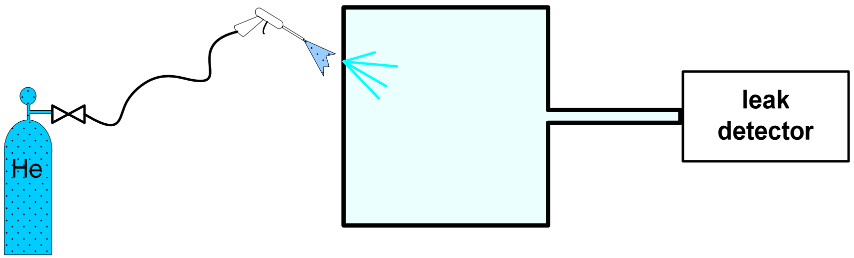
today

Helium Leak Detection

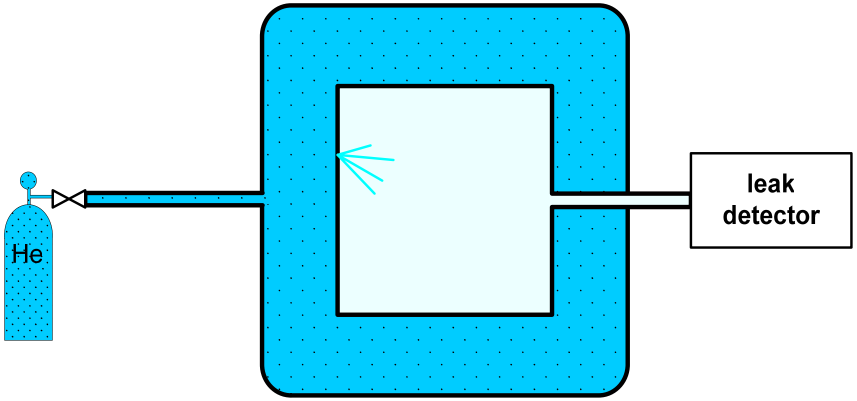
- **Tracer probe**
  - gas penetrating into the system
  - pumped via detector

vacuum systems

leak location



total leakage measurement

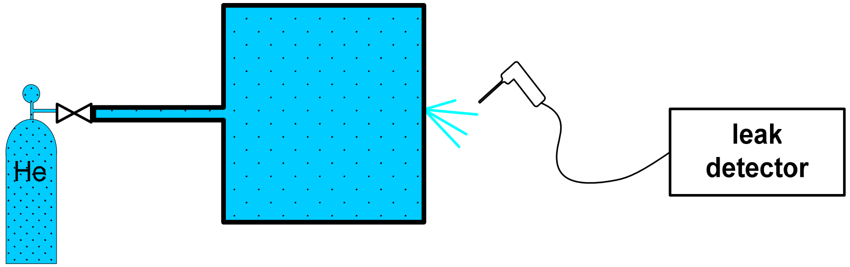


Helium Leak Detection

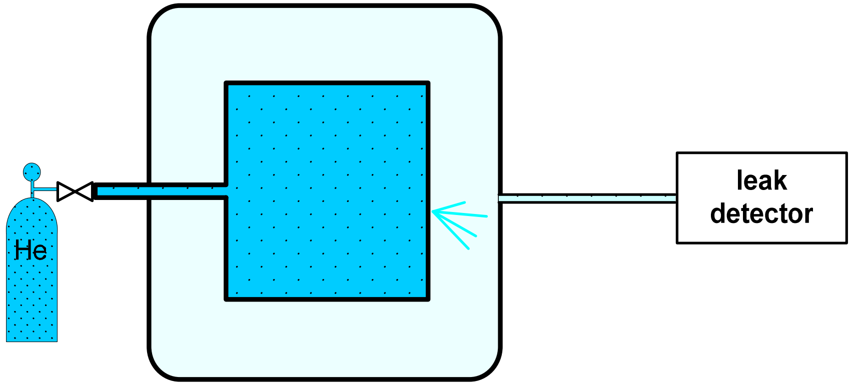
- **Detector probe**
  - system filled with test gas
  - detector (sniffer) connected to leak detector
    - capillary to reduce pressure 1 bar ➥ 10^{-4} mbar
    - detection limit 10^{-7} mbar·l/s (He content of air)

pressurized systems

leak location



total leakage measurement



Direct Flow Method

$$Q_{He} = p_{He} \cdot S_{eff,He}$$

- $p < 10^{-4}$ mbar to start leak check
- high sensitivity ➥ low $S_{eff,He}$ with high pumping speed for water
  - diffusion pump
  - cold trap
    - condensate water, etc. = efficient, selective pump

  skipped in modern leak detectors with TMP

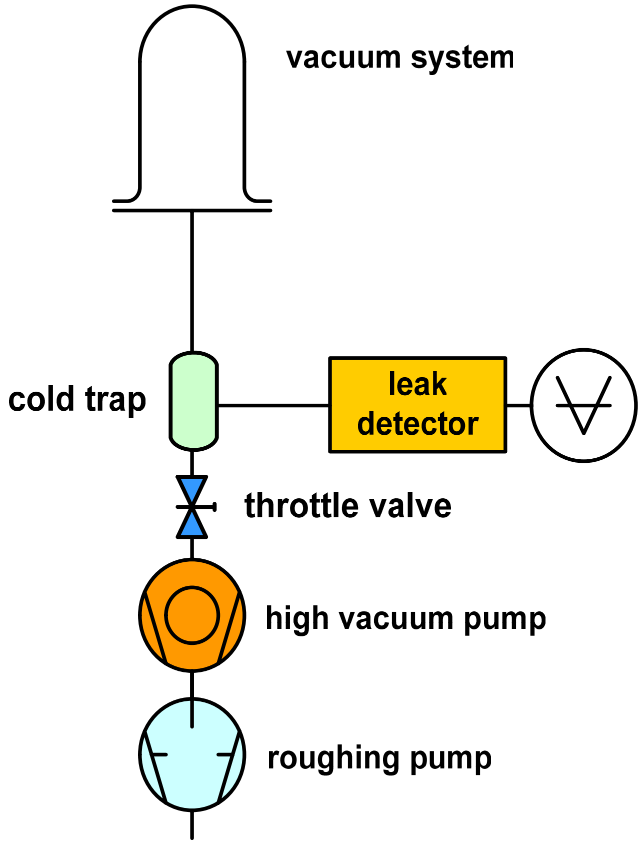
  - optional: throttle valve
    - reduce gas flow to pump
    - increase sensitivity

  Example

  $p_{min,He} = 1\cdot10^{-12}$ mbar

  $S_{He} =$ 10 l/s ➥ $Q_{min} = 1\cdot10^{-11}$ mbar

  $S_{He} =$ 1 l/s ➥ $Q_{min} = 1\cdot10^{-12}$ mbar



- **Advantages**
  - fast
  - very sensitive

Counter Flow Method

- **He partial pressure reduced by turbomolecular pump**

$$Q_{He} = p_{He} \cdot S_{eff,\,He} \cdot K$$

  - other gases suppressed more strongly (compression factor K)

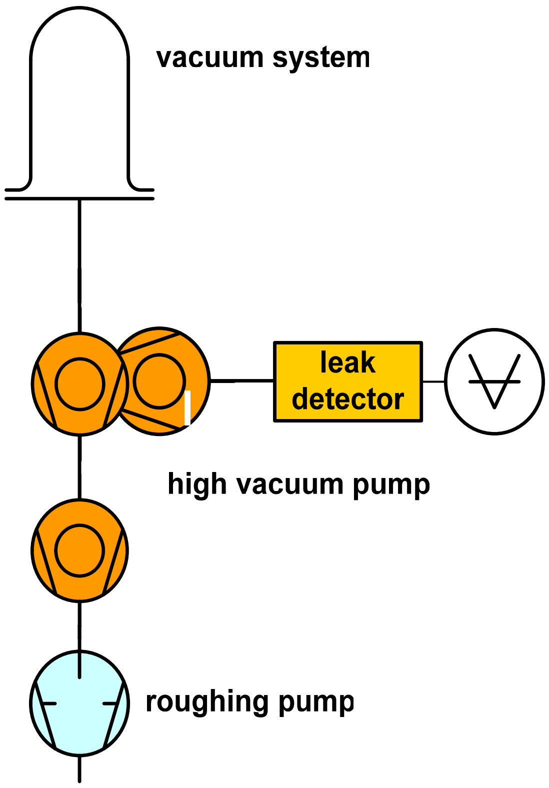
    example

    K_{He} = 50

    K_{H2O} = 4000 ➥ factor 80 suppressed

    K_{N2} = 30.000 ➥ factor 600 suppressed

- **Advantages**
  - no cold trap needed
  - start at high pressure possible ($p \cong 10^{-1}$ mbar)
- **Disadvantages**
  - less sensitive than direct flow ($1 \cdot 10^{-10}$ mbar·l/s)
  - dirty pump connected to system
    - second turbomolecular pump
    - two stage turbomolecular pump

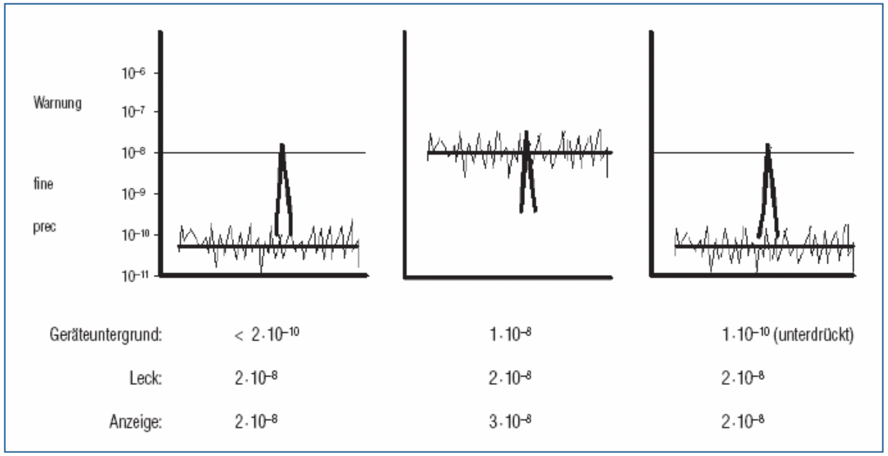


Characteristics

- **Ultimate sensitivity**
  - partial pressure sensitivity of detector
  - He pumping speed of system

$$Q_{He} = p_{He} \cdot S_{eff,He} \cdot K$$

- **Adjustment and stability**
  - zero line
    - drifts from electronics
    - adjustment before measurement and regular checks necessary
  - calibrated leaks
    - regular checks and readjustment necessary



Leybold/ Grundlagen der Vakuumtechnik

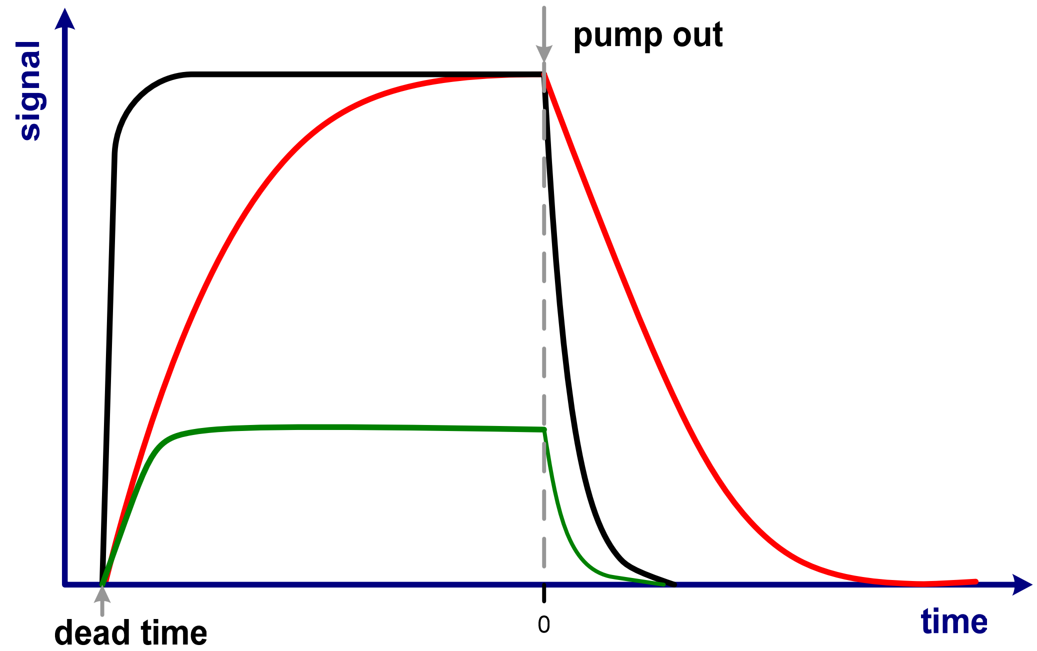
- **Detection limit**
  - Helium background signal
    - He entering via exhaust line into roughing pump ➥ “stored” in pump oil
      counteract: gas ballast to flush roughing pump
    - He entering through leaks or O-rings

Characteristics

- **Warm up time**
  - stable operation of mass spectrometer
- **Response/recovery time**

$$p_{He} = \frac{Q}{S_{eff}}\left(1 - e^{-\frac{t}{\tau}}\right)$$

$$\tau = \frac{V}{S_{eff}}$$



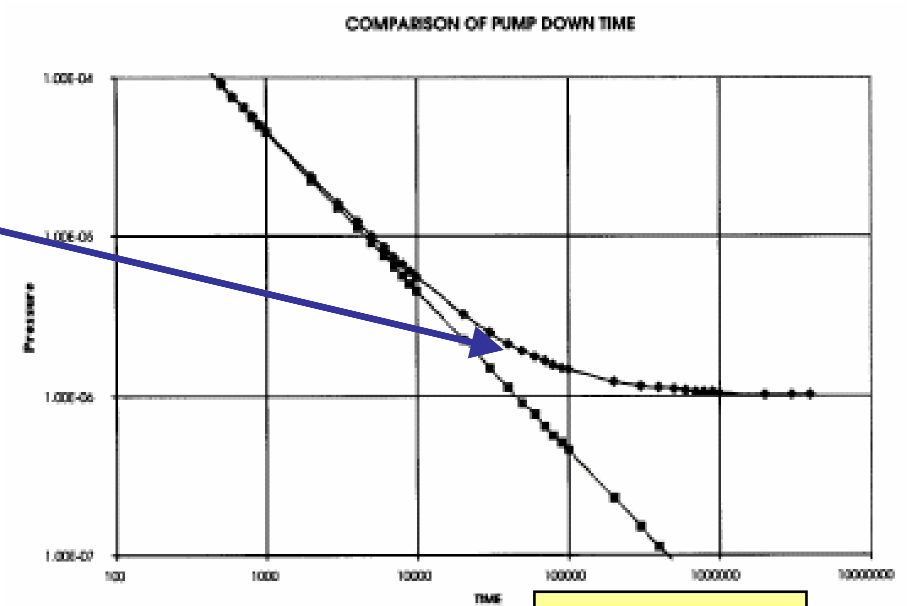
Practical Experience and Examples

- **Proper choice of leak detector**
  - sensitivity/speed
    - leak check of welds during fabrication
    - final leak check prior to installation
  - O-ring/metal seals
  - volume to be leak checked
    - single component
    - vacuum section in accelerator
  - documentation

HERA (1992)

Practical Experience and Examples

- **Systematic work necessary**
  - check leak detector first
  - reduce gas flow from He bottle
  - search from top to bottom
  - work against air flow in tunnel
- **Pump down curve**
  - ↳ **first hints for leak**



N. Hilleret/CAS1999

- **Take your time!**
  - small leak might initially be blocked by water
    - ↳ open up after sufficient pumping time or bake-out

Practical Experience and Examples

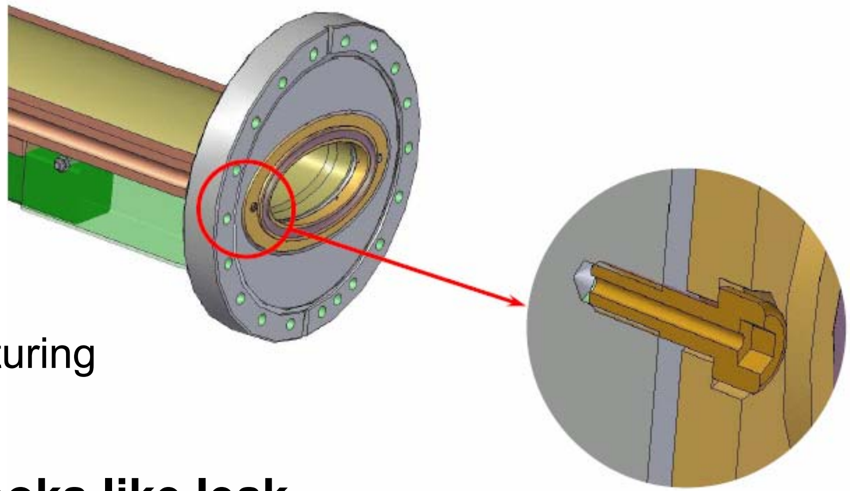
- **Leak check prior to installation into accelerator**
  - leak check of sealing surfaces ➥ use metallic gaskets

100% check of components strongly recommended

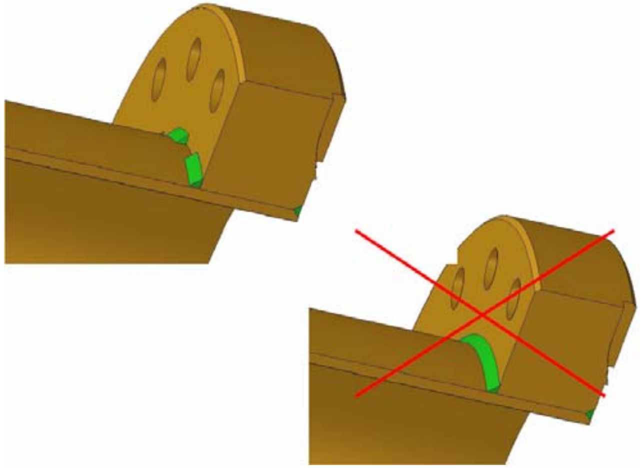
  - easier to find and repair leaks in lab
  - leak check of large systems time consuming

Virtual Leaks

- **Excessive outgassing from**
  - excavations
  - dead holes for screws
  - narrow slits
  - …
  - ↳ mostly poor design and/or poor manufacturing

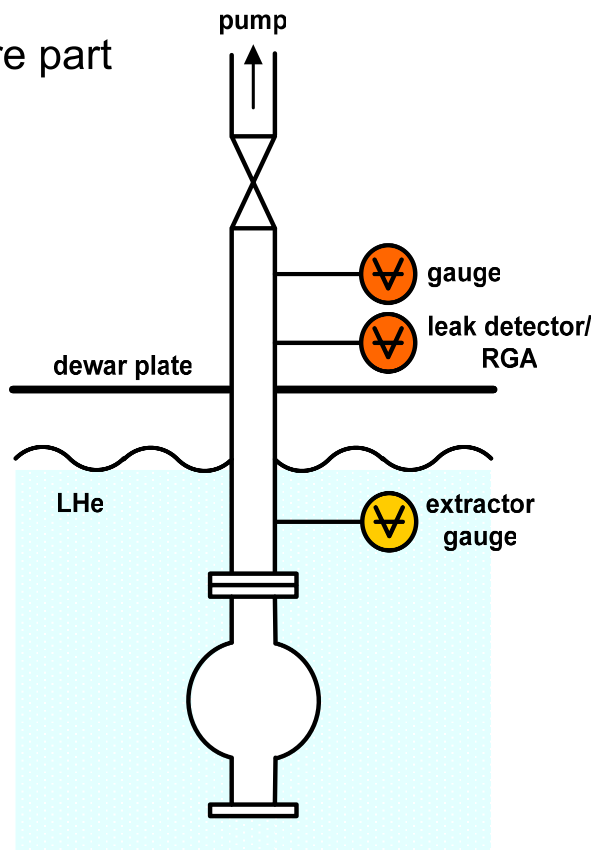


- **Pump down/pressure rise curve ↳ looks like leak**
- **No signal in leak detector**
- **Detection**
  - RGA: check gas composition before and after venting with e.g. Ar
    - ↳ Ar enhancement after venting



Cold Leaks

- **Cooling to extreme temperatures ↪ opening up of additional leaks**
- **System cooled with liquid He (< 4.5 K)**
  - He (partially) absorbed on cold walls
  - leak detector/RGA to be operated at room temperature part
    - delay of He signal might be very long
  - for leak check
    - warm up system to ≅ 10 K
    - check He signal in leak detector
- **Hot extractor gauges might be operated at liquid He temperatures**
  - for large systems ↪ several gauges
    - time profile of response signal
- **Cold leaks sometimes vanish after warm up!!!**



Total Leakage Measurement

- **Vacuum method**
  - complete system enclosed by test gas
    - ➥ detection of very small leak rates (not location)
    - e.g. UHV components to be used in cold systems

Example

- HERA

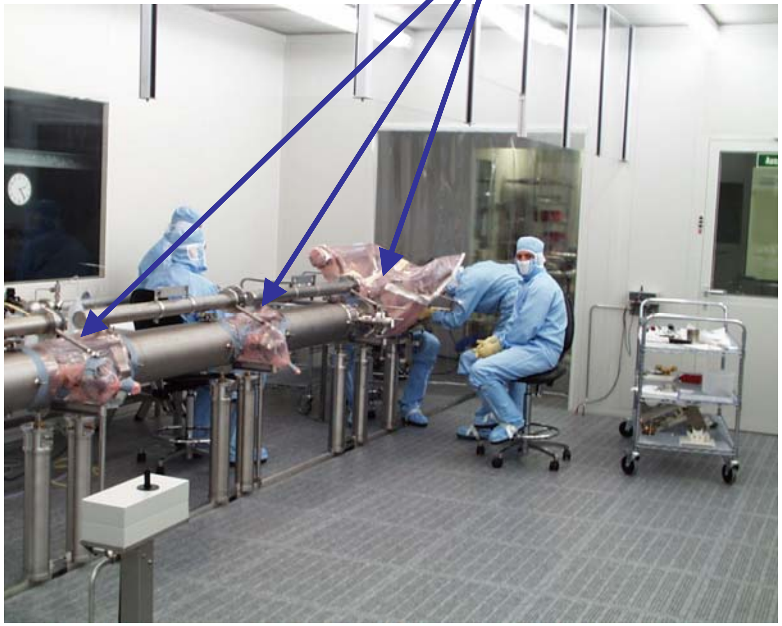
  beam pipe surrounded by liquid He

  (superconducting magnets)

  ➥ measure He signal during warm up with RGA

  ➥ integral leak rate < 10^{-15} mbar·l/s at 4.5 K

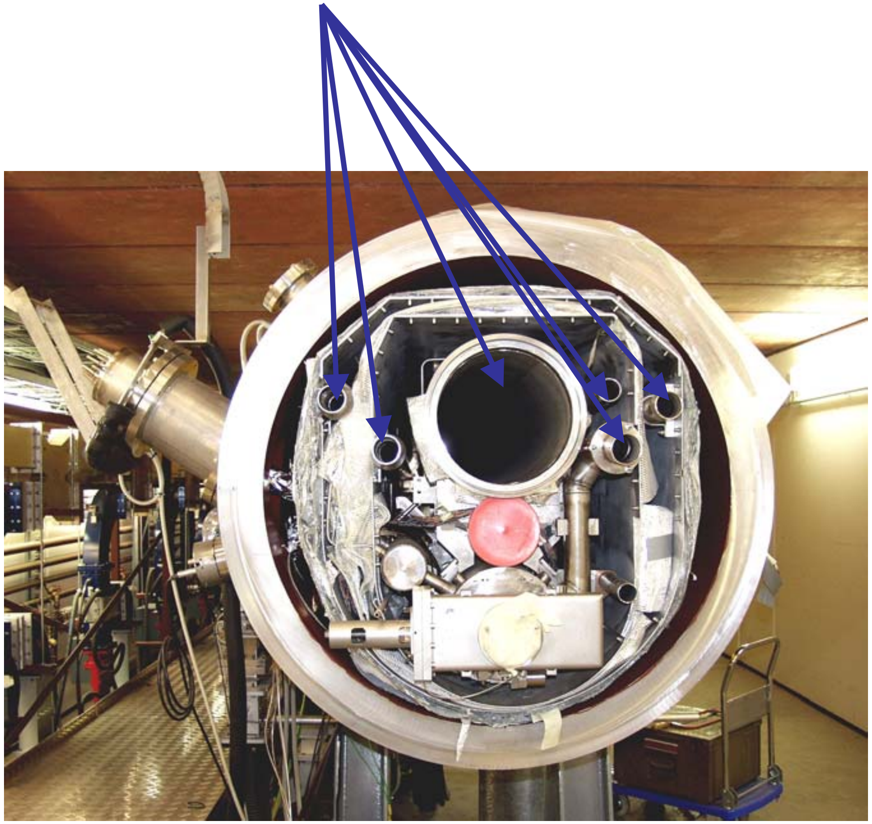
  (D. Trines et al., HEAC 1992, Hamburg)



TTF/XFEL

Total Leakage Measurement

- **Overpressure method**
  - fill system with several bar of test gas
    - e.g. process gas lines in vacuum tank



TTF/XFEL

He Leak Detectors - State of the Art

- **Very compact units**
  - portable!
- **Standard Operation ↪ counter flow method**
  - valve system to inject He at various locations of pumping system
- **Oil free pumps**
  - triggered by semiconductor industry
- **Electronics equipped with semiconductors**
  - sensitive to radiation
  - radiation hard solution ↪ “old fashioned” tubes are still without alternatives

He Leak Detectors - State of the Art

- **Sensitivity**
  - minimum detectable leak
    - $5\cdot 10^{-12}$ mbar·l/s
    - sniffer: $5\cdot 10^{-8}$ mbar·l/s
- **Tracer gas**
  - standard ^4He
  - optional: mass 2 (H_2), 3 (^3He)
- **High degree of automation**
  - fast
    - start-up time ~ few min
    - response time < 1s
  - automated zero (floating zero)
  - automated tuning and calibration

Concluding Remarks

- **Accelerator vacuum system**
  ↳ **demanding requirements for leak tightness**
- **Diagnosis of acceptable leak rates requires**
  - adequate leak detection methods
  - adequate leak detectors
  - well trained personnel
- **Commercial leak detectors**
  - great progress in availability, performance and size since 1950
  - mainly improvements in handling and automation during past 20 years
  - available detectors fit to our demands
- **Nevertheless … finding and repairing leaks**
  ↳ **time consuming process**

prevent leaks during all stages of design, manufacturing and assembly