Physics, Technology and Techniques of the Vacuum

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Outline

- Introduction and basics
- Measuring pressure
- Pumps
- Accessories
-Leaks
Definition of „Vacuum“

- „A vacuum is a volume of space which is substantively empty of matter,…“ [wikipedia]

- Real world vacuums are not perfect: they contain matter!

- Pressure $p$ describes how close to perfect vacuum ($p=0$) a space is.

- Different units of pressure:
# Pressure units

<table>
<thead>
<tr>
<th>Unit</th>
<th>Def.</th>
<th>mbar</th>
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</thead>
<tbody>
<tr>
<td>1mbar</td>
<td>$\equiv 1$ kDyn/cm²</td>
<td>$=1$</td>
</tr>
<tr>
<td>1Pa</td>
<td>$\equiv 1$ N/m²</td>
<td>$=10^{-2}$</td>
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<tr>
<td>1Torr</td>
<td>$\equiv 1$ mmHg</td>
<td>$=1.33 \cdot 10^0$</td>
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<tr>
<td>1at</td>
<td>$\equiv 10$ mH₂O</td>
<td>$=9.81 \cdot 10^2$</td>
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<td>1atm</td>
<td>$\equiv 760$ Torr</td>
<td>$=1.01 \cdot 10^3$</td>
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<tr>
<td>1psi</td>
<td>$\equiv 1$ lbf/in²</td>
<td>$=6.89 \cdot 10^{-1}$</td>
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</tbody>
</table>
## Classification of Vacuums

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pressure range / mbar</th>
</tr>
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<tbody>
<tr>
<td>Atmosphere</td>
<td>~1033</td>
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<tr>
<td>Low vacuum</td>
<td>10^3…3 · 10^1</td>
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<tr>
<td>Medium Vacuum</td>
<td>3 · 10^1…10^{-3}</td>
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<tr>
<td>High Vacuum (HV)</td>
<td>10^{-3}…10^{-8}</td>
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<tr>
<td>Ultra High Vacuum (UHV)</td>
<td>10^{-8}…10^{-12}</td>
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<td>Extremely High Vacuum (EHV)</td>
<td>&lt;10^{-12}</td>
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<tr>
<td>Space: Moon / interstellar</td>
<td>10^{-11} / 10^{-17}</td>
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</tbody>
</table>
Equipment and Proceeding

- pressure gauge(s)
- pump(s)
- housing
- hoses, tubes, flanges, valves
- solvants (cleaning)
- baking facility (UHV)
- leak detector
# Pressure Gauges

## Pressure range of some gauges

<table>
<thead>
<tr>
<th>Pressure / mbar</th>
<th>(10^{-13})</th>
<th>(10^{-12})</th>
<th>(10^{-11})</th>
<th>(10^{-10})</th>
<th>(10^{-9})</th>
<th>(10^{-8})</th>
<th>(10^{-7})</th>
<th>(10^{-6})</th>
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<th>(10^{-2})</th>
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<th>(10^{1})</th>
<th>(10^{2})</th>
<th>(10^{3})</th>
<th>(10^{4})</th>
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<tbody>
<tr>
<td>U-tube</td>
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<td>diaphragm</td>
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<td>hot filament ionization</td>
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<td>cold cathode discharge</td>
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Diaphragm Gauge

- pressure-dependent capacitance
- independent of gas type
- sensitivity approx. independent of diaphragm material and thickness
- can withstand bakeout
Thermal Conductivity Gauge

- heat conductance
  
  \[ j_E \sim \rho (T_2 - T_1) \]

- reduce radiation and convection

- temperature reservoir
Hot Filament Gauge

- electron emission
- Barkhausen oscillations around anode grid
- ionize atoms on their trajectory
- X-ray emission of accelerated electrons
- depends on gas type (ionization energy)
Cold Cathode Discharge Gauge

- electron field emission
- sensitive to gas type
Roots Blower
(Drehkolbenpumpe)

- ~2500 rpm
- 1 mbar...10^{-4} mbar
- vibrations (like every mech. pump)
- no oil or lubrication
Membrane Pump
(Membranpumpe)

- 5 mbar
- robust
- no oil
- backing pump
Rotary Vane Pump
(Drehschieberpumpe)

- 350-700rpm
- ...10^{-1}mbar
- 2 loads in 1 turn
- oil to seal
Turbomolecular Pump
(Turbomolekularpumpe)

- ...60,000rpm
- ...10^{-9}mbar
- momentum transfer
  => less friction, no oil
- magnet bearings
- expensive
Other Mechanical Pumps

Scroll Pump
(Oil-) Diffusion Pump
((Öl-)Diffusionspumpe)

- $10^{-10} \ldots 10^{-2}$ mbar
- backing system: $10^{-1}$ mbar
- cheap
- oil contamination
- durable and reliable
- no vibrations
Cryo and Sorption Pump

**Cryo Pump**
- HV or UHV
- Condensation of atoms on cold wall
- => atoms are trapped
- saturation at higher pressure
- depends on gas type’s boiling/condensation temperature
- regeneration: re-evaporation of trapped atoms (at RT)

**Sorption Pump**
- 10-7mbar
- 3 phases
  - Sorption
  - Desorption
  - regeneration
- material with large surface (coal, zeolite,...)

These two types are often combined.
Getter Pump

- Certain materials are evaporated.
  (barium, aluminium, titanium, sodium,...)

- The evaporated atoms react with / bind residual gas atoms.

- The getter atom condenses on a surface.
Ion Pump

- Emitted electrons ionize gas atoms.
- Ions accelerated to first cathode
- Atoms are sputtered.
- Acceleration towards second cathode
- Atoms are buried in bulk of second electrode.
- Even noble gases are pumped.
Accessories

- valves
  - wearing down by moving parts
  - bakeable
  - most critical part (leaks)

- O-rings outgas (organic)

- sharp edge cut into copper

- Indium wire to seal joints
Leak types and sources

- cryo leaks: temperature dependent expansion
- virtual leaks: e.g. outgasing
- permeation leaks (rubber)
- misfit joints
- damaged O-rings
- leaking cooling tubes
- contamination / insufficient preparation
- untight valves
Leak Detection and Localisation I

- Time dependence can give a hint.
  - log-lin plot; log-log plot

- Rate-of-rise:
  - all valves closed
  - cavities are separated
  - cavity with fast pressure rise is suspect
  - difficult to interpret (normal outgasing)

- Bubble detection:
  - pressurized system
  - spray soap solution on housing, tubes, etc.
  - the stronger the leak the more bubbles...
Leak Detection and Localisation II

- He mass spectrometer leak detector MSLD
  - He is detected with mass spectroscopy
    (partial pressure of He)
  - Under-pressure-method
    - He is sprayed on set up
    - He penetrates leaks
    - He can be detected in a connected MSLD
  - pressed method
    - He is pumped in the system
    - He penetrates out of leaks
    - „Sniffer“ MSLD detects He
- State-of-the-art
- insensitive to source of He
  (damaged He-cooling lines, He in atmosphere, use $^3$He)
Leak Detection and Localisation III

Pictures of He-MSLD