

# Vacuum technology

## High/ultrahigh vacuum pumps and gauges

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### Vacuum pumps

#### Principle of operation

- compression
  - Rough vacuum pumps: the extracted volume is to be compressed above atmosphere
  - High vacuum pumps: rough vacuum pressure is enough (~two-stage rotary vane pump)
    - UHV...
- Trapping
  - Lower background pressure is tolerated

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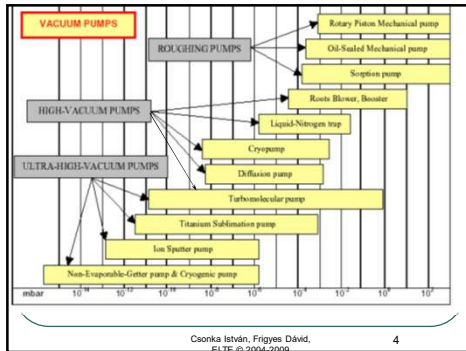
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### High vacuum pumps

- Rough vacuum is a must
- Pressure range
- Pumping speed (gas-dependent!)
  - Static/dynamic system
  - Volume
  - Gas load (XPS, direct EI-MS, GC-MS, HPLC-MS)
- Gas load caused by the pump itself (oil)

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### Diffusion pump

Molecular flow!

Switch on:

- cooling (!)
- Pump down (as short as possible)
- Heat-up (3/4-1 h)
- HV-valve open (not too fast)

Switch off:

- HV valve close
- Heat off (+1/2-1h)
- Rough off
- Cooling off

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### Diffusion pump

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### Multistage diffusion pump

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### Backflow (oil flowing to recipient)

- Always present, some solutions for decreasing:
  - Mexican cap, cold cap
  - Water-cooled baffle
  - IN<sub>2</sub> trap
  - Peltier-trap
  - Diffstak/Diffset™ special shape pumps
- If too high (e.g. oil on a glass window) → troubleshooting (or design problem)

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solutions for decreasing:

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**Diffusion pump oils**

- Hydrocarbons (Apiezon A/B/C, Convoil, Litton)
  - inexpensive, O<sub>2</sub>-sensitive
- Silicons (DowComing-704, DC-705, Invoil 940)
  - Medium price, inert, filaments (EI!!!)
- Polyphenyl ethers (Santovac-5, Convalax-10)
  - expensive, inert
- Esters (Octoil, butilftalát, Amoil, Invoil)
  - közepes árú, O<sub>2</sub>-sensitive
- Perfluoro compounds (Krytox, Fomblin)
  - High price, dangerous gases, special applications (semiconductor industry)

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**Diffusion pumps – main characteristics**

- Undemanding (mechanical contamination, pressure jumps)
- Almost no maintenance (normally no oil change needed), easily cleanable, repairable (feltöltő/leeresztő tömítés!)
- Pumping speed depends on size (from 30 to several 10000 l/s)

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**Turbomolecular pump**

Stator/rotor plates

Velocity:  
~500m/s  
~1500Hz  
~90 krpm

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**Turbomolecular pump**

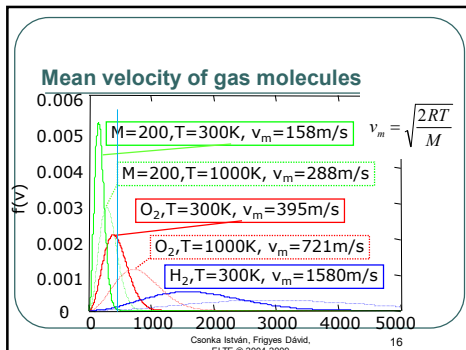
ROTOR BLADE

STATOR BLADE

gjilka.com

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**Characteristics**

- It can work without roughing pump but for good operation P<sub>roughing</sub> < 10<sup>-2</sup>
- Most common main pump for HV
- UHV: “fore vacuum” – usually not applicable for main pump
- Vibrations (can be decreased by compensator)
- Plates are more and more open in the direction of HV
- Sensitive mechanically and pressure jumps
- Compression ratio (P<sub>HV</sub>/P<sub>rough</sub>) depends on M

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**To be careful**

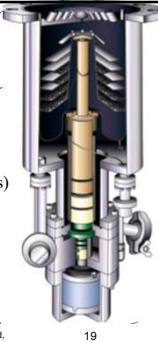
- Not to move while rotating (plates can crash)
- Nothing should fall in
- Avoid pressure jumps
- Venting from HV side slowly while rotating (bearing, rotary pump oil)
- Maintenance (oil change, mesh cleaning, rebuilding every 2-5 years...)

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### Cryopump

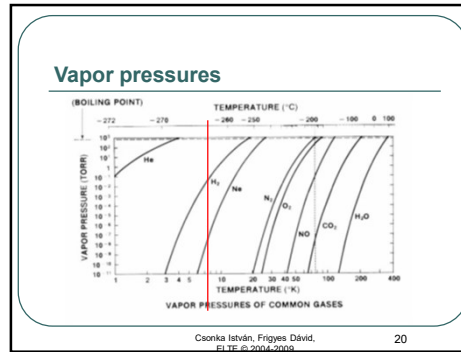
- Trapping pump
- Gases are captured on cooled surfaces:
  - Cryocondensation (heavy gases)
  - Cryosorption (He, H<sub>2</sub>, Ne)
- Working principle ~ fridge refrigerant: He (~10-20K)



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### Characteristics

- It needs to be periodically regenerated: heating up to room temperature in N<sub>2</sub> flow
- There should be molecular sieve between the roughing pump and the cryopump (contamination); it also needs to be regenerated (practically together with cryo regeneration)

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### UHV-pumps

- Gas load is low, thus no high pumping speed is needed – but no backflow allowed
- Main background gas is H<sub>2</sub>
- The pump must tolerate baking
- These pumps can be used in HV as well but are typical in UHV

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### Titanium sublimation pump (TSP)

- A Ti-source is heated (>1300K), a monolayer is created in the surrounding surfaces
- The layer is extremely reactive producing non-volatile compounds from gas molecules
- Pumping speed (l/s):

	H <sub>2</sub>	N <sub>2</sub>	O <sub>2</sub>	CO	CO <sub>2</sub>	H <sub>2</sub> O
300K	20	30	60	60	50	20
70K	65	65	70	70	60	90

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### TSP-characteristics

- Ti-source is a sphere or filament
- Can be switched on in atmosphere but works only in UHV (monolayer speed)
- Effective for N<sub>2</sub>, O<sub>2</sub>, H<sub>2</sub>, CO, CO<sub>2</sub>, H<sub>2</sub>O; moderately for methane, noble gases
- When the surface is coated, a new one is created (usually automated from vacuum gauge)
- No maintenance needed, Ti-source is to be replaced when needed (usually not so often)

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### A titánszublímációs szivattyú



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### Non-evaporable getter (NEG)

- Zr-V-Fe alloy
- Most effective for O<sub>2</sub>, N<sub>2</sub> and CO, capacity for H<sub>2</sub> is independent of other gases
- Regeneration when saturated (350°C, inert gas)
- Replacement after several cycles

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### Ion (Getter) Pump

- Electrons forced on a spiral trajectory (high voltage, strong magnet)
- The electrons ionize gas molecules
- + ions impact the cathode (–A + ionok a katódba (-pole)
  - Captured in the cathode
  - Sputter the cathode material (getter effect)
  - Some gases (H<sub>2</sub>) directly captured in the cathode

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### Geometrical arrangement

- Diode-type
- Triode-type (inert gases)

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### Characteristics

- Self-regulating: higher pressure → higher sputtering
- Ion current shows the pressure (~gauge, orders of magnitude)
- $p < 10^{-2}$  (better:  $10^{-5}$ ) before switching (discharge/pumping speed)
- Lifetime depends on mean pressure, but works fast and takes long if no leaks
- Works in HV as well (Huygens-probe GC-MS, Titan, Saturn's moon)

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### Summary of pumps

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### Hot cathode gauges

- ~electron impact ion source; triode-type ion pump

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### Main characteristics

- Wide pressure range ( $10^{-2}$ .. $10^{-12}$  – range switch) – limiting factors:
  - X-ray limit (low pressure: bremsstrahlung/ braking radiation → photoemission on the collector): to lower the limit: fine wire collector (Bayard-Alpert)
  - High pressure: recombination is probable: to lower it: short electrode distance (higher free path) (Schulz-Phelps)
- Simple design. Only problem: filament can burn out... degas

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### Cold cathode gauges

Penning-gauge

- ~ small diode ion pump – not accidental coincidence
- $p > 10^{-8}$
- No filament, no burnout
- Smaller accuracy: 50%
- Magnet can cause problems

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### Residual nitrogen analyzer

- Cold cathode gauge + optical elements (light-filter, photon detector)
- Total pressure +  $N_2$ -pressure reading
- Useful in distinguishing between holes, virtual holes, outgassing, hole searching

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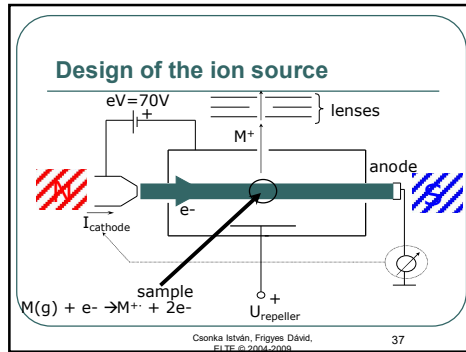
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### Residual Gas Analyser (RGA)

- Small quadrupole mass spectrometer
- Open, room-temperature ion source
- Spectrum is usually recorded in a logarithmic scale
- Usually connected to computer, the partial pressure scale (calibration!, electron impact cross sections differ)

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- ### Characteristics
- One can check what is inside vacuum
  - Hole searching
  - More than a pressure gauge, less than a mass spectrometer (lower price, lower performance)
    - No tricks with sample inlet
    - Mass range: 100-200-300
    - Low resolution
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