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Vacuum Technology
WS 20/21
Virtually presented
Lecture 12, Jan. 26, 2021

Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik
Technische Universität Dresden

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“VT L012 a 13:24

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0. Introduction

Air pressure as a force to the walls of an empty container

1. Gas kinetic

Pressure as momentum transfer, Mol & Molvolume, Pressure units Partial pressure, Boltzmann Velocity&Energy distribution, Impingement rate, monolayer coverage time, mean free path collision rate

2. Pressure Ranges

Viscous, Knudsen, Molecular flow, Rough-, Medium-, High-, Ultrahigh-Vacuum, Heat conduction

3. Vacuum technical terms

Pumping speed, pumping power, gas-flow, residence time, gas flow conduction, impact on tube dimension

4. Vacuum generation

Genealogy of pumps, working principle, rotary plunger, rotary vane, roots, Claw, Scroll, Screw, Diaphragm, Ejector, “ultimate pumping speed” – specific value, Diffusion, TMP

5. Pressure measurement

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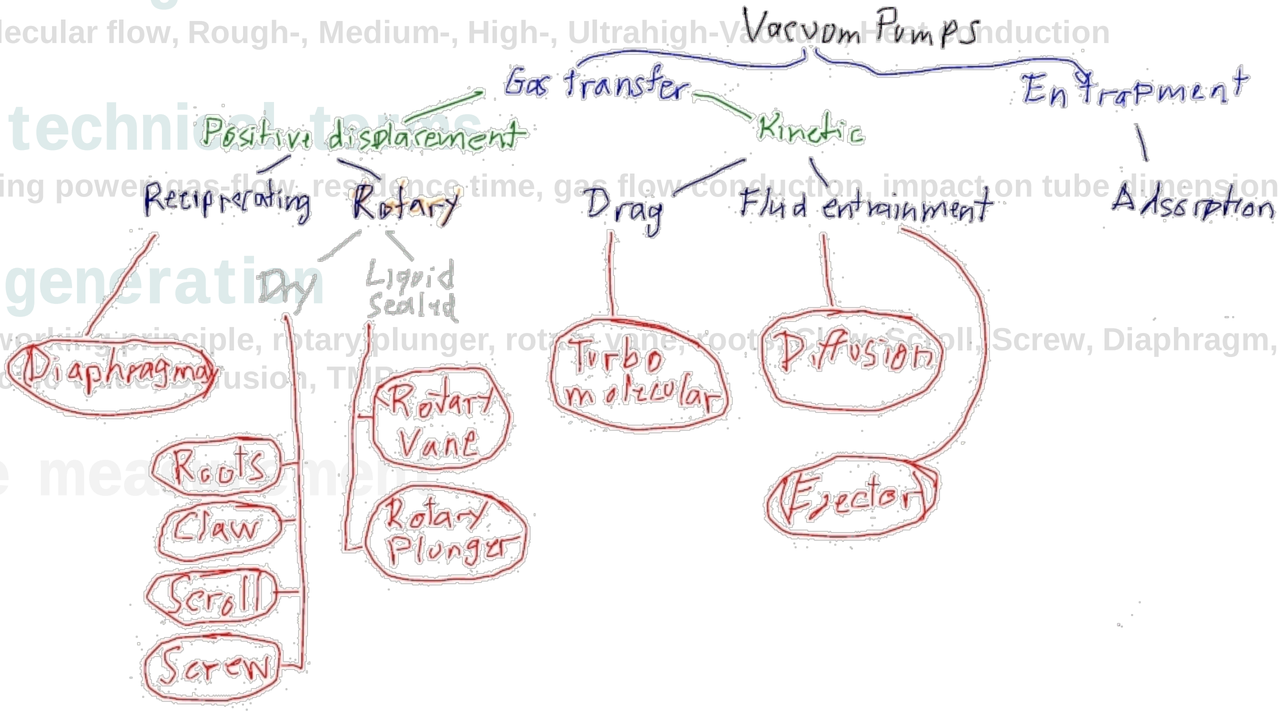

Claw

…ction

…ce to the walls of an empty container

…etic

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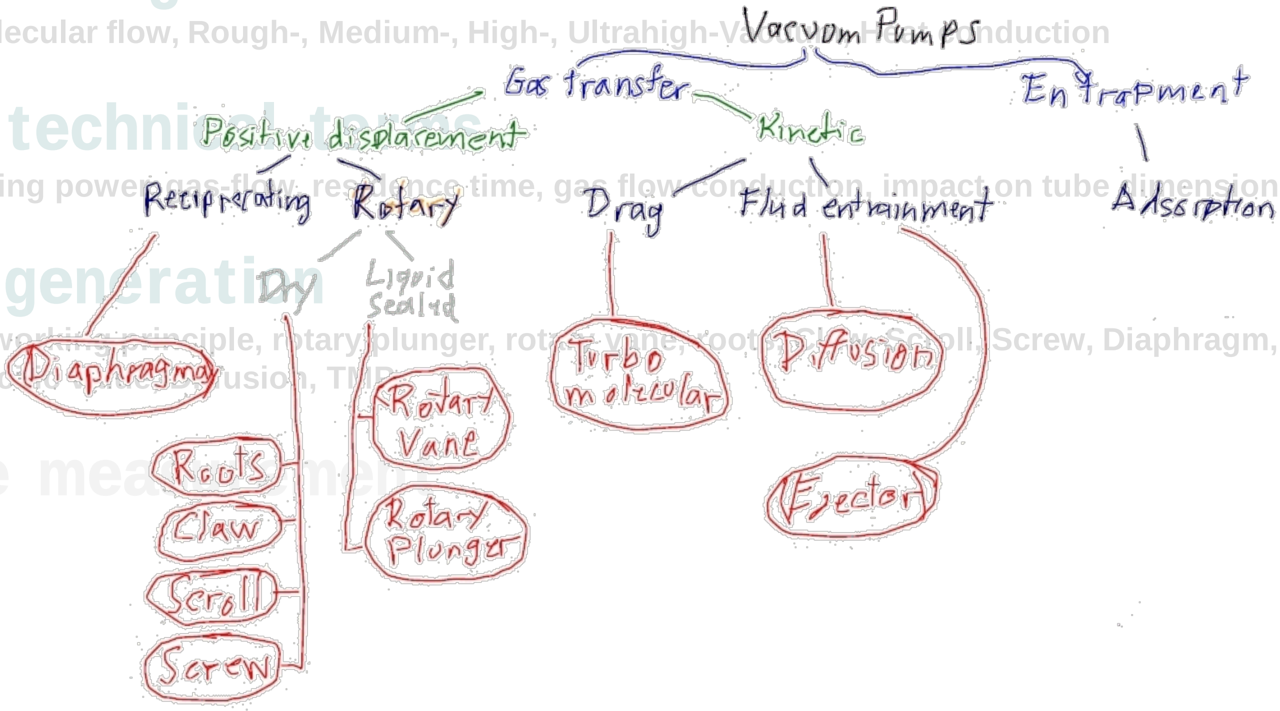

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Claw

Scroll

empty container

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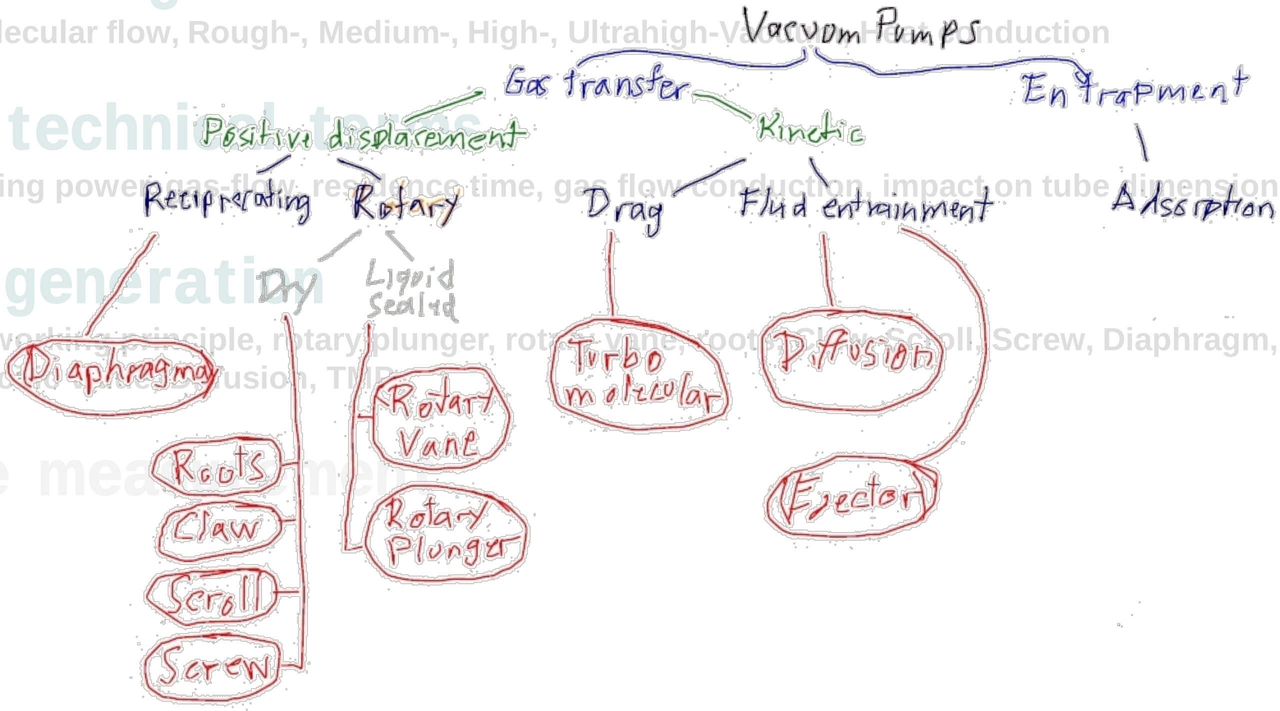

5. Pressure measurement

Claw

Scroll

Screw

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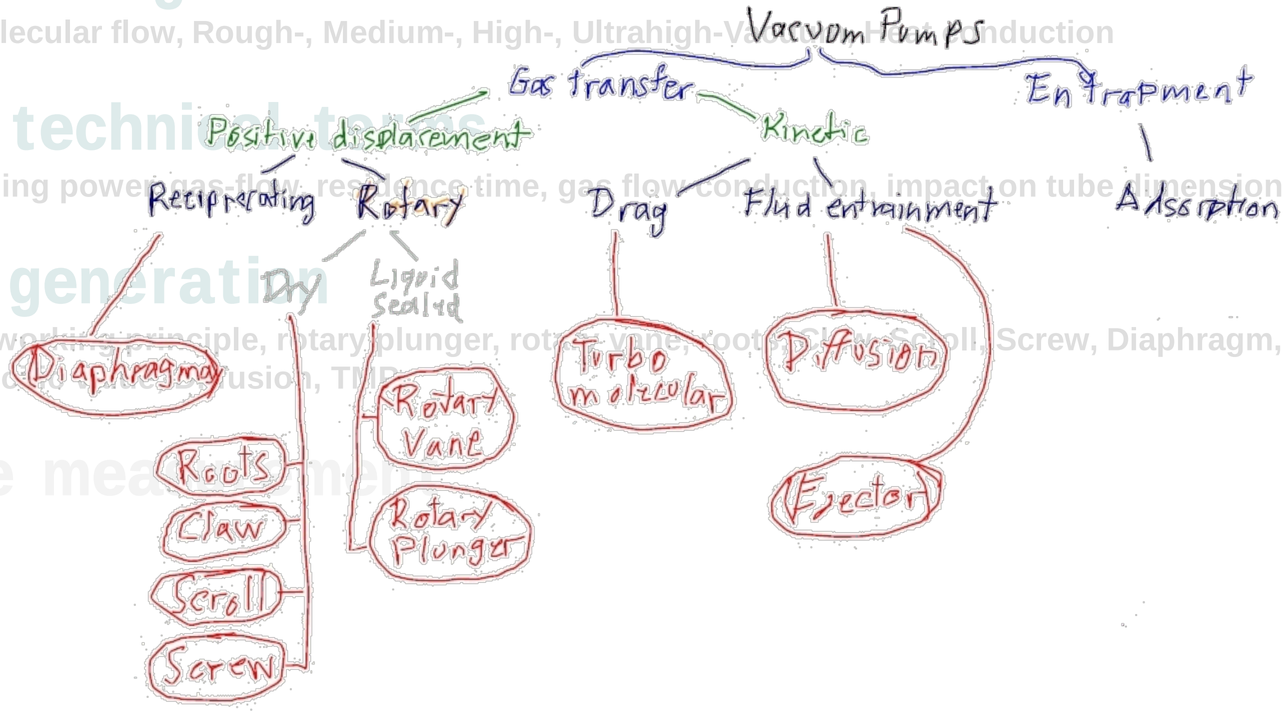

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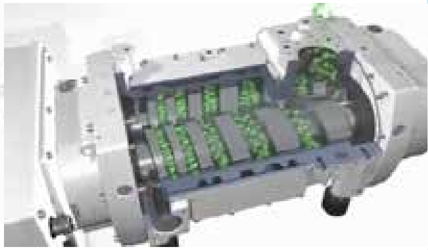
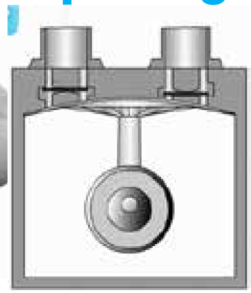
Claw

Scroll

Screw



Diaphragm



Boltzmann Velocity&Energy distribution,

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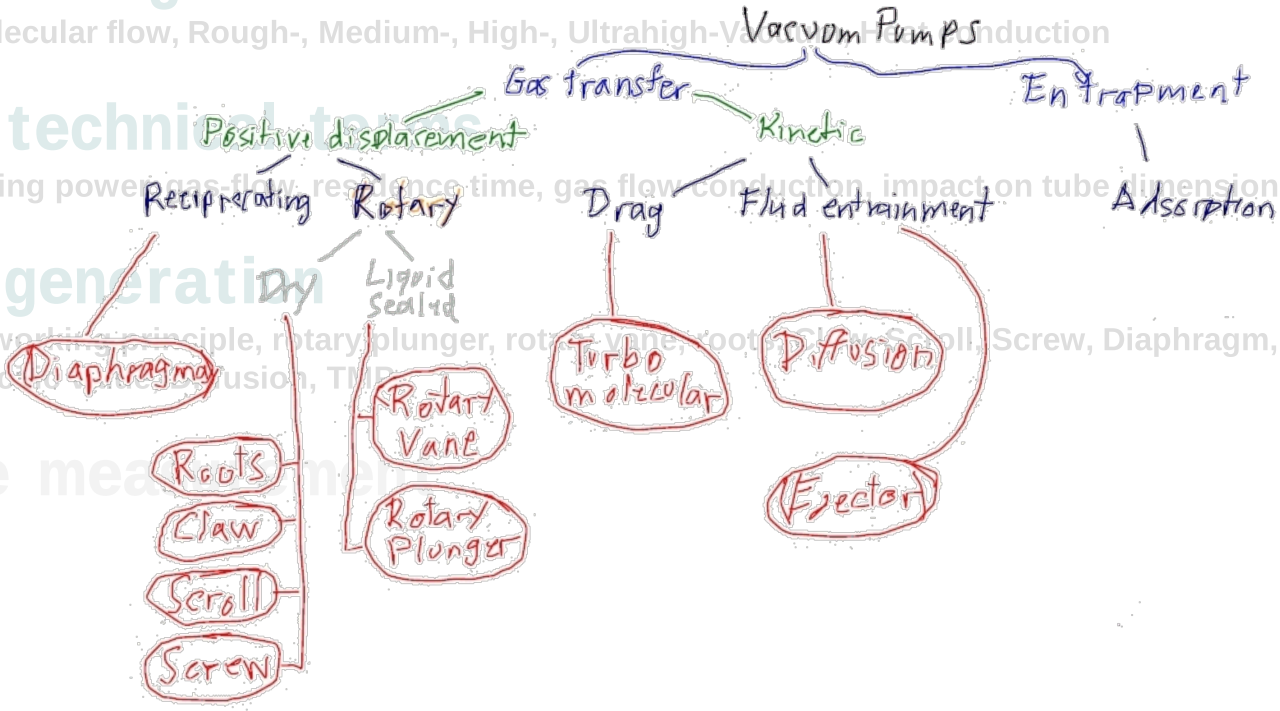

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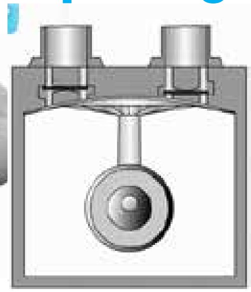

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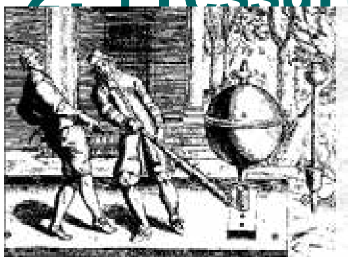

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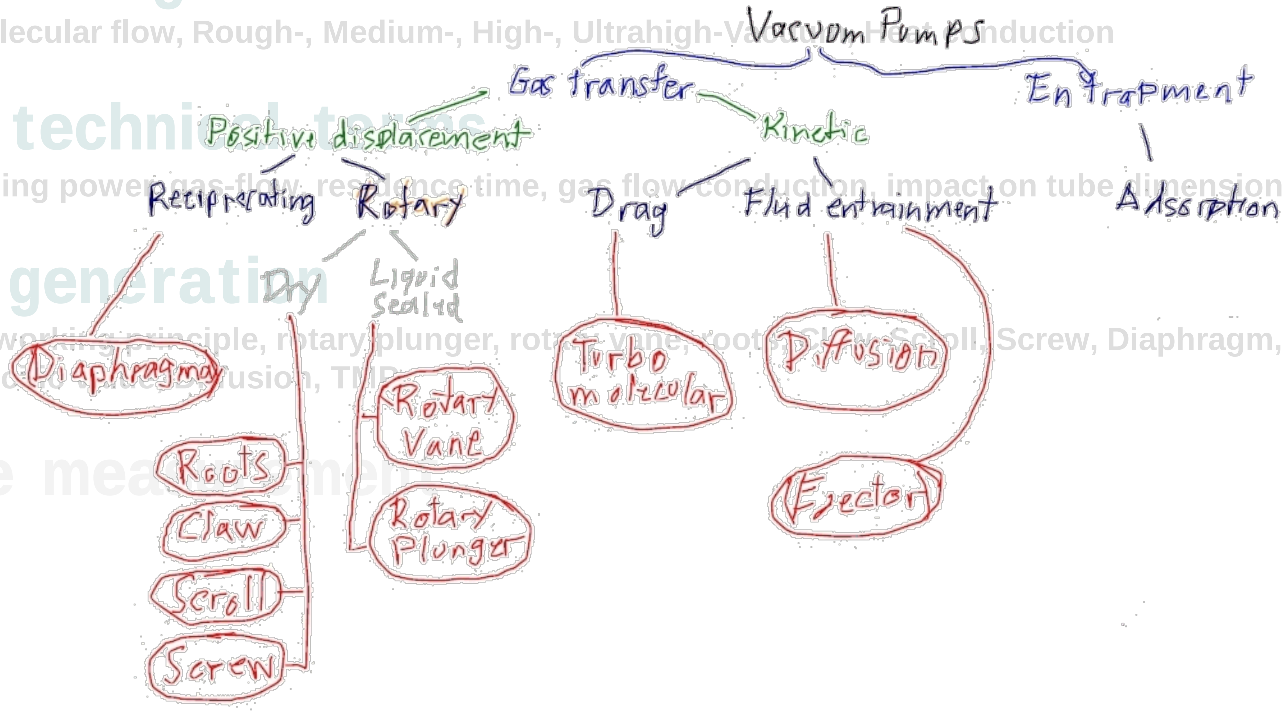

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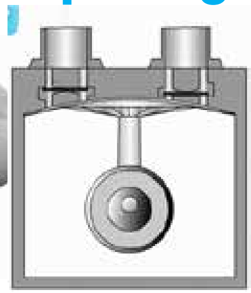
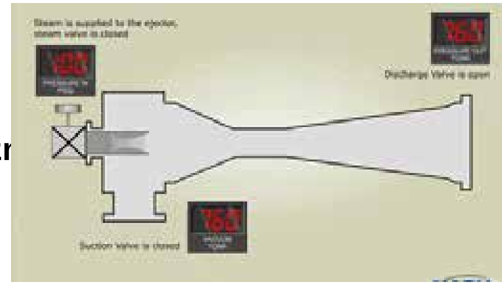
Claw Scroll Screw Diaphragm Ejector



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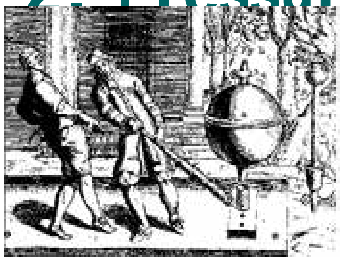

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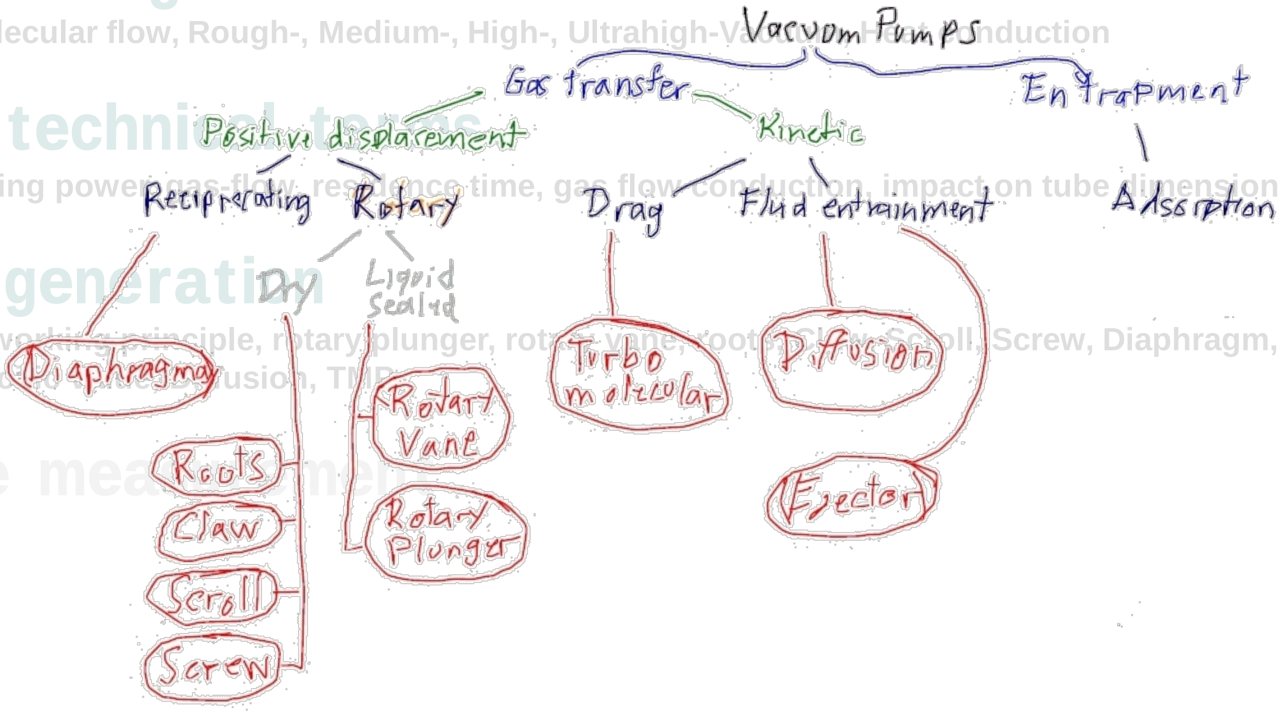


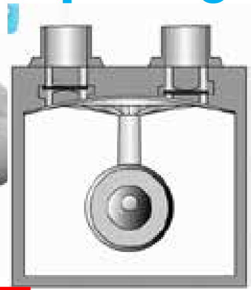
5. Pressure measurement

Claw

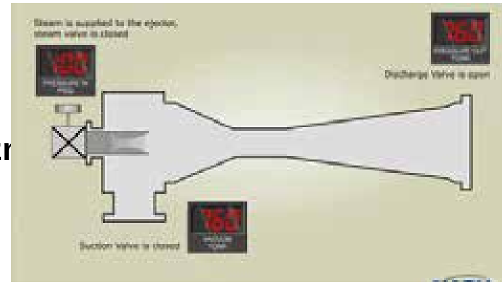
Scroll

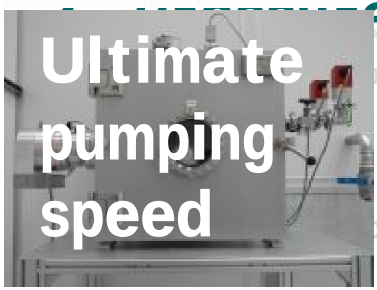
Screw

Diaphragm

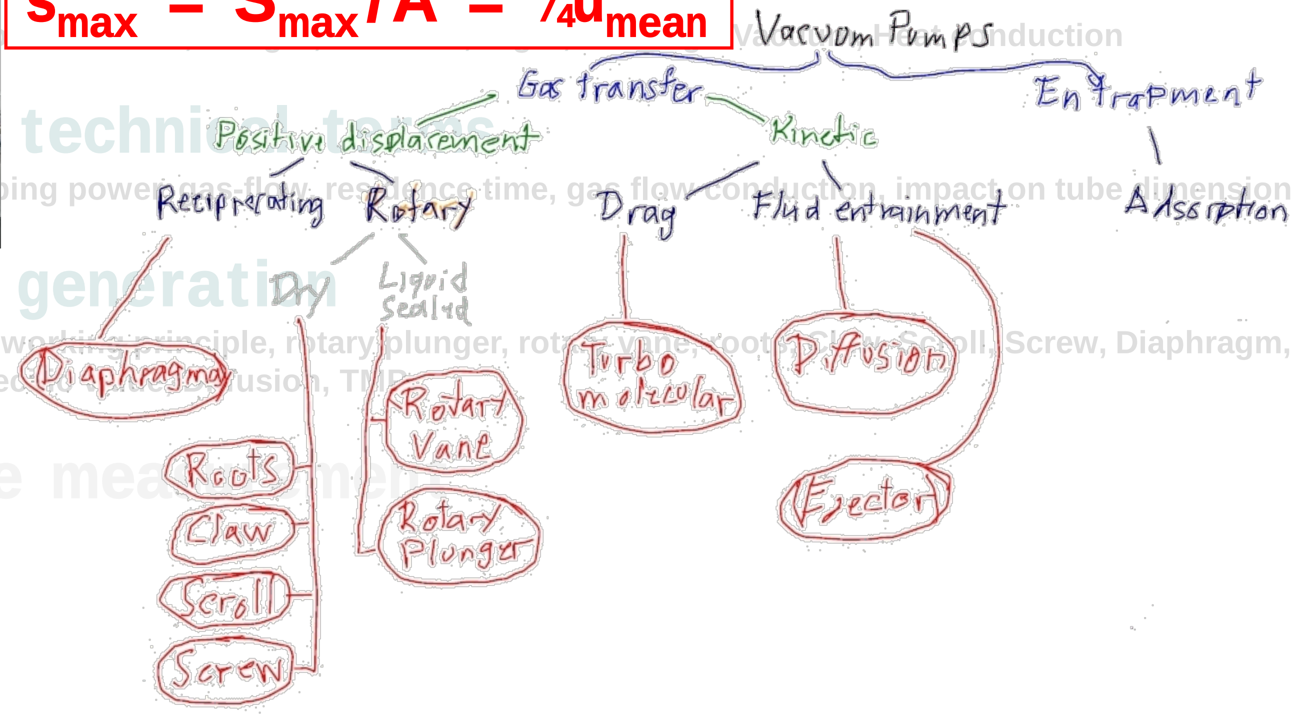


Ejector





$$s_{max} = S_{max} / A = \tfrac{1}{4} u_{mean}$$



technical terms

...ing power, gas-flow, residence time, gas flow conduction, impact on tube dimension

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Genealogy of pumps, working principle, rotary plunger, rotary vane, roots, Claw, Scroll, Screw, Diaphragm, Ejector, **"ultimate pumping speed" – sp**eed of tubes, diffusion, TMP

5. Pressure measurement

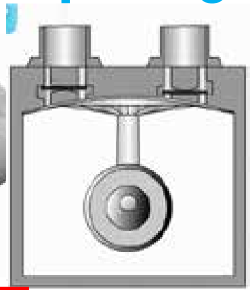
Review L11

Claw

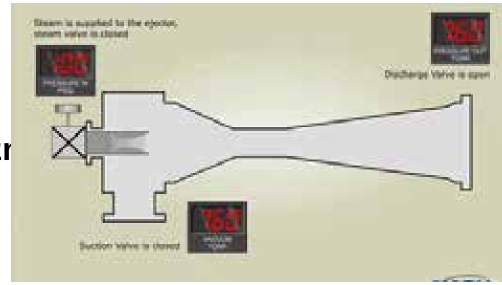
Scroll

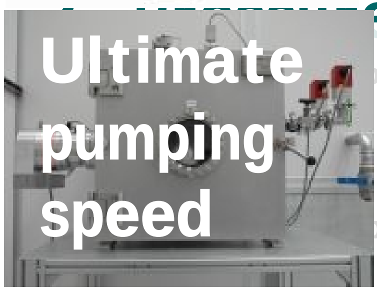
Screw

Diaphragm



Ejector





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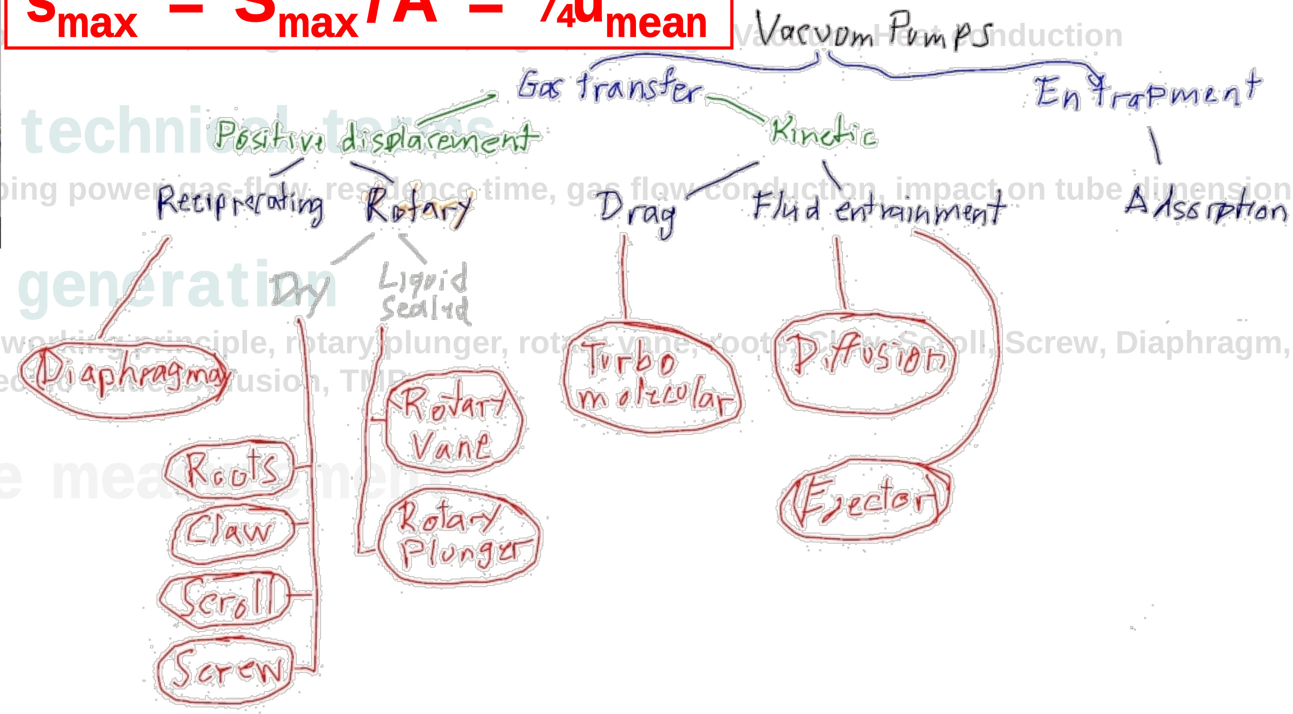
technical terms

...ping power, gas-flow, residence time, gas flow conduction, impact on tube dimension

...m generation

...nps, working principle, rotary plunger, rotary vane, roots, Claw, Scroll, Screw, Diaphragm, Ejector, **"ultimate**
- speed", diffusion, TMP

...ure measurement

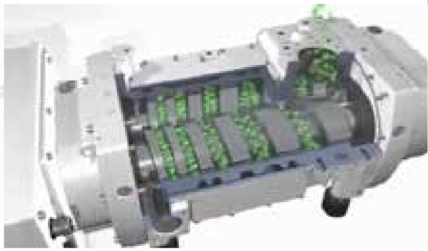


Diffusion

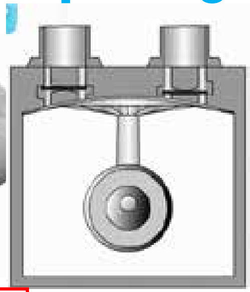
Claw

Scroll

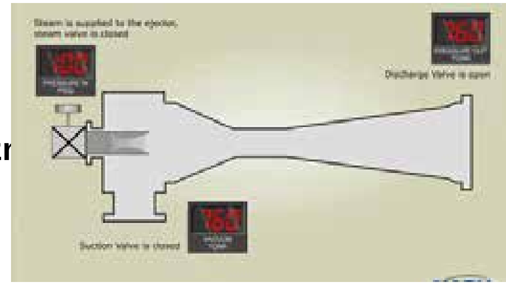
Screw



Diaphragm



Ejector



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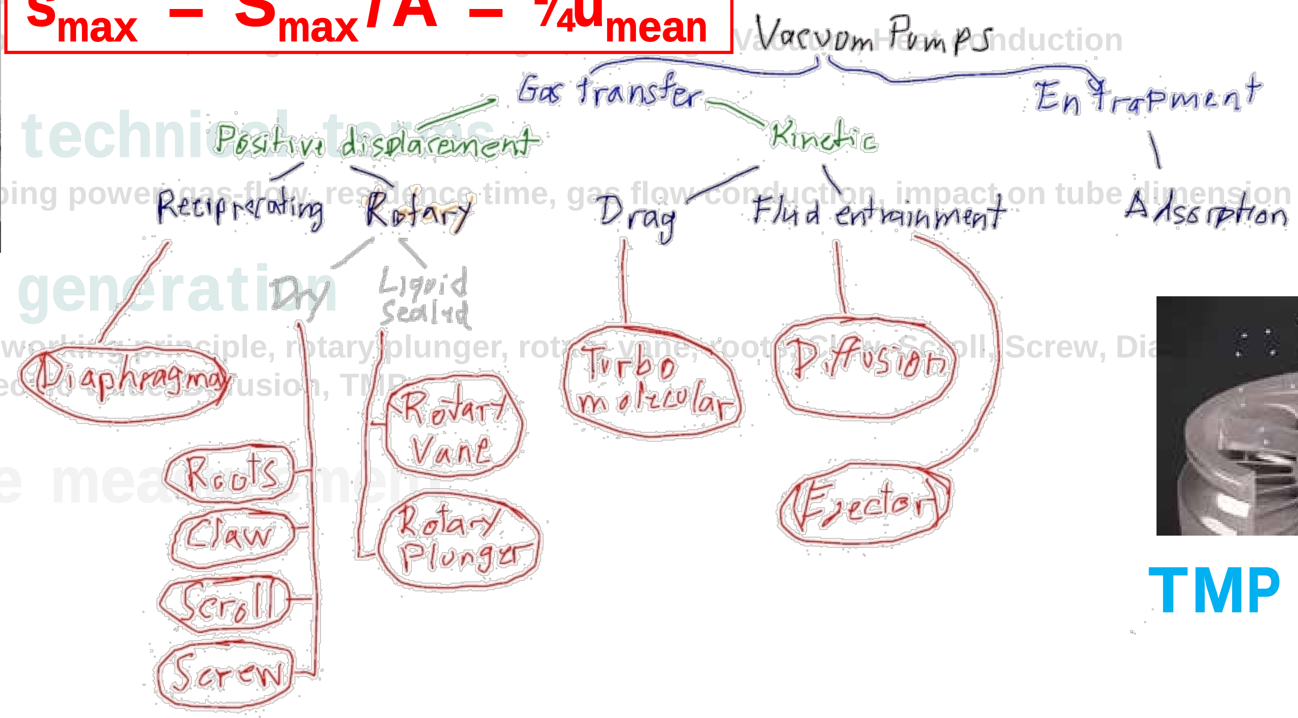

Diffusion

TMP

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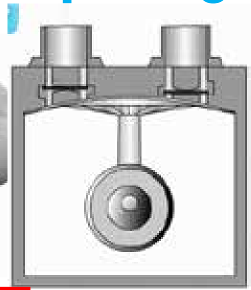
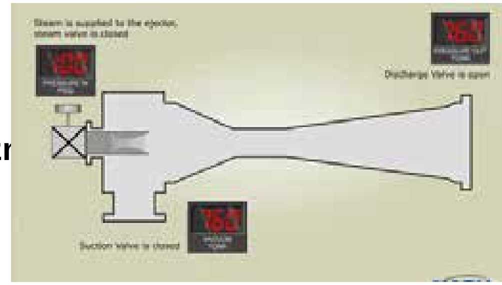
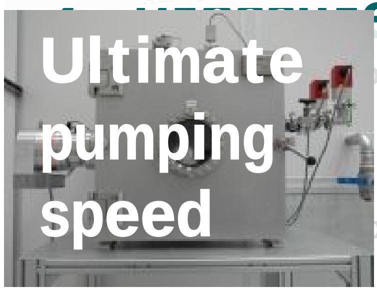
Review L11

Claw **Scroll** **Screw** **Diaphragm** **Ejector**





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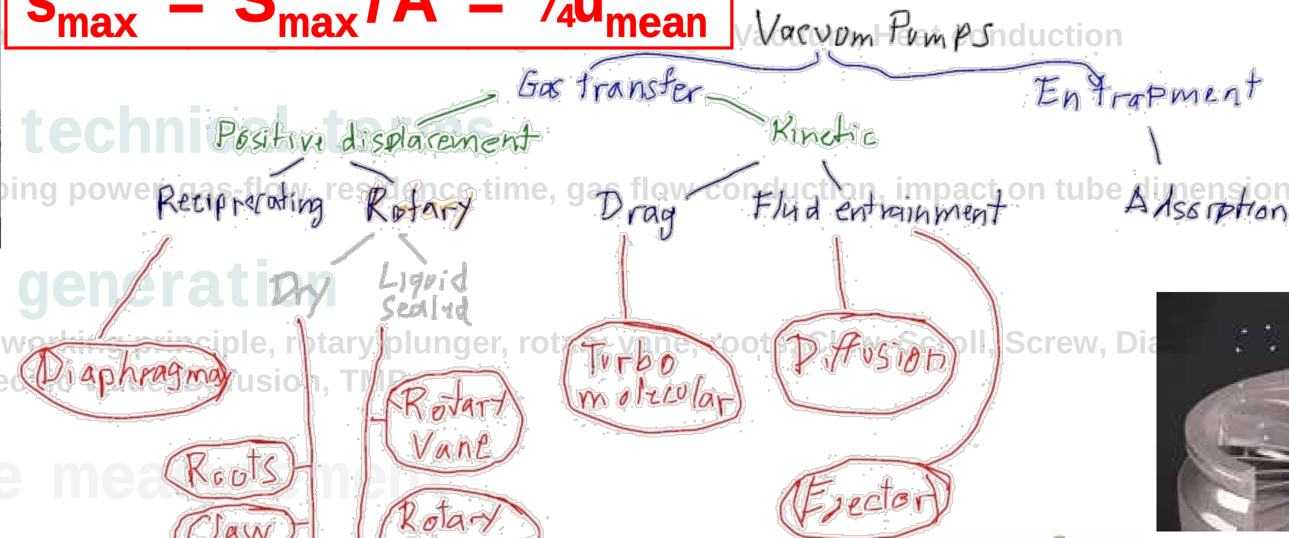
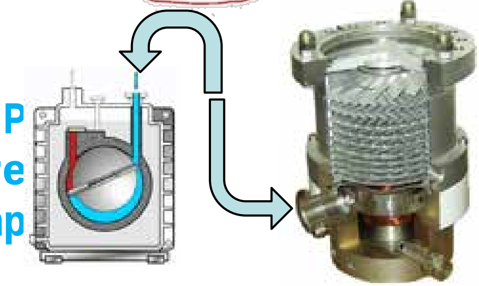


Diffusion

TMP

Diff- and TMP require roughing pump



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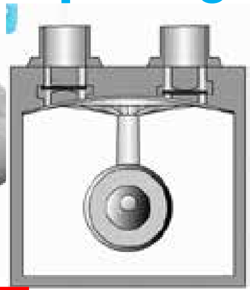
Claw

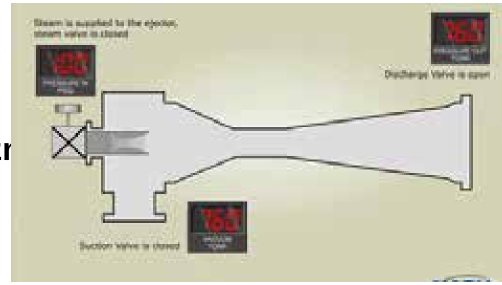
Scroll

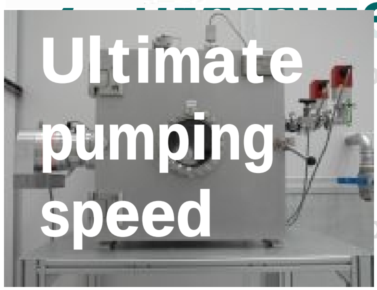
Screw

Diaphragm



Ejector

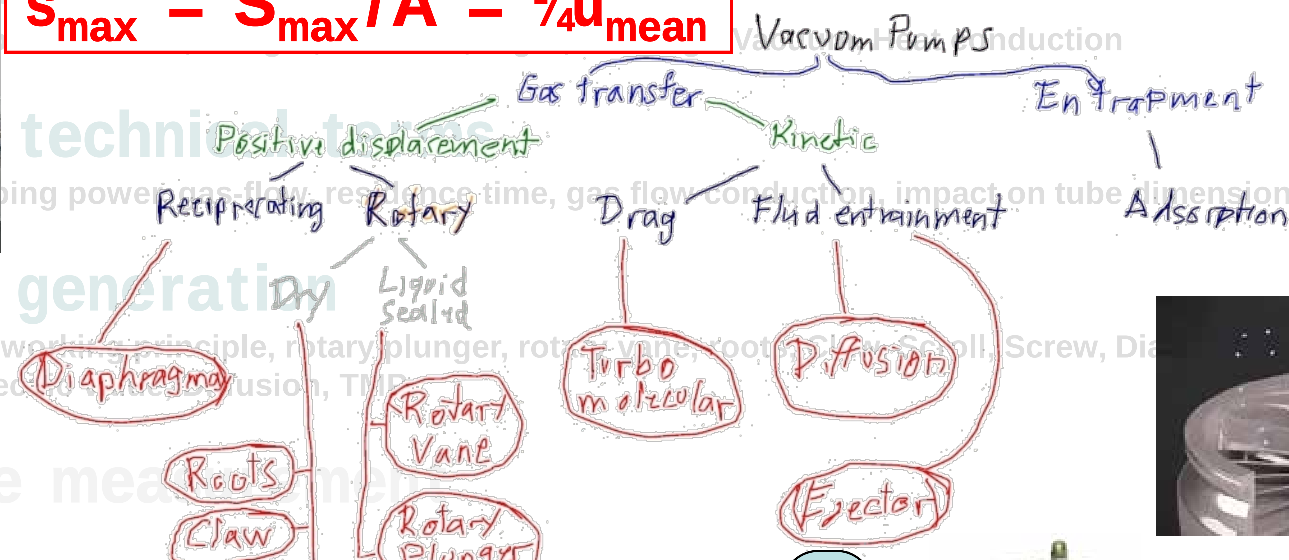




$$s_{max} = S_{max} / A = ¼ u_{mean}$$

technical terms

pumping power, gas-flow, residence time, gas flow conduction, impact on tube dimension



m generation

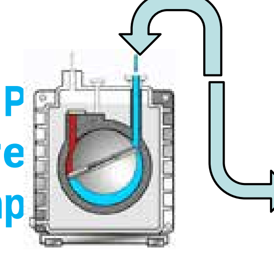
mps, working principle, rotary plunger, rotary vane, roots, Claw, Scroll, Screw, Dia

- speed ... Diffusion, TMP

ure measurement

Diffusion

TMP



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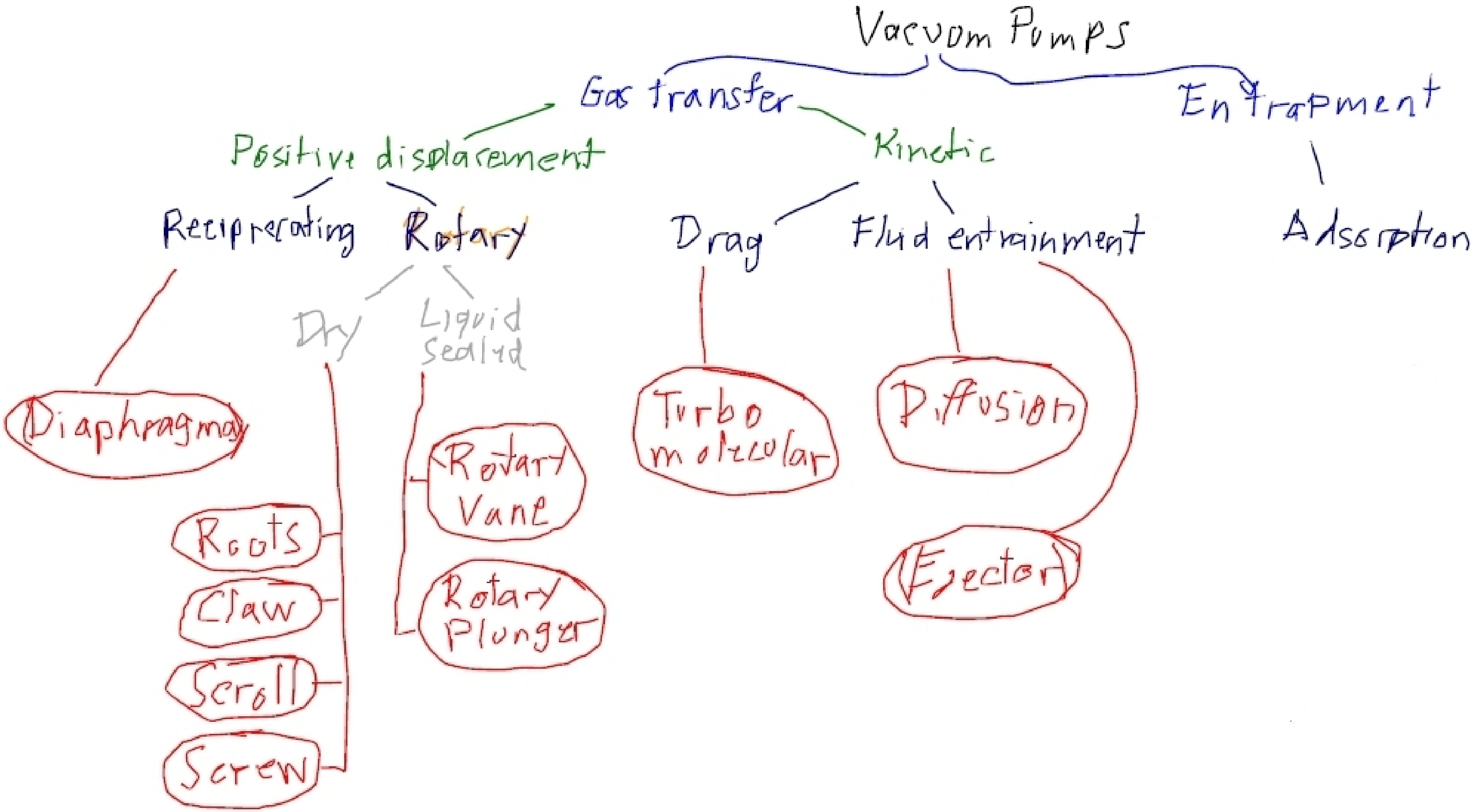
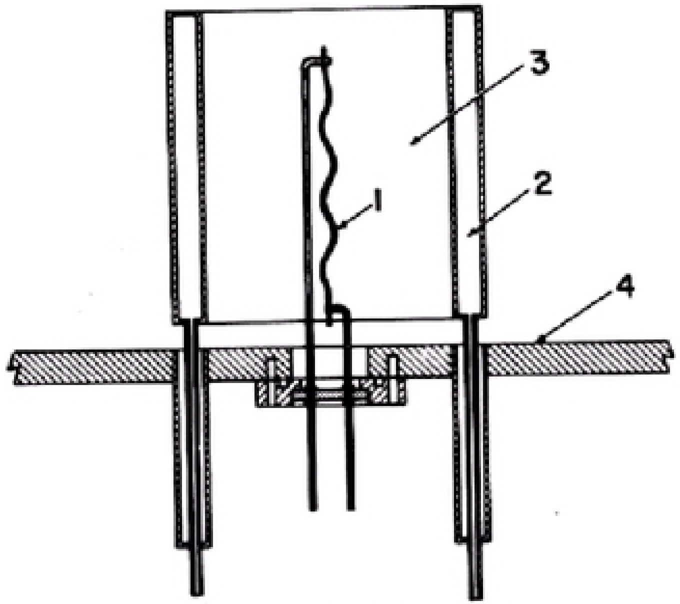

Vacuum Pumps
Gas transfer
Entrapment
Positive displacement
Kinetic
Reciprocating
Rotary
Drag
Fluid entrainment
Adsorption
Dry
Liquid Sealed
Diaphragma
Roots
Claw
Scroll
Screw
Rotary Vane
Rotary Plunger
Turbo molecular
Diffusion
Ejector

Ti-Sublimation pump

https://www.youtube.com/watch?v=CAOVrX49MTk



Schematic of a basic titanium sublimation pump.
(1) Titanium alloy filament
(2) coolant reservoir
(3) titanium deposit
(4) vacuum wall

Fig.7

https://www.youtube.com/watch?v=9vJedaxRsxI

Ti-Sublimation pump

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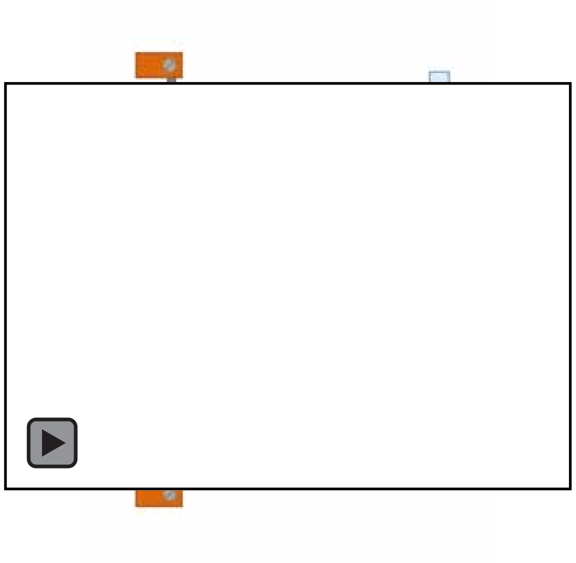

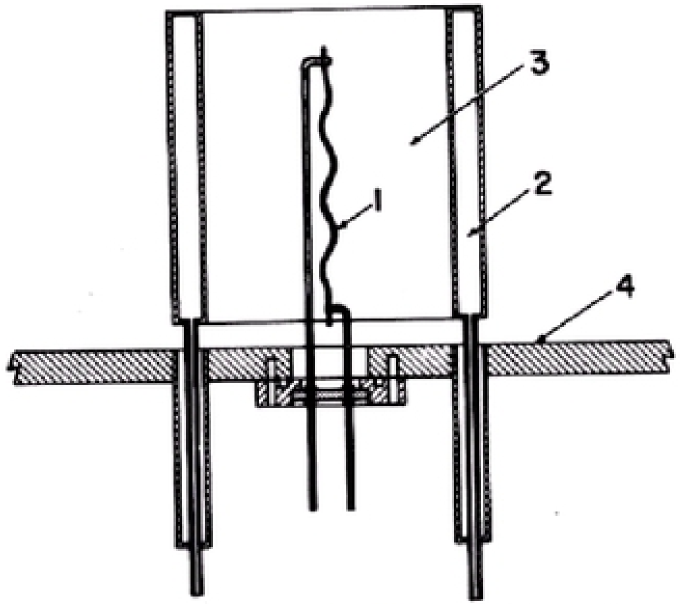

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https://www.youtube.com/watch?v=9vJedaxRsxI

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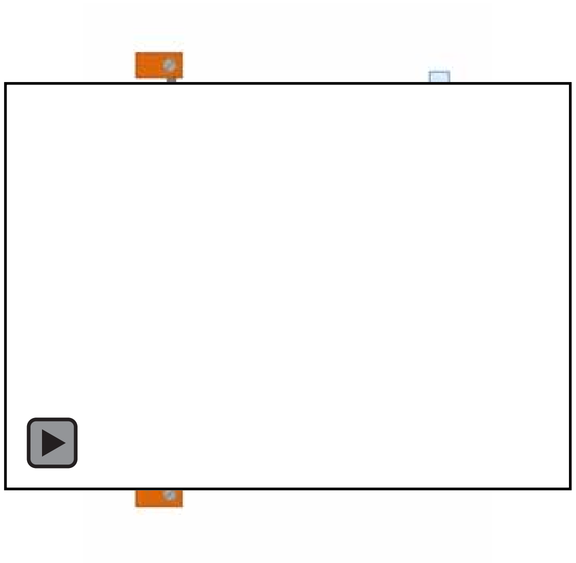
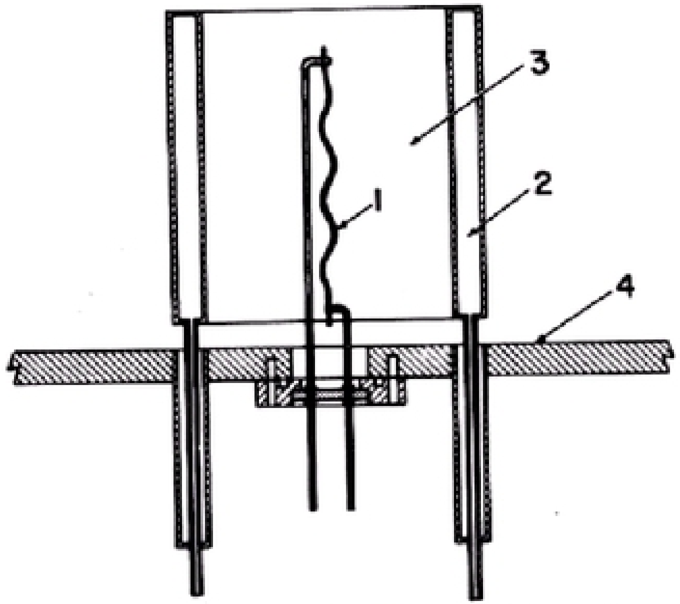
Ti-Sublimation pump

Remember monolayer coverage time ~ 1min @ 10^{-7} mBar

https://www.youtube.com/watch?v=CAOVrX49MTk





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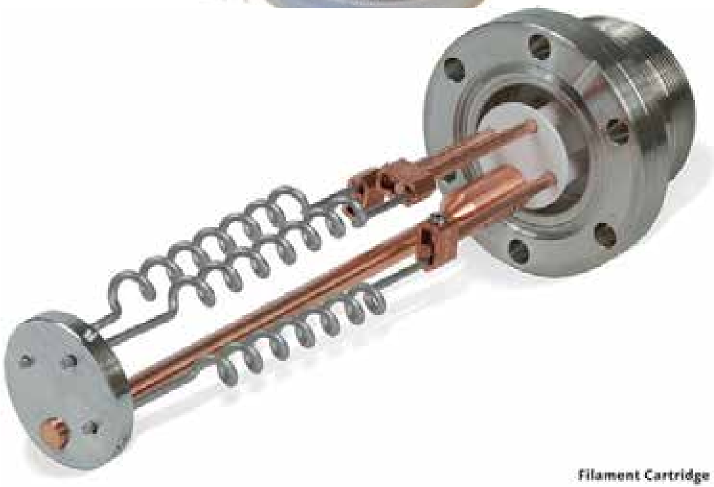
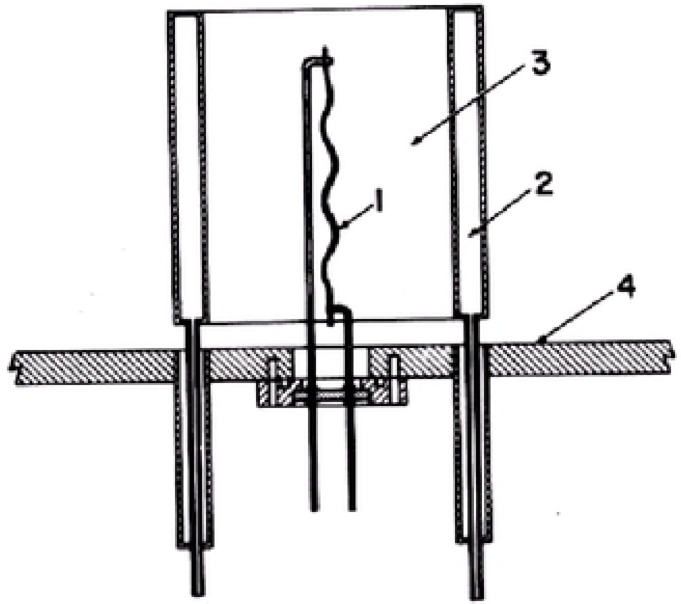
Ti-Sublimation pump





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https://www.youtube.com/watch?v=DRPgo5QUzY0
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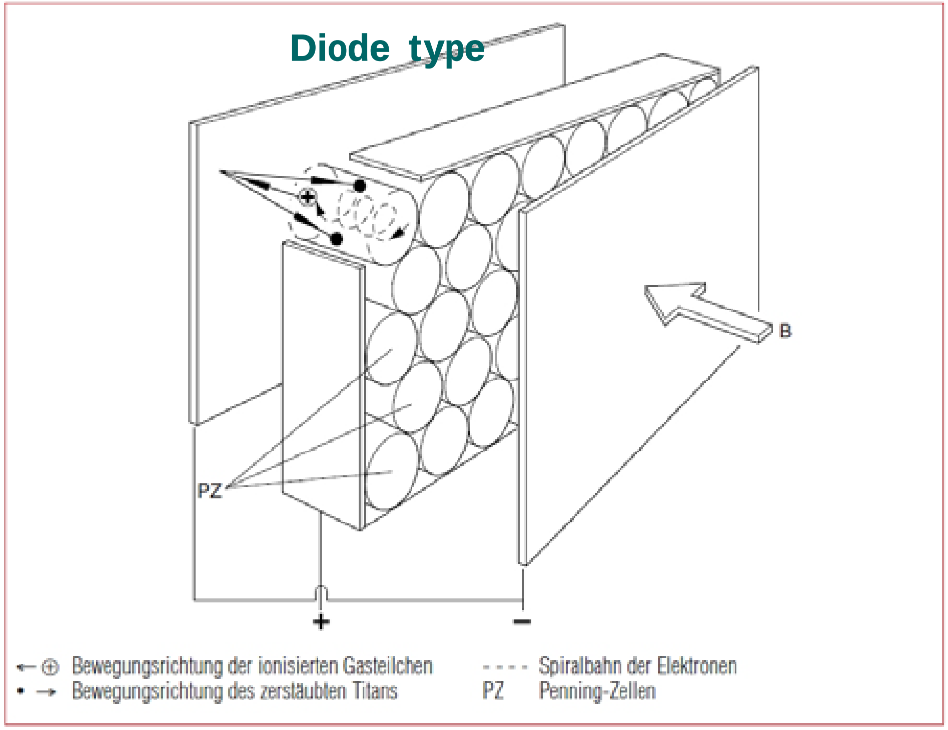
Ion getter pump

https://www.youtube.com/watch?v=_snzYepQTjI
https://www.youtube.com/watch?v=5d0T1DYI1t0
https://www.youtube.com/watch?v=k0USEdasbVg



Ion getter pump

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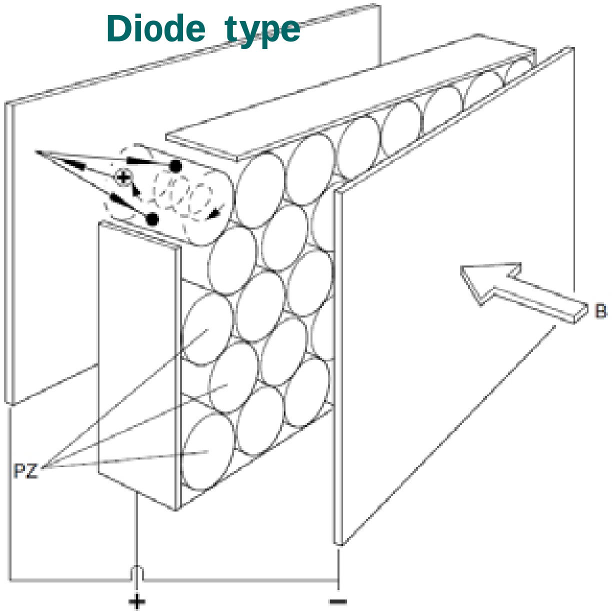
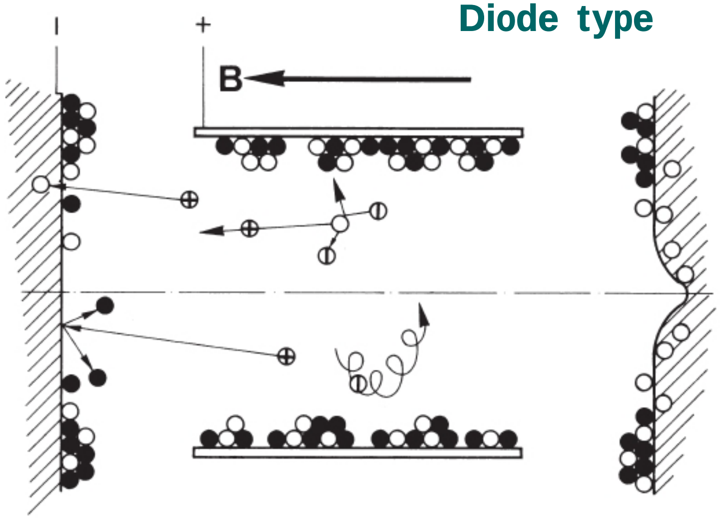
https://www.youtube.com/watch?v=5d0T1DYI1t0
https://www.youtube.com/watch?v=k0USEdasbVg

Diode type



←⊕ Bewegungsrichtung der ionisierten Gasteilchen
• → Bewegungsrichtung des zerstäubten Titans
- - - - Spiralbahn der Elektronen
PZ Penning-Zellen

Diode type

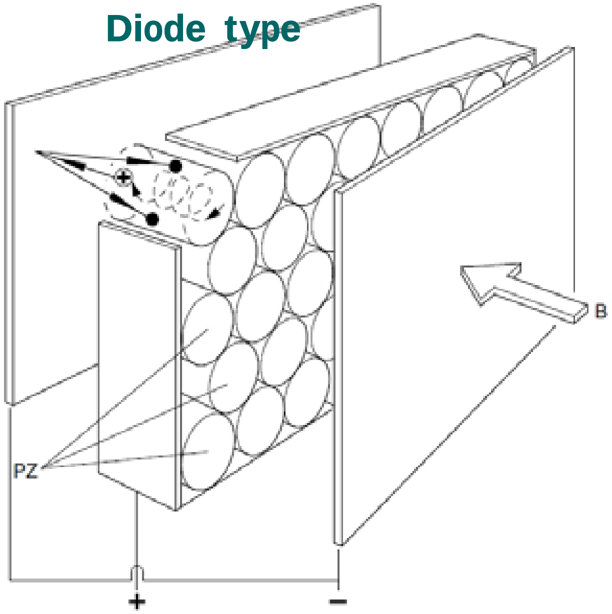


● Titanatome
○ Gasteilchen
⊕ Ionen
⦶ Elektronen
B Magnetfeld

Ion getter pump

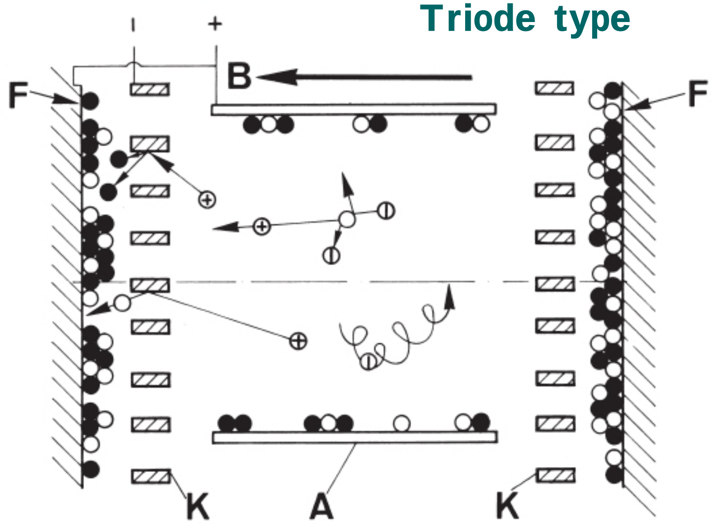
https://www.youtube.com/watch?v=_snzYepQTjI
https://www.youtube.com/watch?v=5d0T1DYI1t0
https://www.youtube.com/watch?v=k0USEdasbVg

Diode type



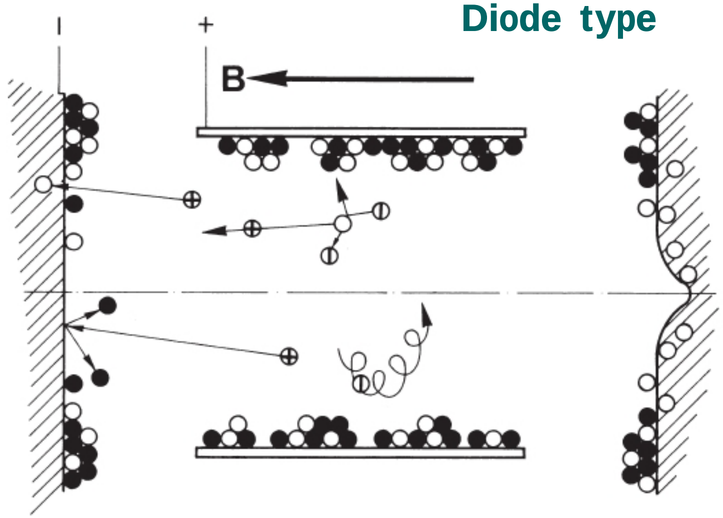
←⊕ Bewegungsrichtung der ionisierten Gasteilchen
•→ Bewegungsrichtung des zerstäubten Titans
---- Spiralbahn der Elektronen
PZ Penning-Zellen

Triode type



- ● Titanatome
- ○ Gasteilchen
- ⊕ Ionen
- ⦶ Elektronen
- A Anodenzylinder (wie bei der Diodenpumpe)
- B Magnetfeld
- F Auffänger (Pumpengehäuse) als dritte Elektrode
- K Kathodengitter

Diode type



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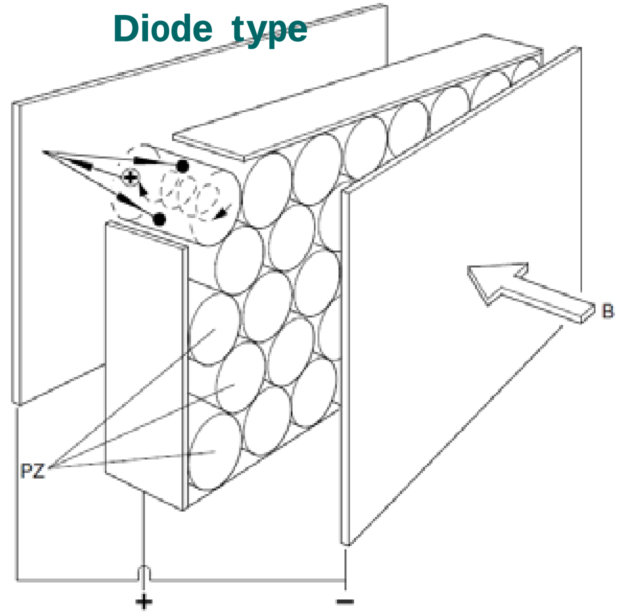
Ion getter pump

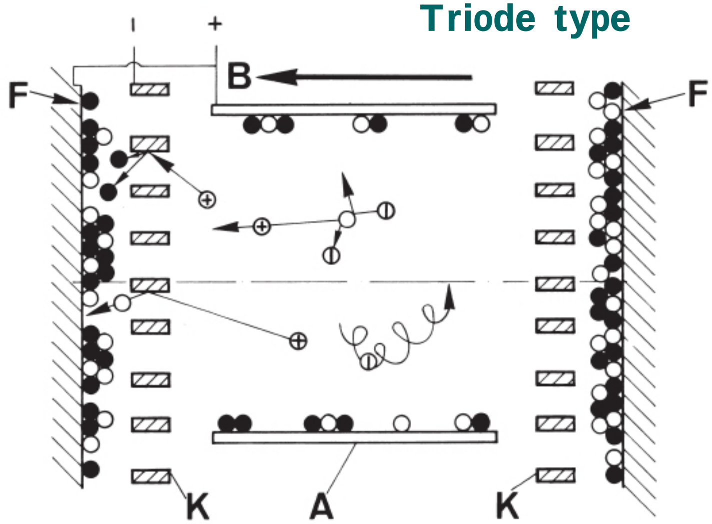
https://www.youtube.com/watch?v=_snzYepQTjI
https://www.youtube.com/watch?v=5d0T1DYI1t0
https://www.youtube.com/watch?v=k0USEdasbVg

Diode type



←⊕ Bewegungsrichtung der ionisierten Gasteilchen
• → Bewegungsrichtung des zerstäubten Titans
- - - - Spiralbahn der Elektronen
PZ Penning-Zellen

Triode type



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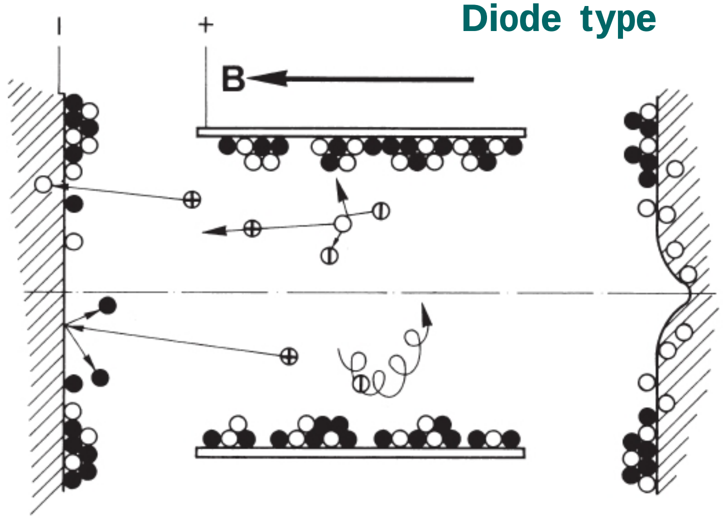

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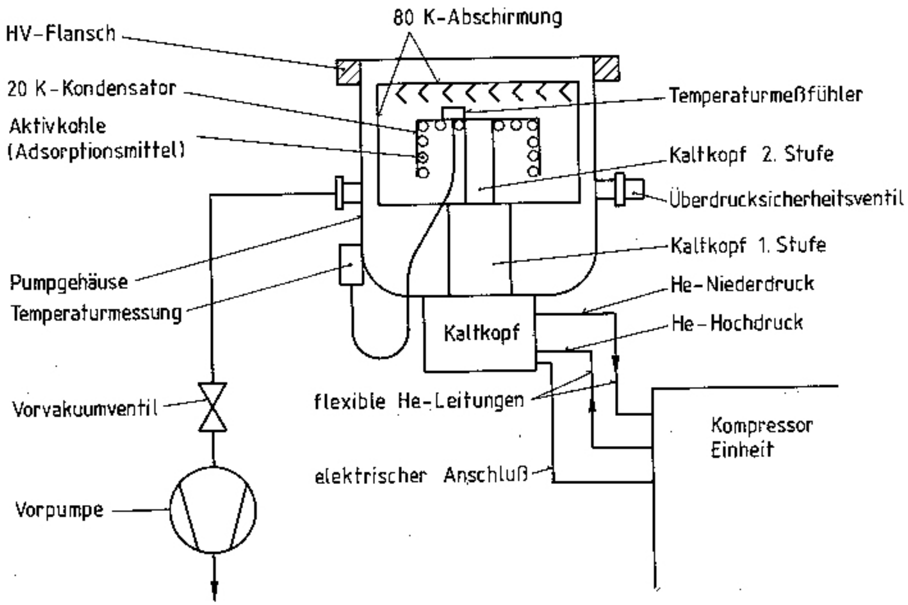
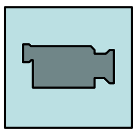
Cryo pump (condensation of gases)



1 Kompressoreinheit
2 Flexible Druckleitungen

Kryopumpe mit
3 Kaltkopf

4 Baffle und
5 Pumpflächen



https://www.youtube.com/watch?v=6IxFH7nnbUc&t=1s

https://www.vacuumscienceworld.com/blog/cryopumps

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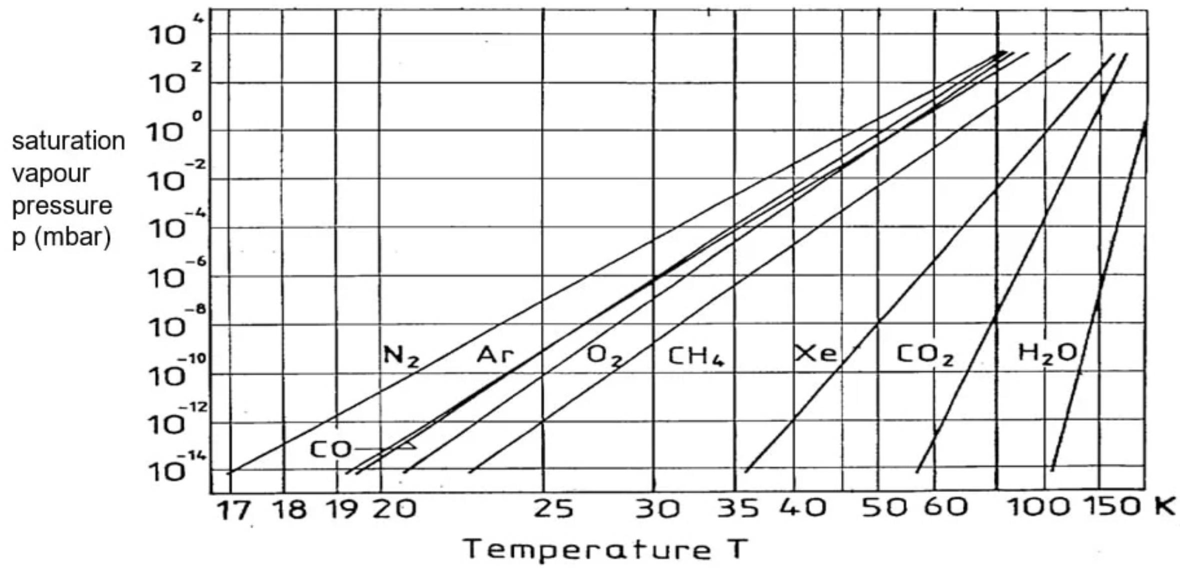
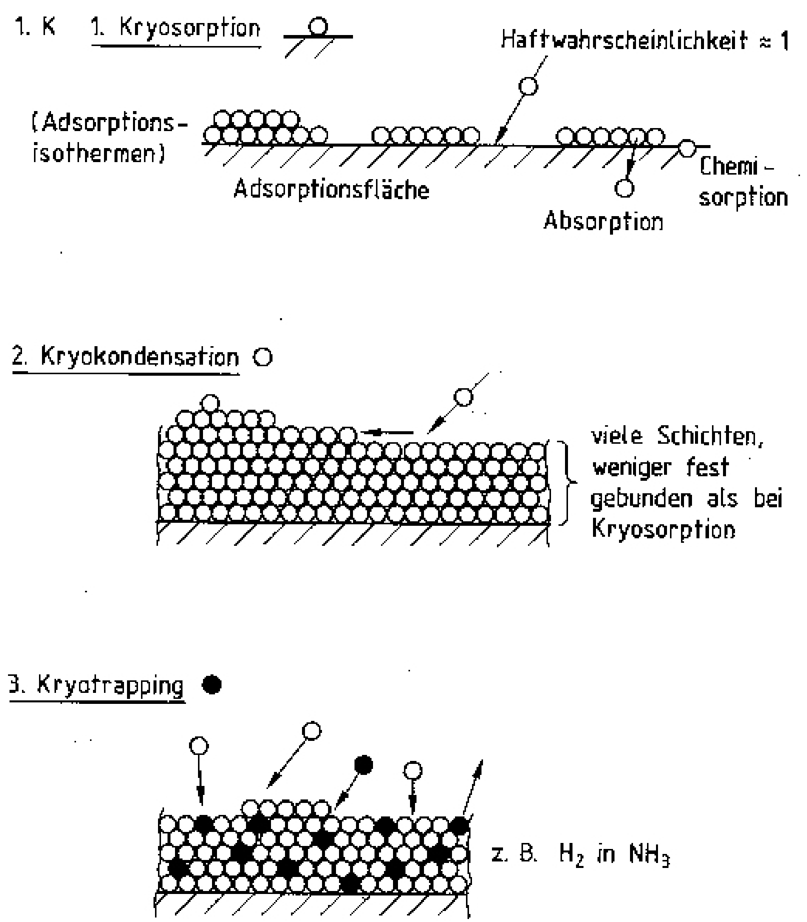
Cryo pump (condensation of gases)



Three mechanisms of gas binding



Cryo pump (condensation of gases)

https://youtu.be/6IxFH7nnbUc

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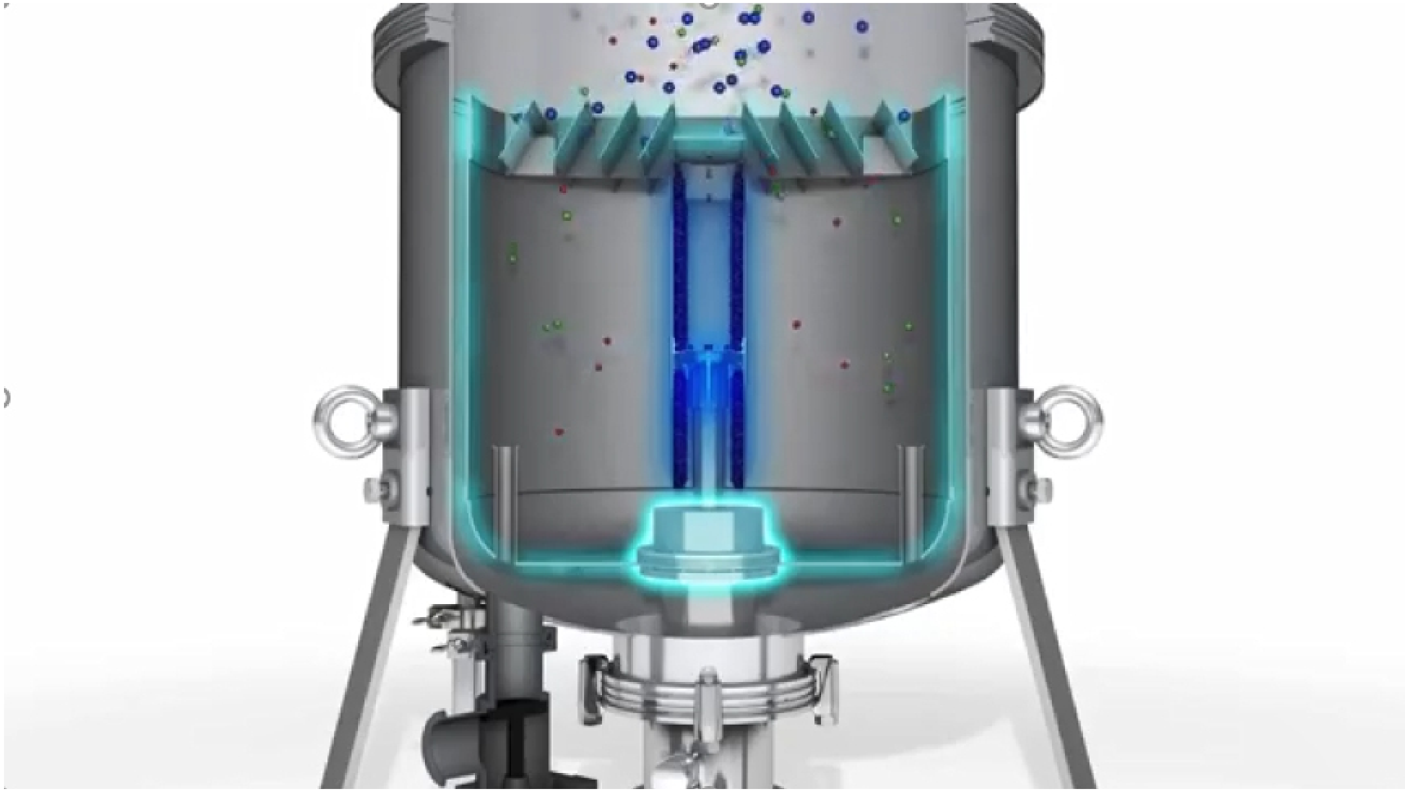

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Adsorption pump

https://www.youtube.com/watch?v=wUVgLlqJcxY

https://www.youtube.com/watch?v=X6ihHB9UTkg

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TECHNISCHE UNIVERSITÄT DRESDEN

VIDEO CAMPUS SACHSEN

“VT L012 d 17:20

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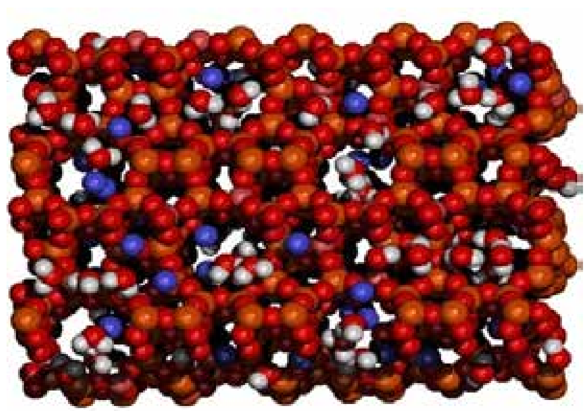

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Adsorption pump

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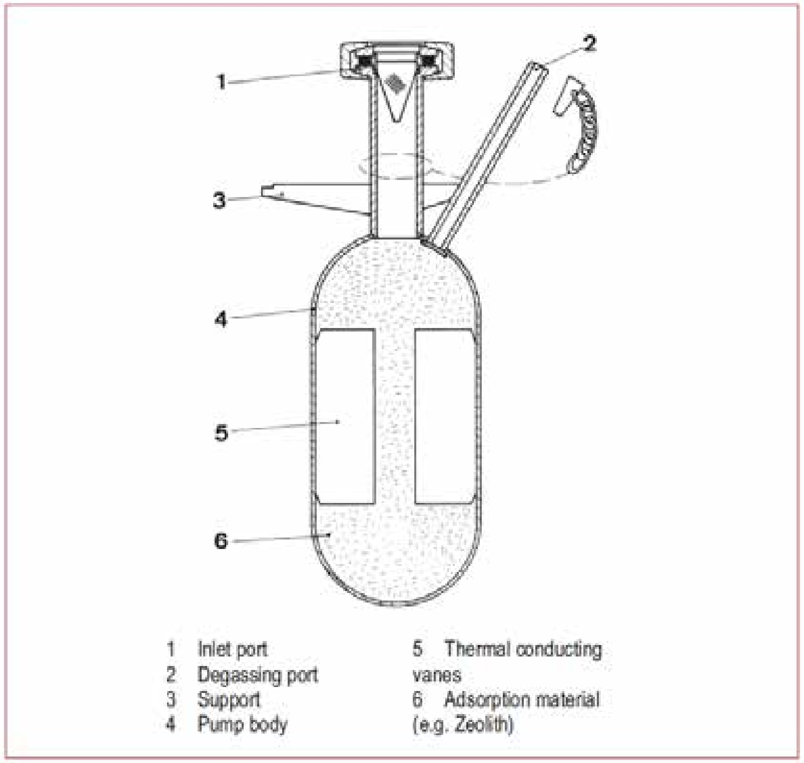

Cross section of an adsorption pump

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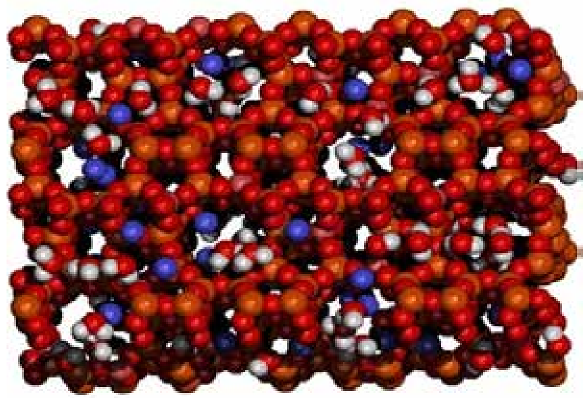

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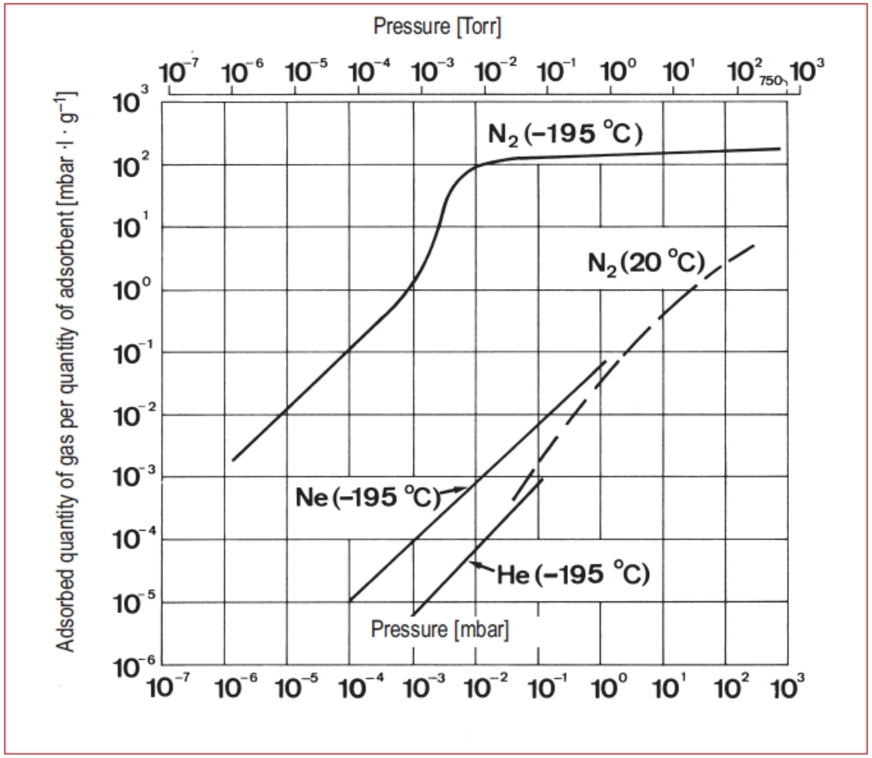
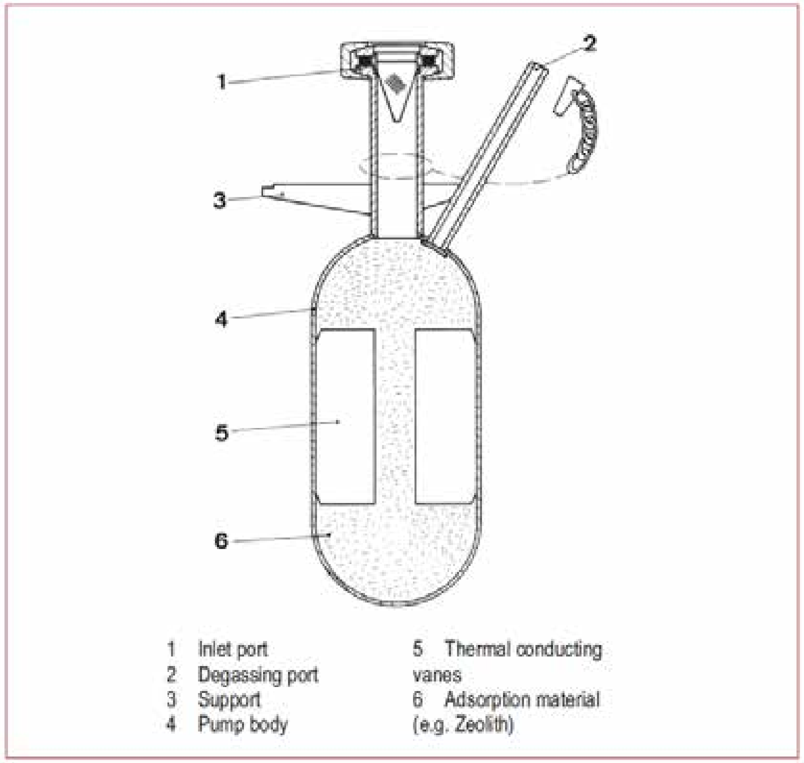


Adsorption isotherms of zeolite 13X for nitrogen at –195 °C and 20 °C, as well as for helium and neon at –195 °C



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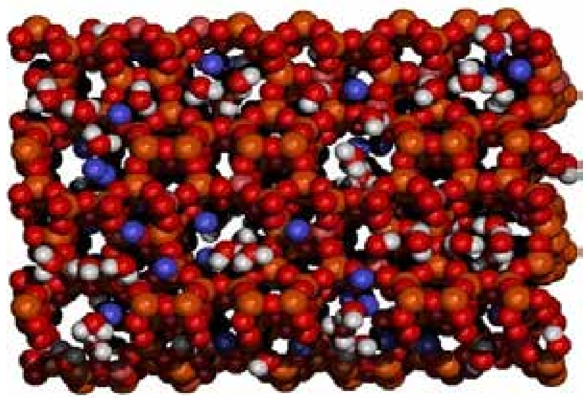

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Adsorption pump

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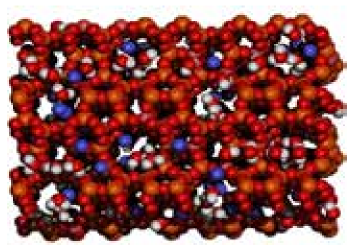
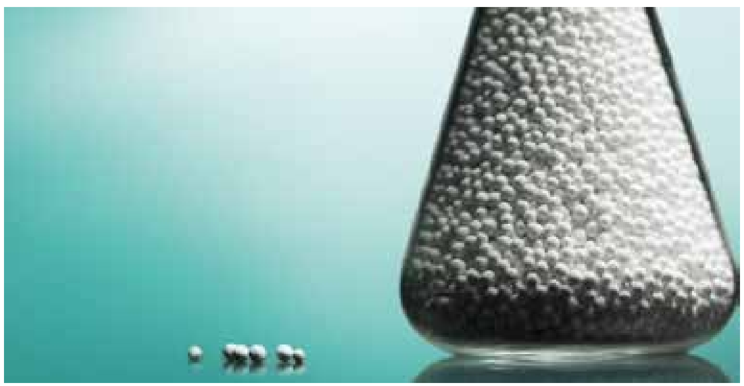
Adsorption „host“ is a porous material (one brand name is Zeolith which is an Alkali-Alumino-Silikat) with a large specific inner surface (ca. 10^3 m^2/g)
Question: How much gas can be trapped by 1 Kg Zeolith?





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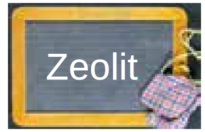

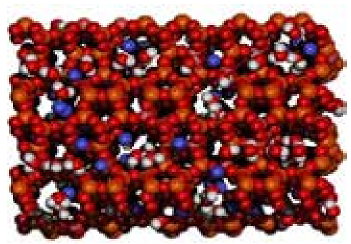

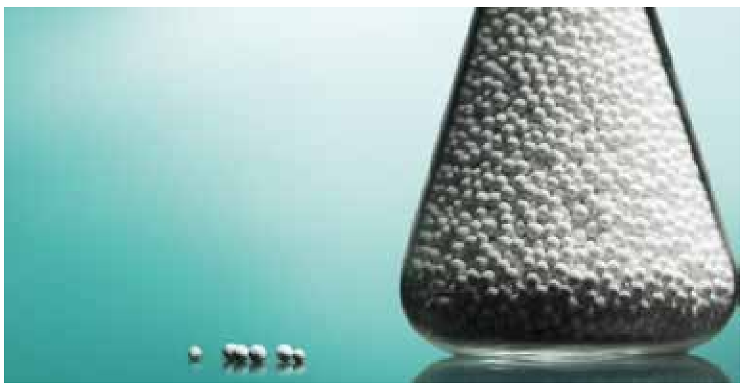

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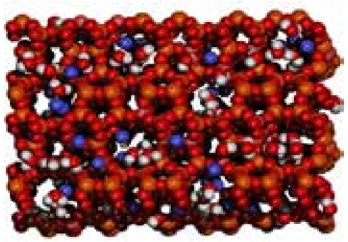
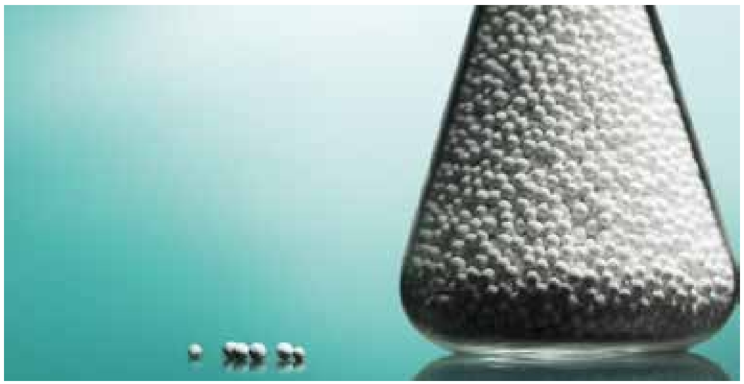
Question: How much gas can be trapped by 1 Kg Zeolith?

Considering 1ML = 10^{19} $1/m^2$, 1Kg Zeolith (having a total surface of 10^6 m^2) would trap $10^{19} \cdot 10^6 = 10^{25}$ gas particles.
(Since 1 Mol corresponds to $6 \cdot 10^{23}$ particles)
These 10^{25} gas particles are equivalent to 16,6 Mol which is 373 l gas @ STP (1Mol @ STP: 22,4 l)



1 Kg Zeolith may bind 373 l gas!



Zeolith – inner surface (ca. $10^3\ m^2/g$)

Question:

How much gas can be trapped by 1 Kg Zeolith?

Considering $1 ML = 10^{19}\ 1/m^2$

1 Kg Zeolith ≙ $10^6\ m^2$

would trap $10^{19} \cdot 10^6 = 10^{25}$ gas particles.

(1 Mol corresponds to $6 \cdot 10^{23}$ particles)

10^{25} gas particles ≙

16,6 Mol which is 373 l gas @ STP

1 Kg Zeolith may bind 373 l gas!

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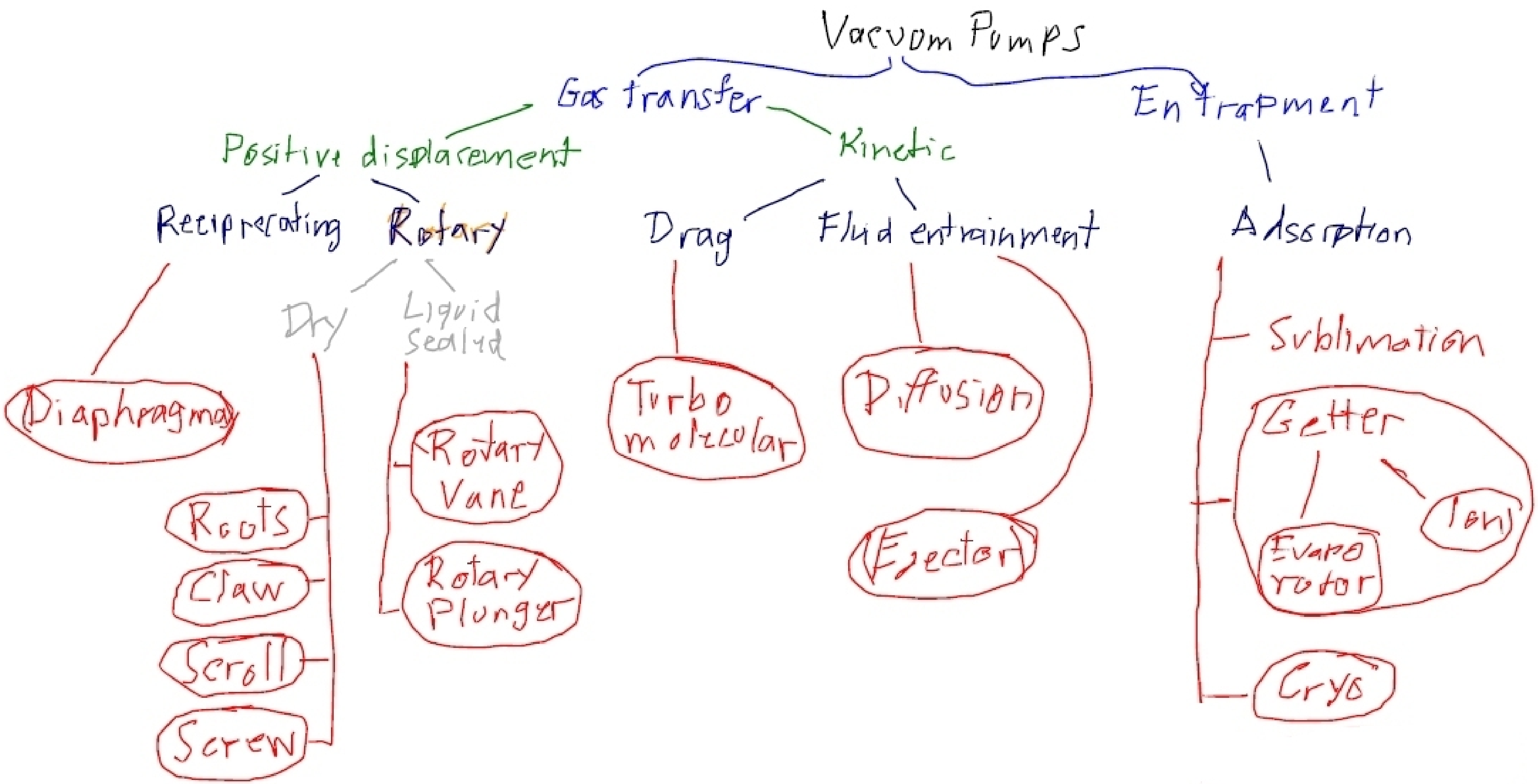
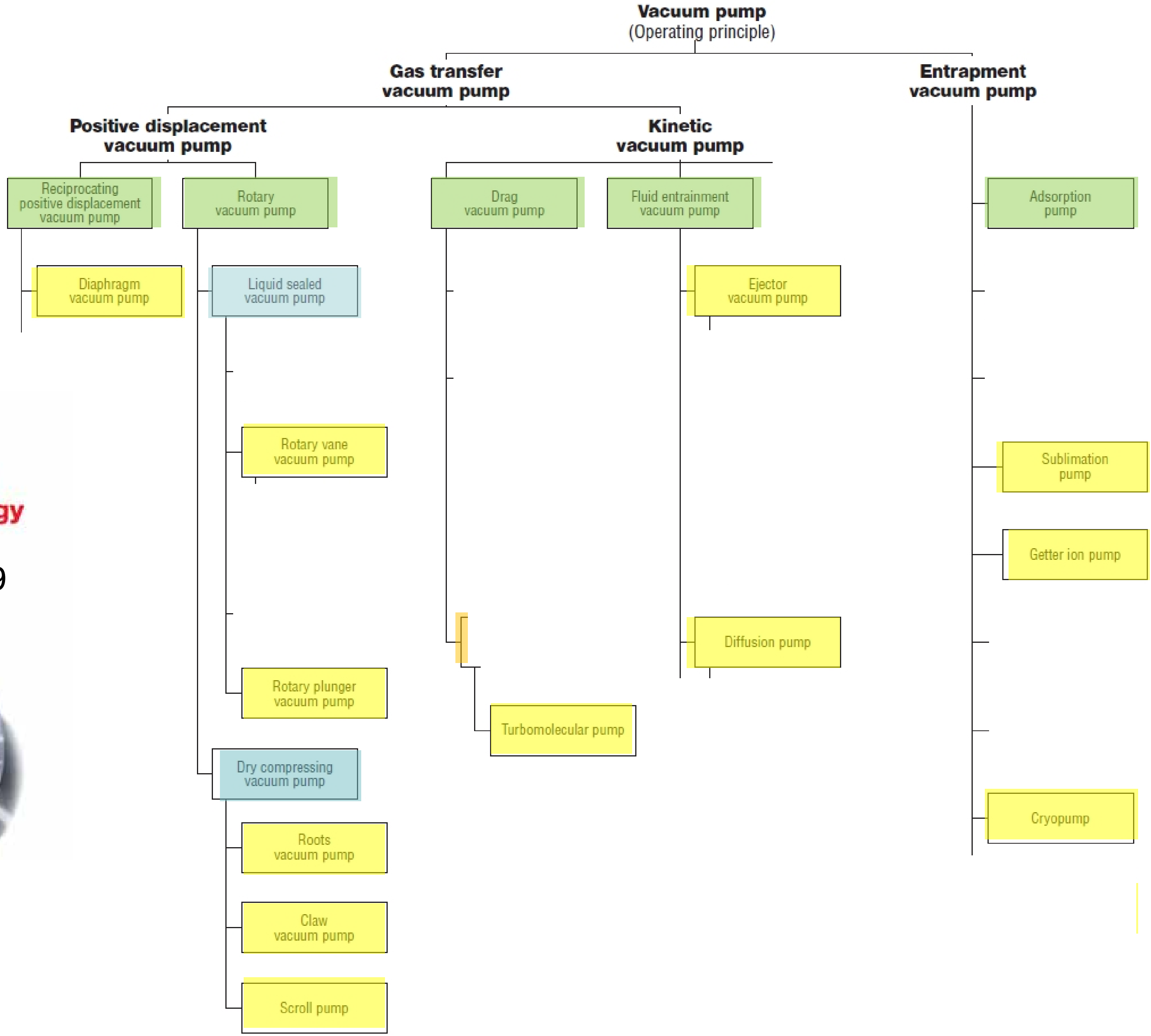
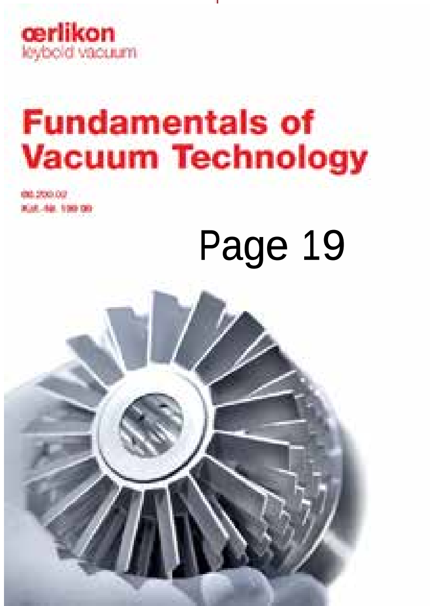

Vacuum Pumps
Gas transfer
Entrapment
Positive displacement
Kinetic
Reciprocating
Rotary
Drag
Fluid entrainment
Adsorption
Dry
Liquid sealed
Diaphragma
Roots
Claw
Scroll
Screw
Rotary Vane
Rotary Plunger
Turbo molecular
Diffusion
Ejector
Sublimation
Getter
Ion
Evaporator
Cryo


Vacuum pump
(Operating principle)
Gas transfer vacuum pump
Entrapment vacuum pump
Positive displacement vacuum pump
Kinetic vacuum pump
Reciprocating positive displacement vacuum pump
Rotary vacuum pump
Drag vacuum pump
Fluid entrainment vacuum pump
Adsorption pump
Diaphragm vacuum pump
Liquid sealed vacuum pump
Ejector vacuum pump
Rotary vane vacuum pump
Sublimation pump
Getter ion pump
Diffusion pump
Rotary plunger vacuum pump
Turbomolecular pump
Dry compressing vacuum pump
Cryopump
Roots vacuum pump
Claw vacuum pump
Scroll pump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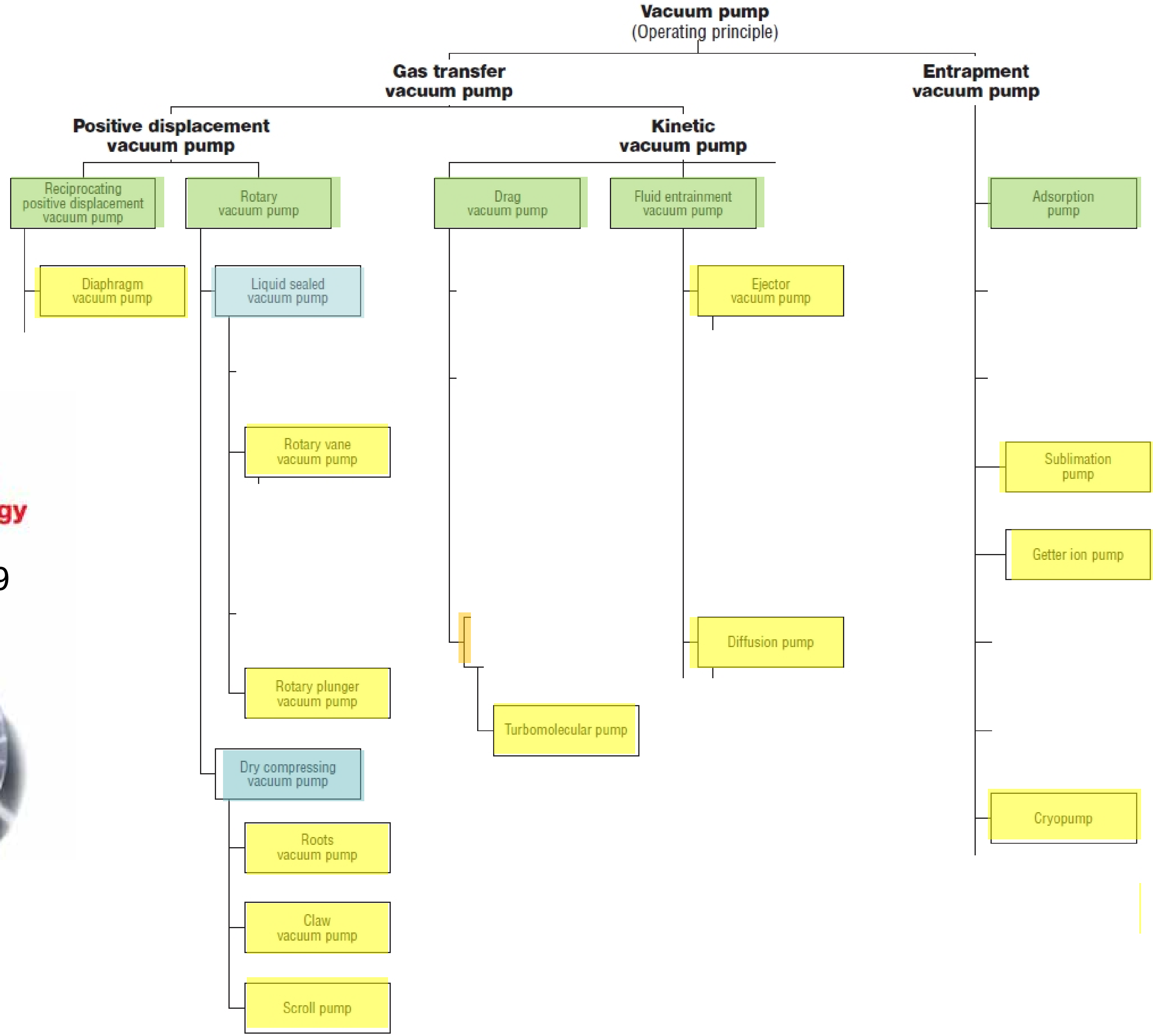
leybold vacuum
Fundamentals of Vacuum Technology
Page 19



Vacuum pump
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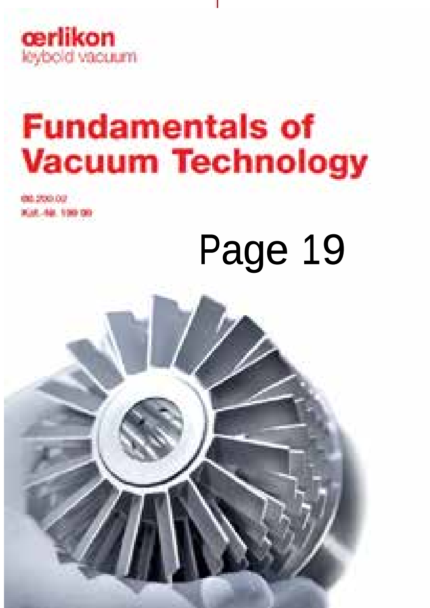

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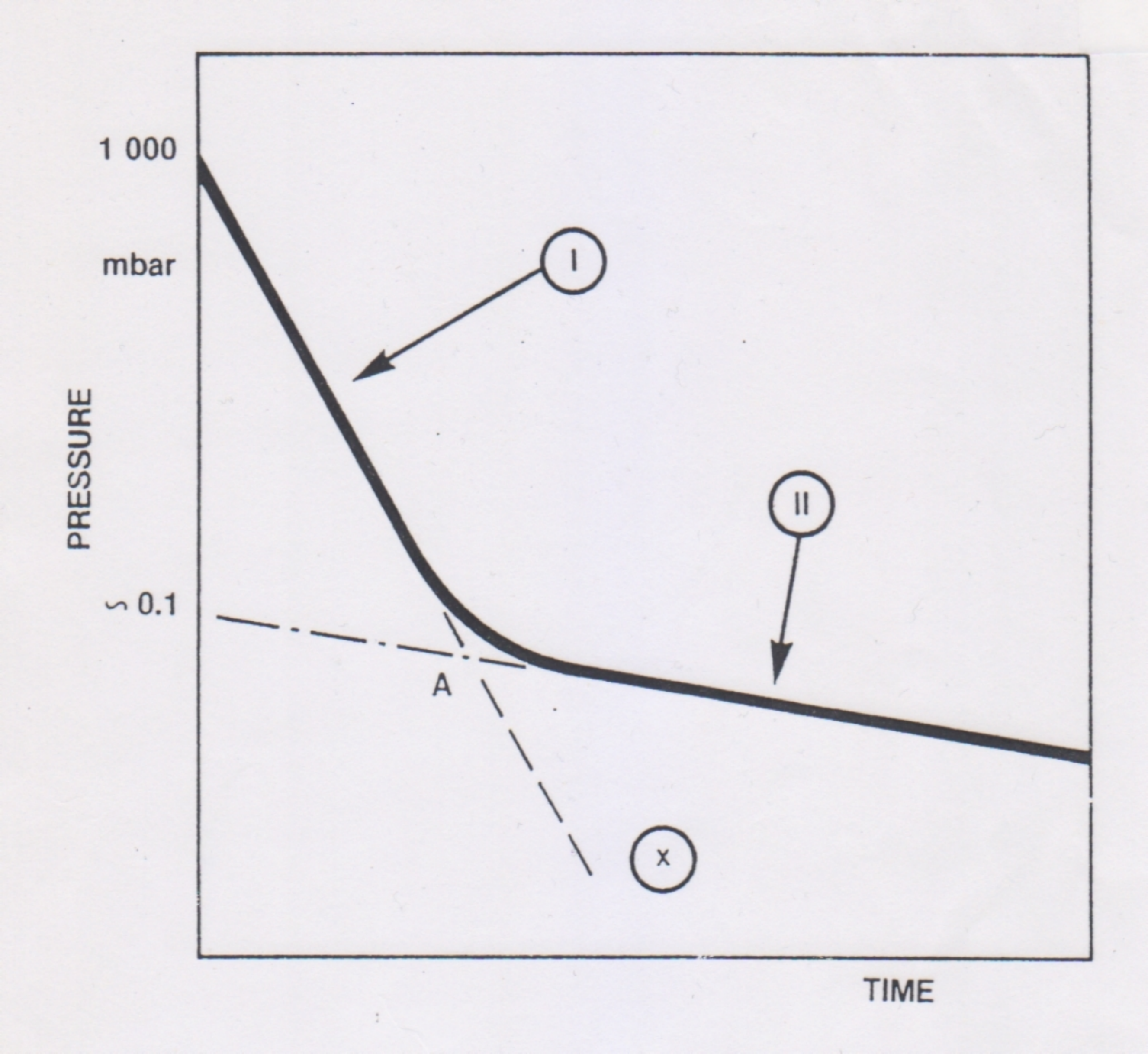
Characteristic pump down curve

“VT L012 e 19:13



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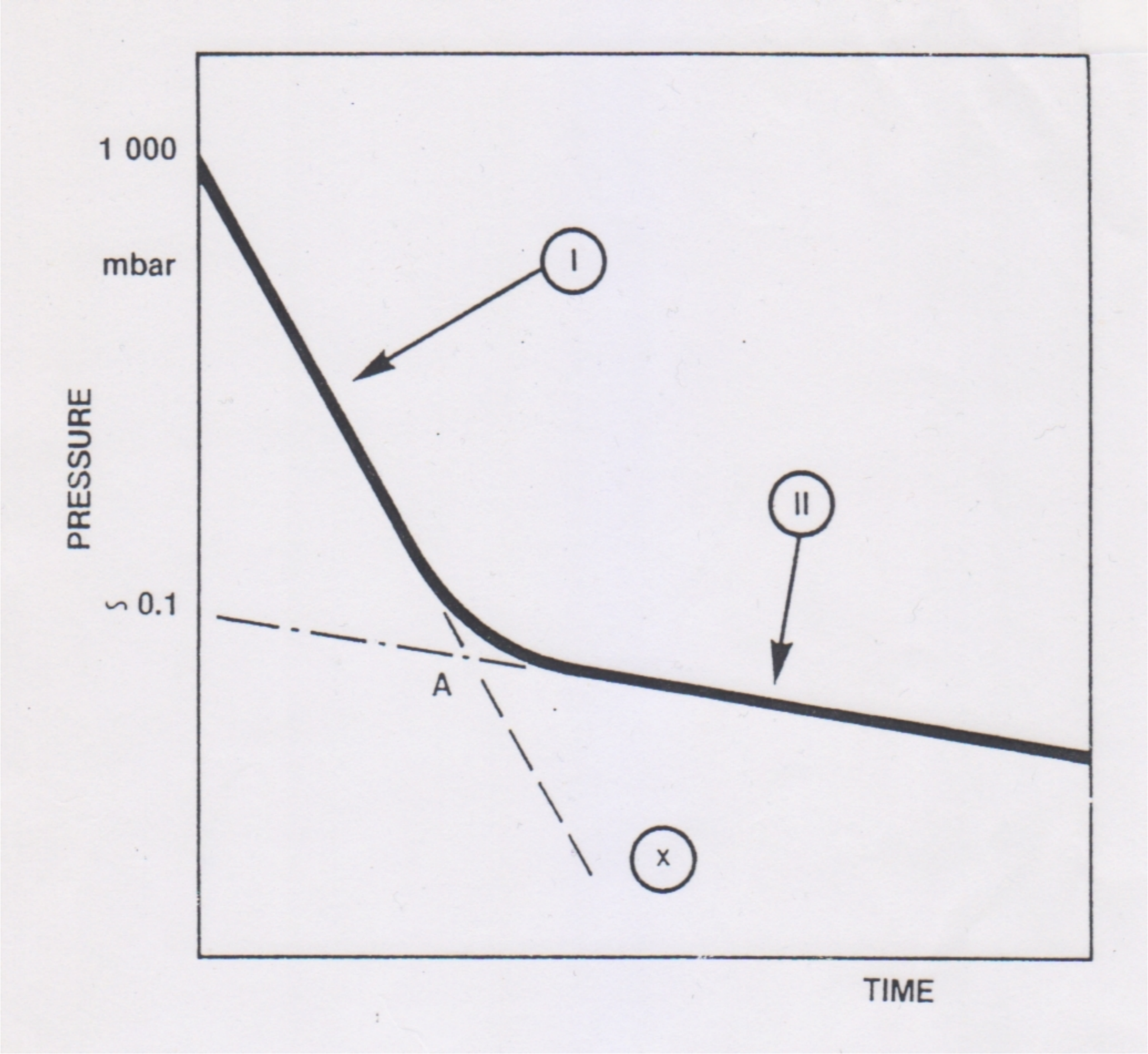
Characteristic pump down curve

“VT L012 e 19:13



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Pump EQ

Evacuation in the rough vacuum range P≥1 mBar

Example: A Recipient of 500 l has to be pumped to 100 Pa within 10 min. Which is the required pumping speed?

$S_{eff} = (500\,l/600\,s) \cdot 2{,}3 \cdot \log(10^5 Pa/10^2 Pa)$

$S_{eff} = 0{,}833\ l/s \cdot 2{,}3 \cdot 3 = \underline{5{,}75\ l/s \approx 20{,}7\ m^3/h}$

For a given pumping speed, the time →

$t = (V/S_{eff}) \cdot 2{,}3 \cdot \log(10^5 Pa/P(t))$

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Evacuation in the rough vacuum range P>1 mBar

Continuity of gas flow from the chamber $Q=-V \cdot dP/dt$ into the pump $Q=P \cdot S_{eff}$

Þ $-V \cdot dP/dt = P \cdot S_{eff}$ respectively $dP/dt = -(S_{eff}/V) \cdot P$ or

$\int 1/P \, dP = -(S_{eff}/V) \int dt$ Integration from $P_0=10^5$ Pa at t=0 to P(t) at t →

$\ln(P(t)/10^5 \text{ Pa}) = -(S_{eff}/V) \cdot t$ =>

$S_{eff} = (V/t) \cdot \ln(10^5 \text{Pa}/P(t)) = (V/t) \cdot 2{,}3 \cdot \log(10^5 \text{Pa}/P(t))$

Example: A Recipient of 500 l has to be pumped to 100 Pa within 10 min. Which is the required pumping speed?

$S_{eff} = (500 \text{l}/600 \text{s}) \cdot 2{,}3 \cdot \log(10^5 \text{Pa}/10^2 \text{Pa}) = 0{,}833 \text{ l/s} \cdot 2{,}3 \cdot 3 =$ <u>5,75 l/s = 20,7 m³/h</u>

For a given pumping speed, the required pumping time is calculated by:
$t = (V/S_{eff}) \cdot 2{,}3 \cdot \log(10^5 \text{Pa}/P(t))$

Evacuation in the high vacuum regime $P<10^{-3}$ mBar

No general closed formulas!

Pumping time depends on the gas release rate q (including leaks) and therefore relies on:

- **Chamber wall material,**
- **its's quality (roughness and porosity),**
- **and it's temperature as well as**
- **leaks.**

q can be obtained by the measurement of pressure rise when the pump port is closed

$q=(\Delta P/\Delta t)\cdot V$

Relation between gas release rate q and „final“ pressure P_{end}:

$S_{eff}=q/P_{end}$ **respectively** $P_{end}=q/S_{eff}$

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Evacuation into the ultra high vacuum regime P<10^{-7} mBar

http://gescott14.blogspot.com/2007/12/uhv-part-2-bake-out.html

Baking of the chamber to 150 – 250 ºC

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»Wissen schafft Brücken.«