Vacuum technology
Introduction and history

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The goals of the course

- Providing basic knowledge of vacuum technology and technique (theory/practice, qualitative/quantitative info)
- Do not be affraid (see “horror vacui”), but do not make mistakes either
- Why to learn from a “Master”
- Exam
- Ability to use a high vacuum system

Outline of the course

1. Introduction, goals, scope (FD, CSIP)
2. Theoretical basis (FD) Kinetic theory of gases, number of collisions, mean free path. Heat and electric conductivity, particle transport.
3. Forevacuum pumps and gauges (CSIP) Positive displacement and other pumps. Absolute and other vacuum gauging.
4. High Vacuum (HV) and Ultra High Vacuum (UHV) pumps and gauges (FD)

Outline of the course

5. Materials (CSIP) What to use? Everything has vapor pressure. Metal, plastic, ceramic, glass, oil, grease, vax.
6. Components and standard parts (CSIP) What can be bought readymade? What is to be done? Standards and other need-to-knows.
7. Preparative vacuumsystems (CSIP) Rotavapor, vacuum-line, metal-atom reactor, CVD.
8. HV-systems (FD) Without intermolecular collisions.

Outline of the course

9. UHV-systems (FD) Clean surfaces.
10. Design, build, and maintenance (CSIP)
11. Searching for errors, (pseudo)holes, cleaning (FD)
12. Exam (FD, CSIP)

What is vacuum? (I)

- From the practical point of view: a space where the pressure is lower than the surroundings (or the mean air pressure)

Pressure units

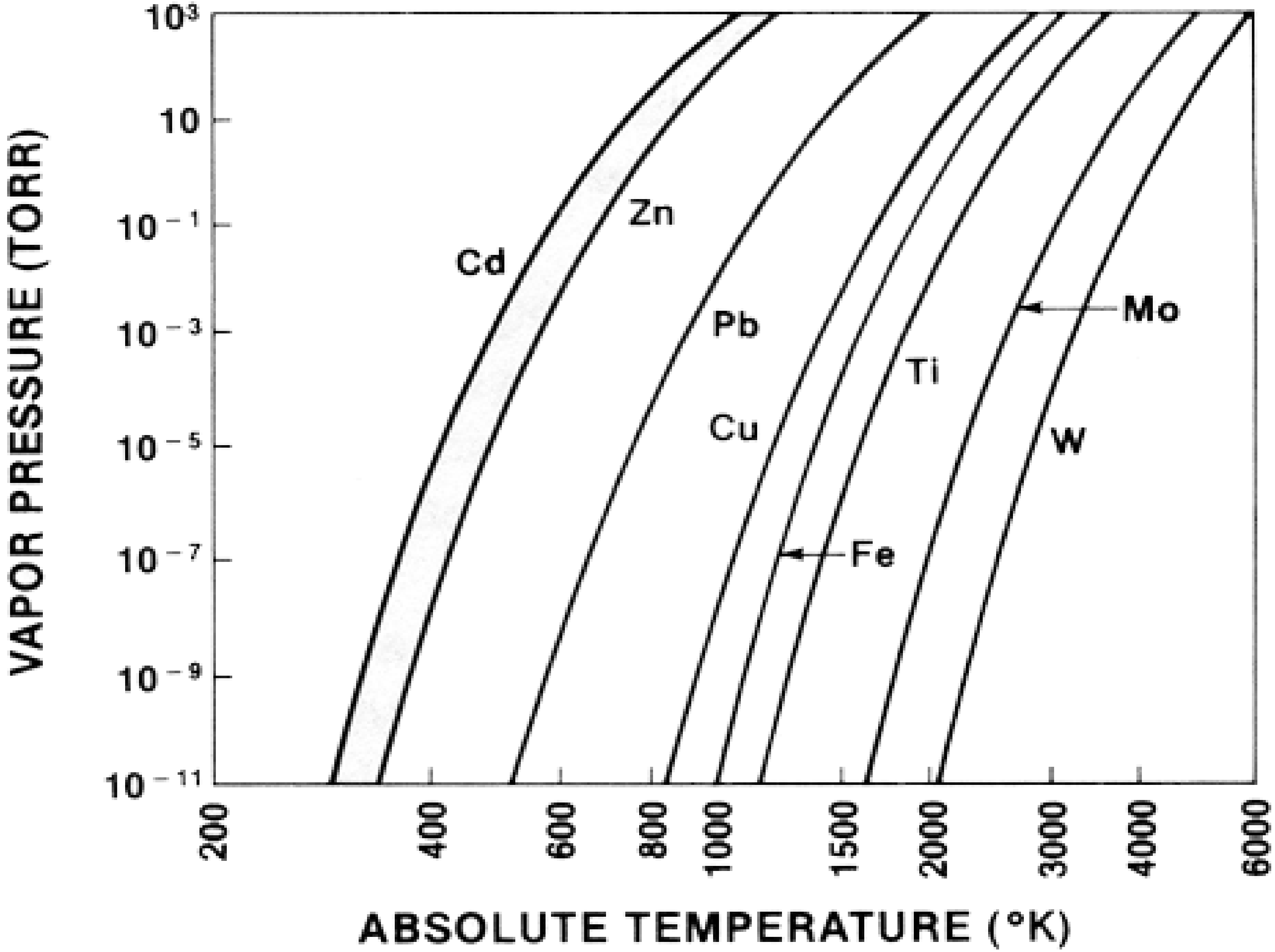
- SI: 1 Pa ($\equiv$1 N/m^2)
- 1 bar=10^5 Pa (1 mbar=1 hPa$\approx$1/1000atm)
- 1 atm=1,013 bar
- 1 torr=1 mmHg=1/760 atm
- (1 psi (psia, lbs; pound/in^2)= 1/14,7 atm)
- (1 inchHg=1/30 atm)
- mm water

Misunderstandings

- Scale on a vacuum / gas cylinder gauge
  - Pressure (0...), excess pressure (-1…0…)
- 10^{-6} mbar? Will it damage the material?
  - Δp matters for the material rather than pressure. The actual difference in force between 20mmHg and 10^{-6}mbar is less than 3%
- I open the valve just for a second…
  - $1cm^3$ of 1 atm + $1m^3$ of 10^{-6} : $1{,}001 \cdot 10^{-3}$

What is there in the vacuum system?

- Vacuus (3), űr, vide, vuoto means empty… but
  - air (78% N_2, 21% O_2, <1% Ar, 0,03% CO_2…)
  - water
  - Anything else
- Where does it come from?
  - No pump is perfect
  - holes
  - walls (desorption)
  - evaporation

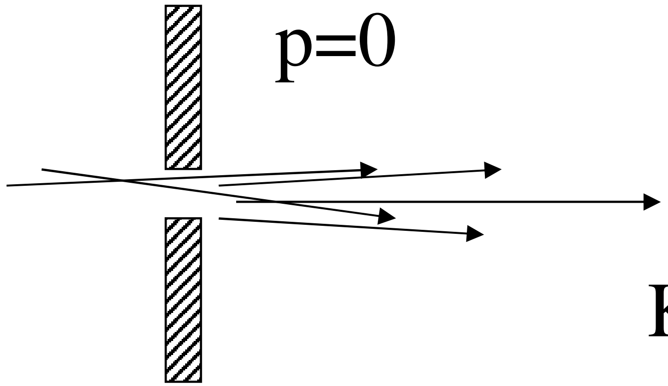


VAPOR PRESSURES OF SOME COMMON MATERIALS NORMALLY CONSIDERED SOLID

What is vacuum? (II)

- From the theoretical point of view: a space where the mean free path is longer than the „characteristic size" of the container
- Mean free path (λ): the distance between two adjacent collisions of a particle

Flow through a hole

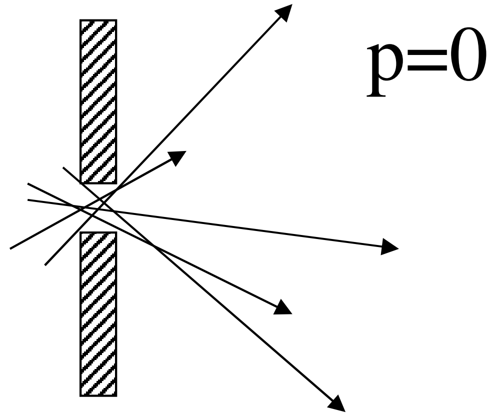


Viscous flow

$Kn < 0{,}01$

Knudsen-number

$$Kn = \frac{\lambda}{L}$$



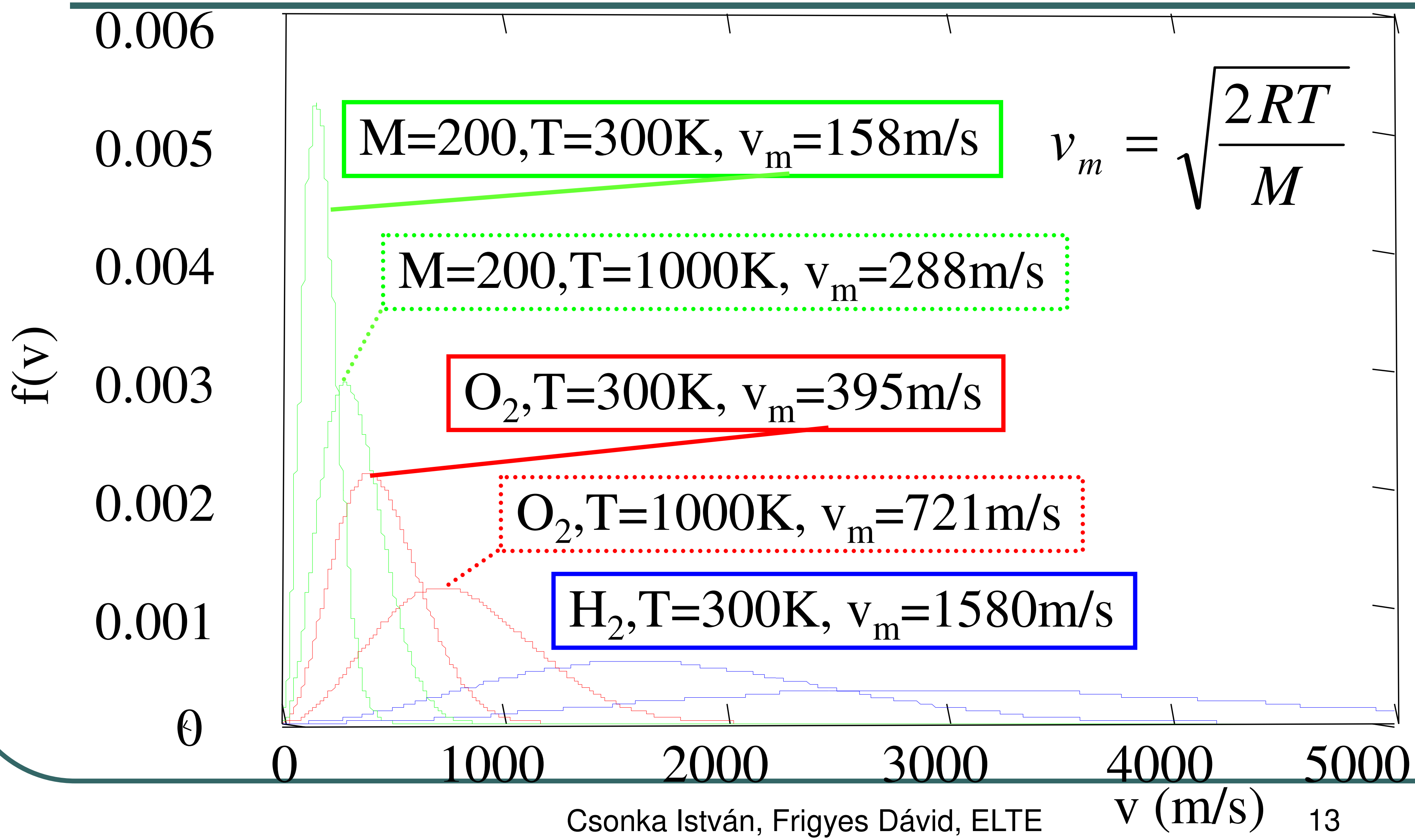
Molecular flow

$Kn > 1$

backflow!!!

Characteristic size of the container, i.e. the diameter of the hole

Mean velocity of the molecules



Vacuum systems I.

Fore (rough) vacuum	High vacuum	Ultrahigh vacuum
$1\ atm > p > 10^{-3}$	$10^{-5} > p > 10^{-8}$	$p < 10^{-8}$
„many" collisions	„few" collisions	wall-collisions are rare too
Thermal equilibrium	Therm. cond. Is low	Therm. cond. is low
Electric conductivity		
Chemical reactions	Only unimolecular	Surface reactions
preparative processes, Evaporation,	Gas phase instruments	Surface analysis/prep. Molecular beam epitaxy

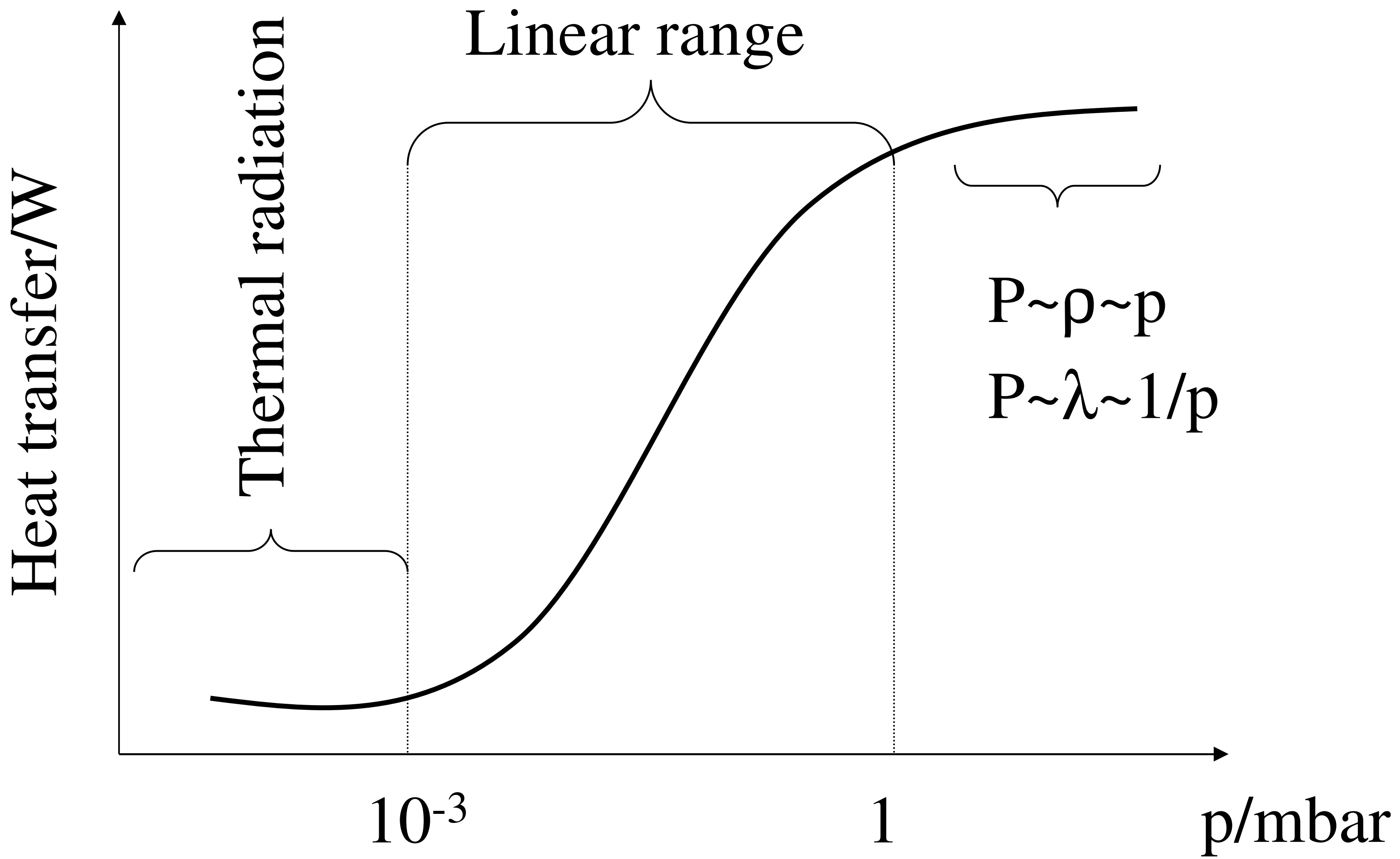
Vacuum systems I.

- Definition of high vacuum (HV) and ultra high vacuum (UHV) are scale dependent.
  - There are pressure waves in interstellar space: although particle density is very low, mean free path is still much lower than interstellar distances. Not a high vacuum in this sense, having viscous flow.
  - In thin tubes mean free path is larger than diameter: atmospheric vacuum with not viscous but molecular flow – high vacuum.
  - Surface is Moon is formed by solar wind: although particle bombarding is rare, time scale is very long. Not an ultra high vacuum in this sense.

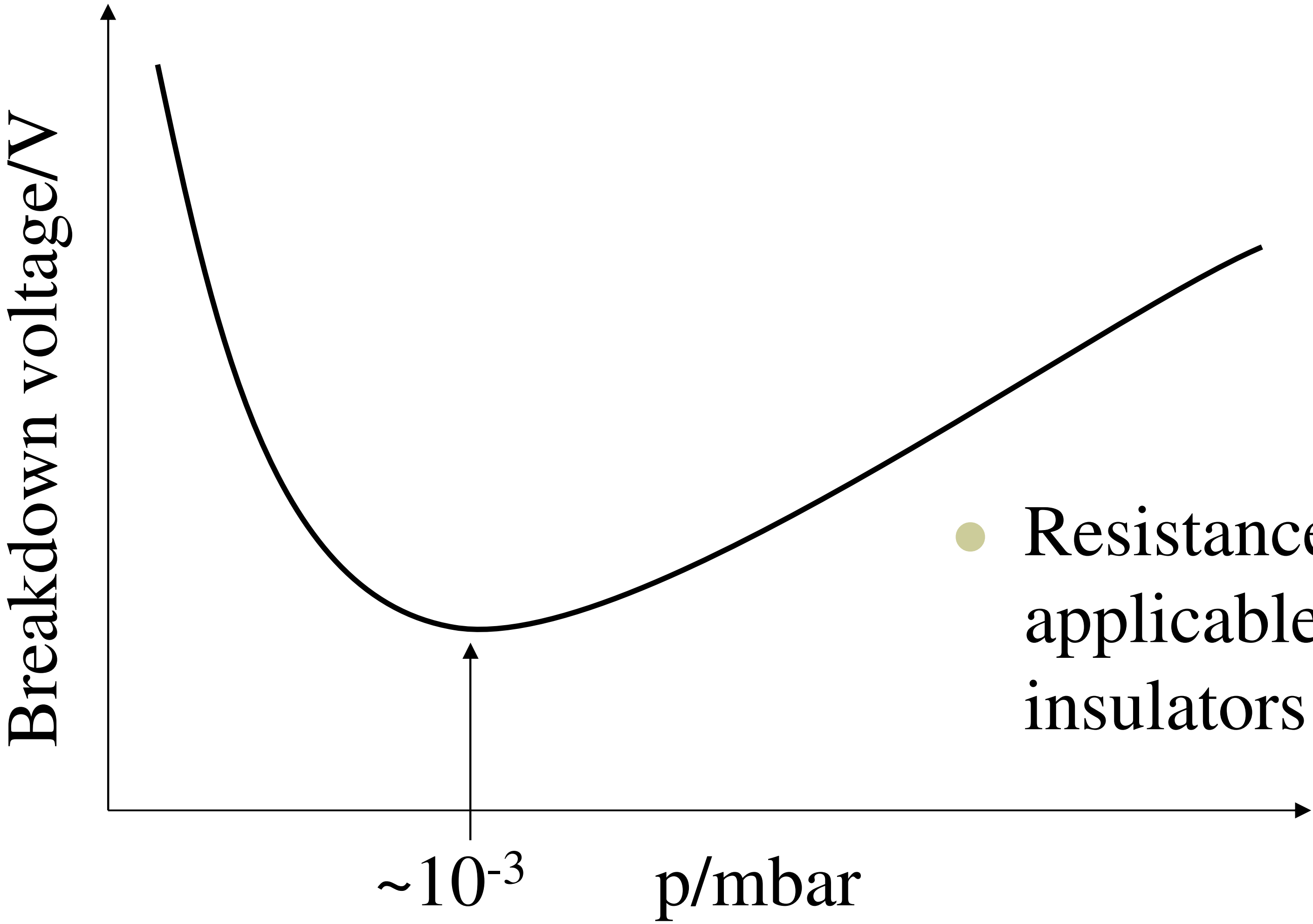
Vacuum systems II.

N_2, 300K	Atmosphere	Rough vacuum	High vacuum	Ultrahigh vacuum	
Pressure (mbar)	10^3	10^{-3}	10^{-6}	10^{-10}	
Particle density ($1/cm^3$)	$2\cdot 10^{19}$	$2\cdot 10^{13}$	$2\cdot 10^{10}$	$2\cdot 10^6$	$\sim p$
Mean free path (m)	$7\cdot 10^{-8}$	$7\cdot 10^{-2}$	70	$7\cdot 10^5$	$\sim 1/p$
Mol. Collisions ($/s\cdot cm^3$)	$2\cdot 10^{29}$	$2\cdot 10^{17}$	$2\cdot 10^{11}$	$2\cdot 10^5$	$\sim p^2$
Wall collisions ($/s\cdot cm^2$)	$3\cdot 10^{23}$	$3\cdot 10^{17}$	$3\cdot 10^{14}$	$3\cdot 10^{10}$	$\sim p$
Monolayer time (s)	10^{-9}	10^{-3}	1	10^4	$\sim 1/p$

Thermal conductivity of gases



Electrical conductance of gases



- Resistance is not applicable for insulators

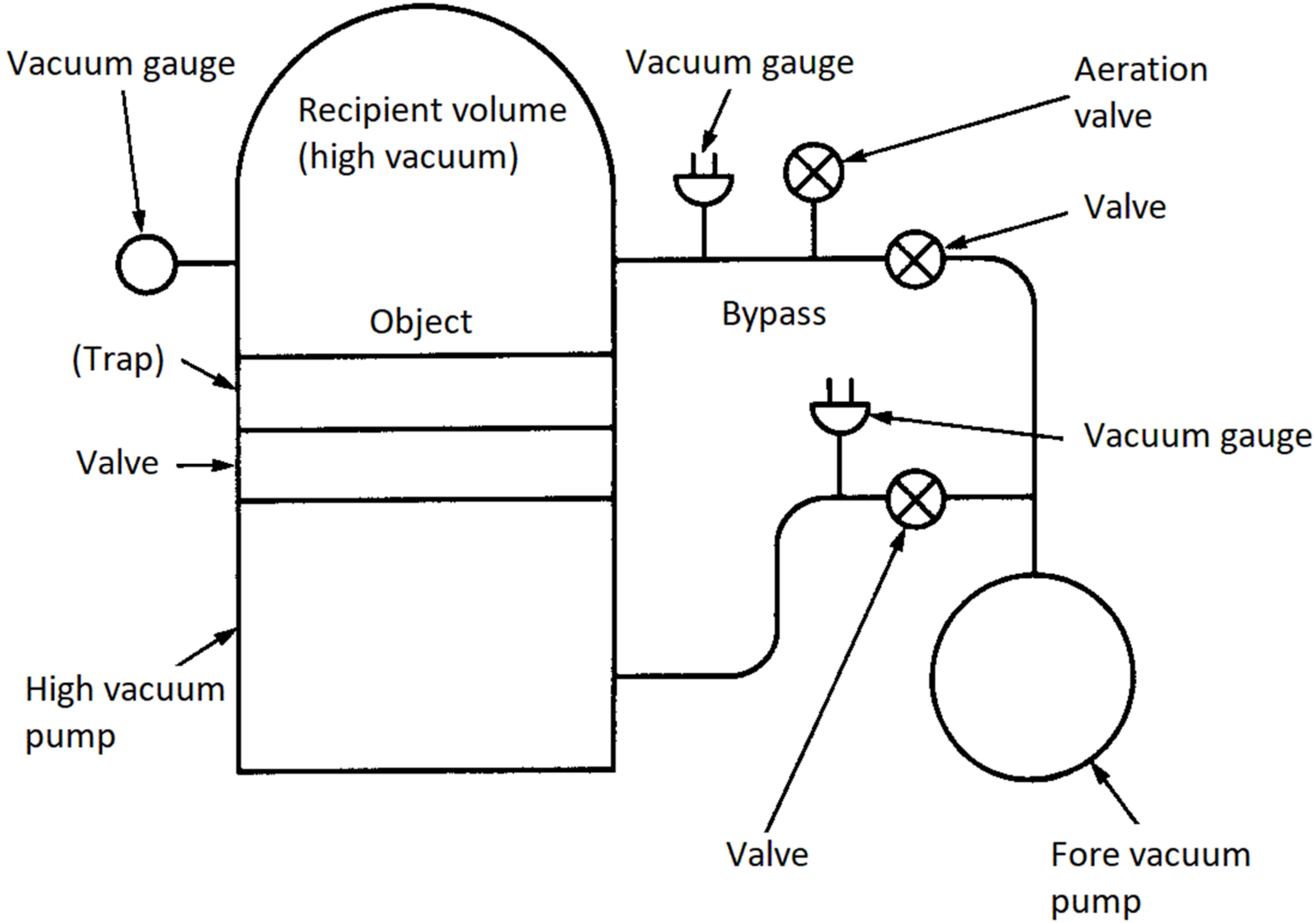
What can vacuum (technology) be used for?

- (radical) ions, free electrons, vacuum ultraviolet photons, focused laser beams, etc.
- Reactive matter (free radicals, cheese)
- Preparation of really clean surfaces
- Decreasing boiling/sublimation point
- Decreasing thermal conductivity

Where can we use it?

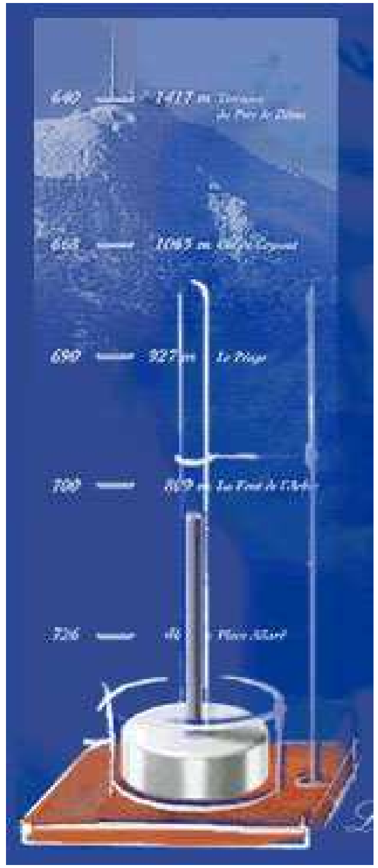
- Instruments
  - Chemical analysis, structure determination (mass spectrometry, photoelectron spectroscopy)
  - Surface analysis (XPS, STM, LEED…)
- Preparative processes
  - Vacuum distillation
  - CVD
  - Drying (e.g. wood, food)
- Surface analysis
  - catalysis
- Others
  - Light sources (filament lamp, discharge lamp, ~~LED~~)
  - microelectronics
  - Thermal insulation (cf. Vacuum bottle)
  - Vacuum tube (electronic)
  - lyophilization
  - Space research

A general high vacuum system



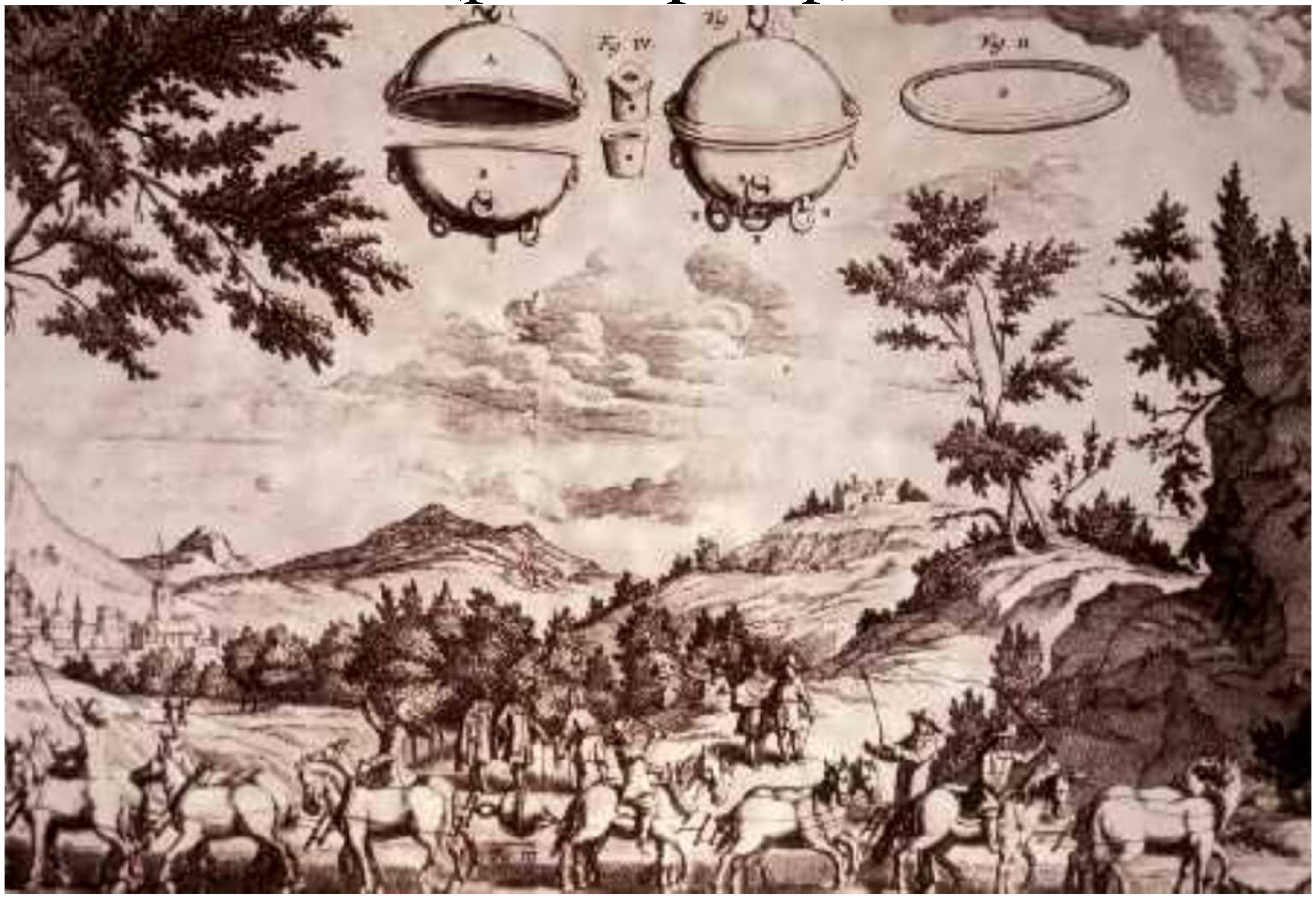
History

- Old greeks used it and dealt theoretically with it „Horror vacui” (Aristotle)
- Galilei. Why cannot water sucked up from any depth?
- 1643 Torricelli
- 1648 Pascal – in fact the pressure of air push up the mercury column, and not the horror vacui sucks it up: torricelli-barometer in torricelli-void



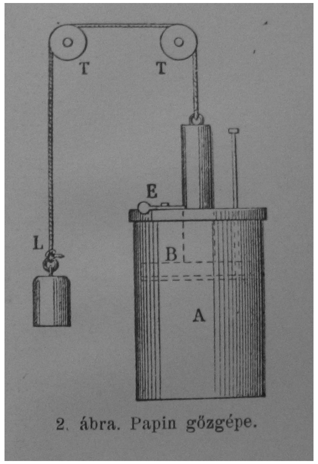
History

- 1657 Otto von Guericke (piston pump)

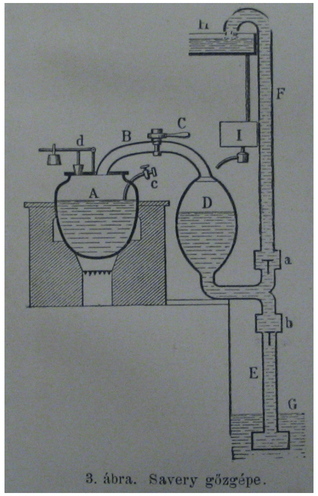


History

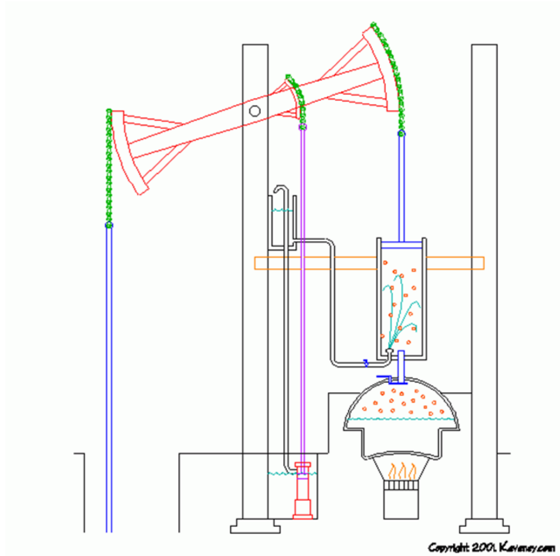
- 1692 Papin steam engine
- 1698 Savery steam engine
- 1712 Newcomen steam engine
- ~1780 Watt steam engine (condenser, forced draft by steam ejector)
- 1866 Otto-Langen gas engine
- And: piston pumps (Toepler with Hg-piston), water jet pump, not much industrial use



2. ábra. Papin gőzgépe.

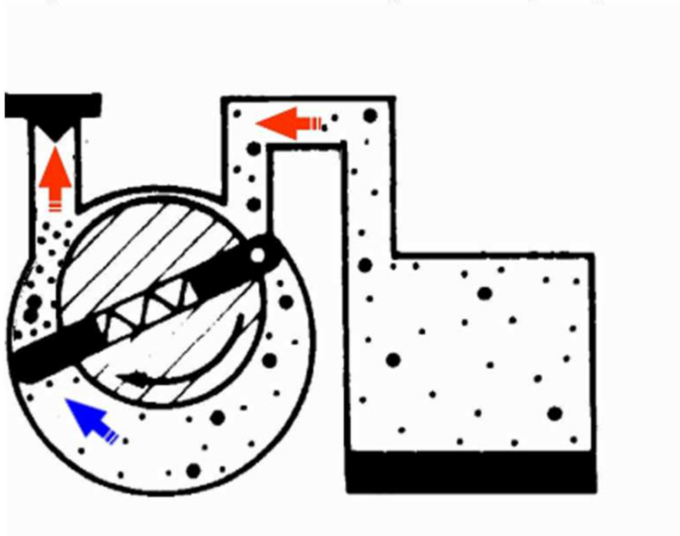


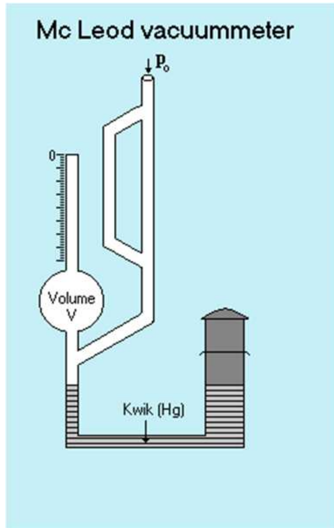
3. ábra. Savery gőzgépe.



History

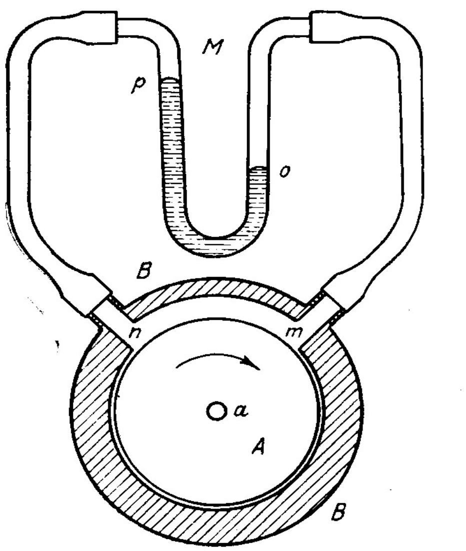
- End of XIX. century: „real" vacuumtechnology borns. Driving force: incadescent lamp (1879). Fore vacuum range (mean free path much shorter than characteristicdimension of vessel – viscous flow). Getter pump in incadescent lamp.
- Positive displacement pump (W. Gaede), absolute vacuum gauging.



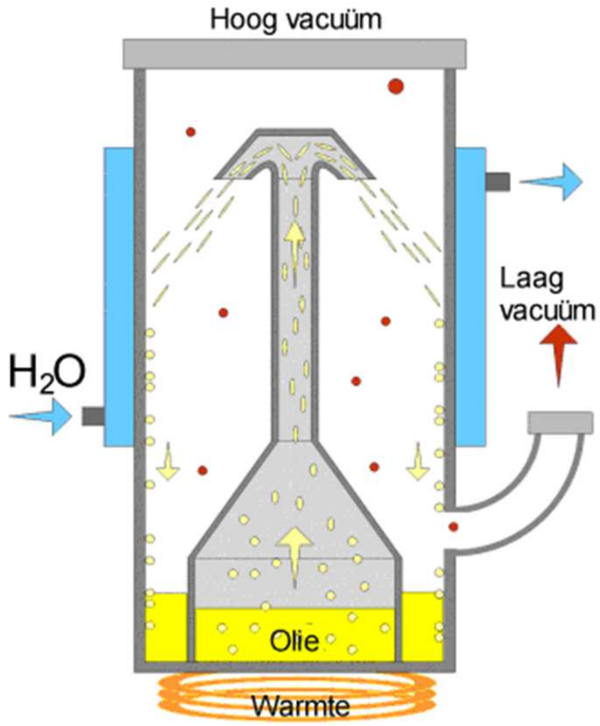


History

- 1913 molecular pump (Gaede; ancestor of turbo pump)
- 1915-16 steam diffusion pump with oils and Hg (Gaede, Langmuir)



18. ábra. A Gaede-féle molekuláris szivattyú vázlata.



History

- The two above pumps made high vacuum achiavable on scale – electron/vacuum tube!
- And: non-absolute vacuum gauges (thermal conductivity, „viscosity”, ionization)
- 1928 Alkane, phtalate, sebacate oils in diffusion pumps.

History

- UHV was probably reached in the ´30s (monolayer deposition in hours)
- Vacuum in chemical and food industry
- ´40s: ion pump, titan sublumation pump
- ´60s: turbomolecular pump
- Oil free systems
- Vacuum everywhere