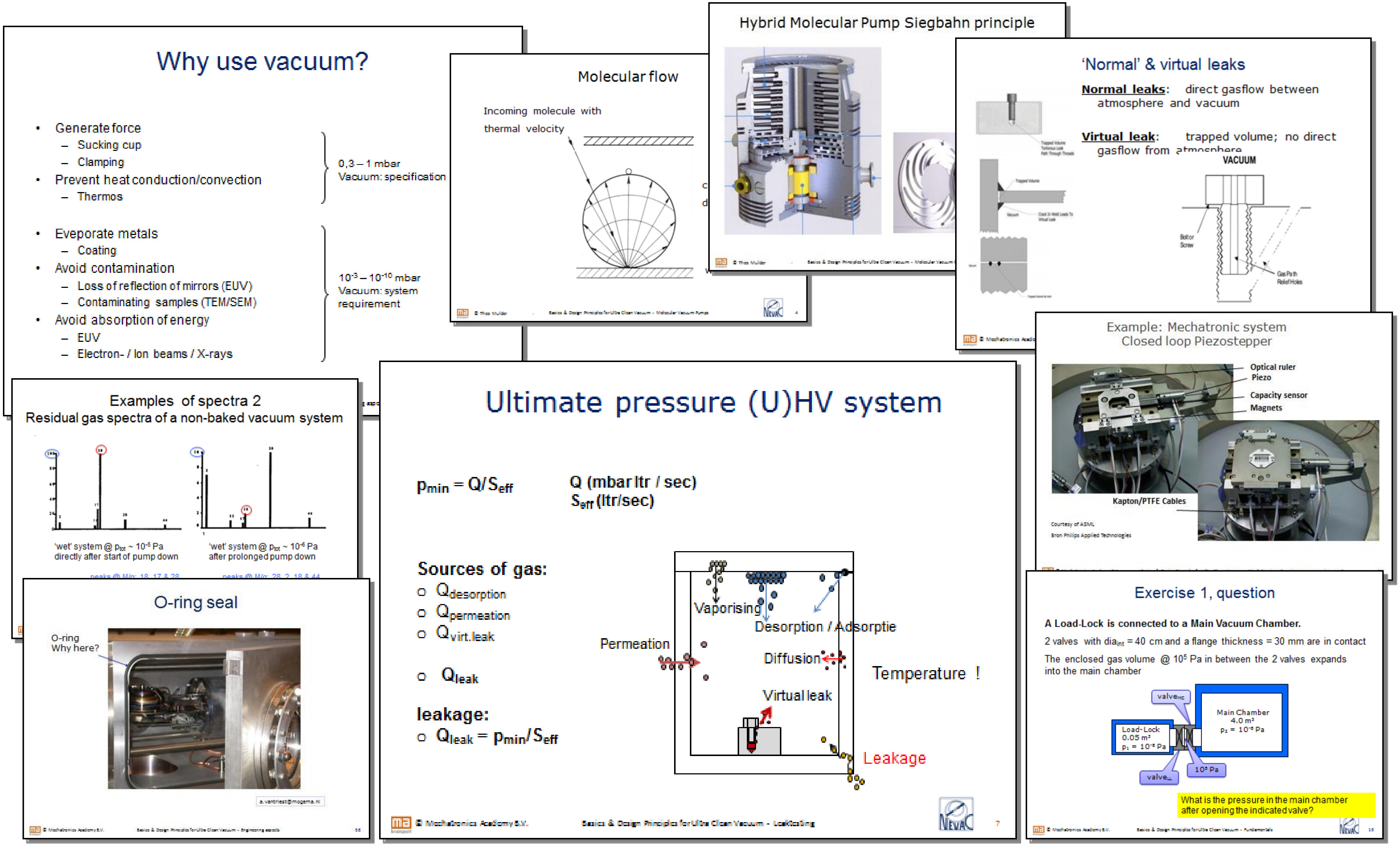
Basics & Design for Ultra Clean Vacuum



Why use vacuum?

- Generate force
  - Sucking cup
  - Clamping
- Prevent heat conduction/convection
  - Thermos

0,3 – 1 mbar
Vacuum: specification

- Eveporate metals
  - Coating
- Avoid contamination
  - Loss of reflection of mirrors (EUV)
  - Contaminating samples (TEM/SEM)
- Avoid absorption of energy
  - EUV
  - Electron- / Ion beams / X-rays

10^{-3} – 10^{-10} mbar
Vacuum: system requirement

Molecular flow

Incoming molecule with thermal velocity

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Hybrid Molecular Pump Siegbahn principle

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'Normal' & virtual leaks

Normal leaks: direct gasflow between atmosphere and vacuum

Virtual leak: trapped volume; no direct gasflow from atmosphere

Example: Mechatronic system
Closed loop Piezostepper

Courtesy of ASML

Bron Philips Applied Technologies

Examples of spectra 2
Residual gas spectra of a non-baked vacuum system

'wet' system @ p_{tot} ~ 10^{-5} Pa
directly after start of pump down

'wet' system @ p_{tot} ~ 10^{-6} Pa
after prolonged pump down

peaks @ M/q: 18, 17 & 28

peaks @ M/q: 28, 2, 18 & 44

Ultimate pressure (U)HV system

$p_{min} = Q/S_{eff}$

Q (mbar ltr / sec)
S_{eff} (ltr/sec)

Sources of gas:

- ○ $Q_{desorption}$
- ○ $Q_{permeation}$
- ○ $Q_{virt.leak}$
- ○ Q_{leak}

leakage:

- ○ $Q_{leak} = p_{min} / S_{eff}$

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O-ring seal

O-ring
Why here?

a.vantriest@mogema.nl

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Exercise 1, question

A Load-Lock is connected to a Main Vacuum Chamber.

2 valves with dia_{int} = 40 cm and a flange thickness = 30 mm are in contact

The enclosed gas volume @ 10^5 Pa in between the 2 valves expands into the main chamber

What is the pressure in the main chamber after opening the indicated valve?

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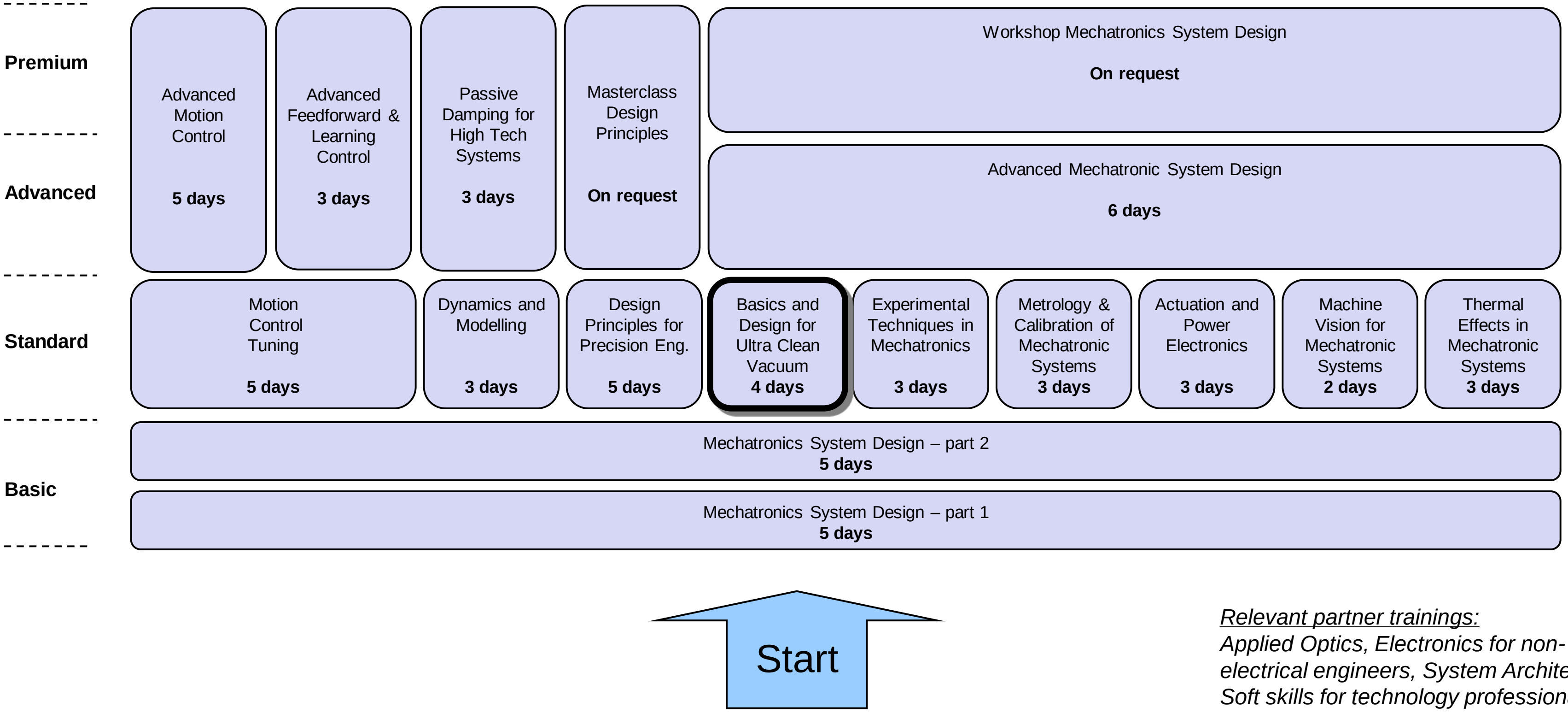
Contents

- Mechatronics Training Curriculum
- Details of Course *Basics & Design for Ultra Clean Vacuum*

Mechatronics Training Curriculum



Premium

Advanced

- Advanced Motion Control — **5 days**
- Advanced Feedforward & Learning Control — **3 days**
- Passive Damping for High Tech Systems — **3 days**
- Masterclass Design Principles — **On request**
- Workshop Mechatronics System Design — **On request**
- Advanced Mechatronic System Design — **6 days**

Standard

- Motion Control Tuning — **5 days**
- Dynamics and Modelling — **3 days**
- Design Principles for Precision Eng. — **5 days**
- Basics and Design for Ultra Clean Vacuum — **4 days**
- Experimental Techniques in Mechatronics — **3 days**
- Metrology & Calibration of Mechatronic Systems — **3 days**
- Actuation and Power Electronics — **3 days**
- Machine Vision for Mechatronic Systems — **2 days**
- Thermal Effects in Mechatronic Systems — **3 days**

Basic

- Mechatronics System Design – part 2 — **5 days**
- Mechatronics System Design – part 1 — **5 days**

Start

Relevant partner trainings:
Applied Optics, Electronics for non-electrical engineers, System Architecture, Soft skills for technology professionals,
…

www.mechatronics-academy.nl

Mechatronics Academy

- In the past, many trainings were developed within Philips to train own staff, but the training center CTT stopped.

- **Mechatronics Academy B.V.** has been setup to provide continuity of the existing trainings and develop new trainings in the field of precision mechatronics. It is founded and run by:
  - Prof. Maarten Steinbuch
  - Prof. Jan van Eijk
  - Dr. Adrian Rankers

- We cooperate in the **High Tech Institute** consortium that provides sales, marketing and back office functions.

Basics & Design for Ultra Clean Vacuum

Course Director(s) / Trainers

Trainers

- Dr. Dick van Langeveld (NEVAC)
- Dr. Gesa Welker (TU Delft)
- David Schijve (NEVAC & VacTec)
- Thom Bijsterbosch, BSc (Settels Savenije van Amelsvoort)
- Ing. Mark Meuwese (Settels Savenije van Amelsvoort)
- Ir. Sven Pekelder (Settels Savenije van Amelsvoort)

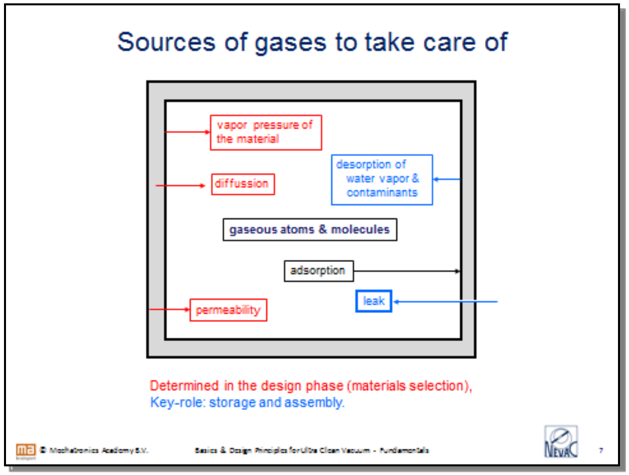
Course Director(s)

- Ing. Mark Meuwese (Settels Savenije van Amelsvoort)
- Dr.ir A.M. Rankers (Mechatronics Academy)

Program

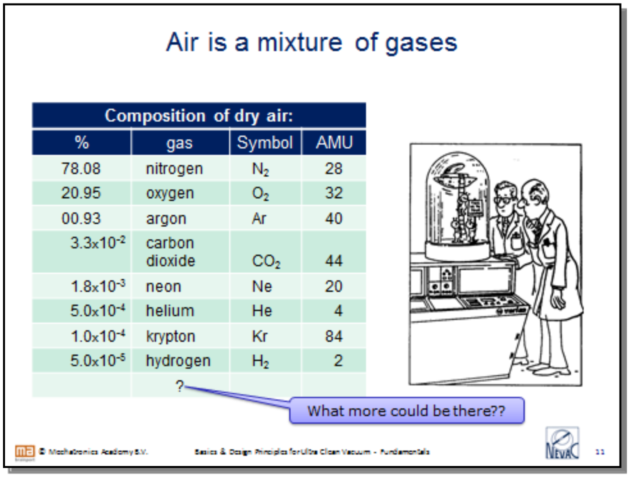
Day	Topic	Presenter
1	09.00 Fundamentals / Flow of gases **12.30 Lunch** 13.30 Total & Partial Pressure 17.00 End of day	Gesa Welker Dick van Langeveld
2	09.00 Pumps / Applied RGA **12.30 Lunch** 13.30 Leak Tightness (Theory & Practice) 17.00 End of day	David Schijve + Dick van Langeveld David Schijve
3	09.00 Engineering Aspects **12.30 Lunch** 13.30 Mechatronic Aspects 17.00 End of day	Dick van Langeveld Mark Meuwese
4	09.00 Design for Qualification **12.30 Lunch** 13.30 Vacuum Budgetting 17.00 End of day	Thom Bijsterbosch / Sven Pekelder Sven Pekelder + Mark Meuwese

Day 1 (morning)



Sources of gases to take care of

Determined in the design phase (materials selection),
Key-role: storage and assembly.

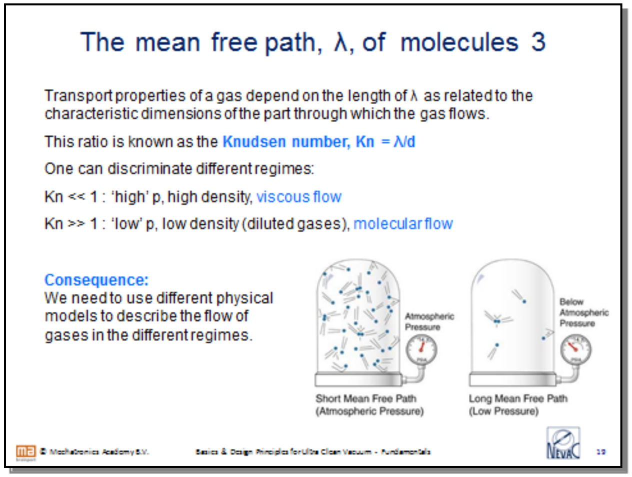


Air is a mixture of gases

Composition of dry air:

%	gas	Symbol	AMU
78.08	nitrogen	N_2	28
20.95	oxygen	O_2	32
00.93	argon	Ar	40
3.3×10^{-2}	carbon dioxide	CO_2	44
1.8×10^{-3}	neon	Ne	20
5.0×10^{-4}	helium	He	4
1.0×10^{-4}	krypton	Kr	84
5.0×10^{-5}	hydrogen	H_2	2
	?		

What more could be there??



The mean free path, λ, of molecules 3

Transport properties of a gas depend on the length of λ as related to the characteristic dimensions of the part through which the gas flows.

This ratio is known as the **Knudsen number, Kn = λ/d**

One can discriminate different regimes:

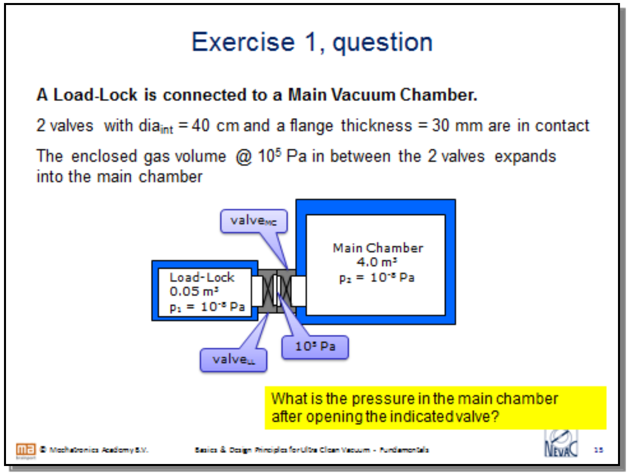
Kn << 1 : 'high' p, high density, viscous flow

Kn >> 1 : 'low' p, low density (diluted gases), molecular flow

Consequence:
We need to use different physical models to describe the flow of gases in the different regimes.

Short Mean Free Path (Atmospheric Pressure)

Long Mean Free Path (Low Pressure)



Exercise 1, question

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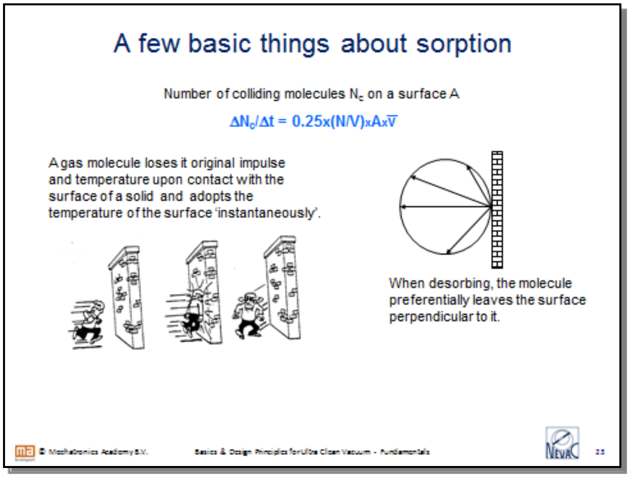


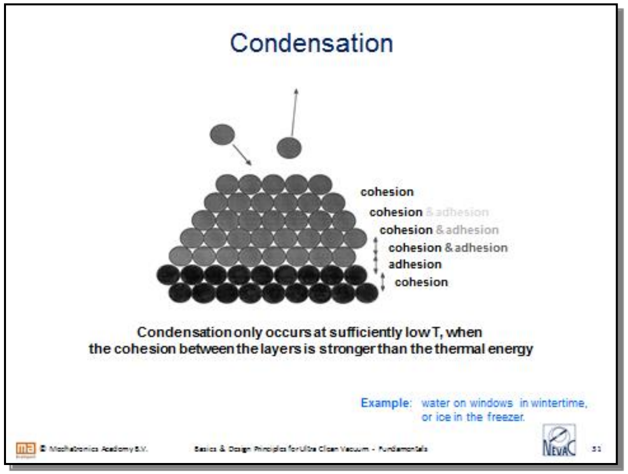
A few basic things about sorption

Number of colliding molecules N_c on a surface A

$$\Delta N_c/\Delta t = 0.25 \times (N/V) \times A \times \overline{v}$$

A gas molecule loses it original impulse and temperature upon contact with the surface of a solid and adopts the temperature of the surface 'instantaneously'.

When desorbing, the molecule preferentially leaves the surface perpendicular to it.

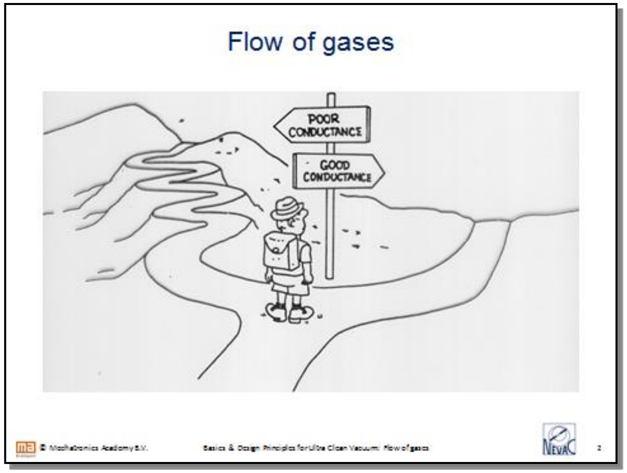


Condensation

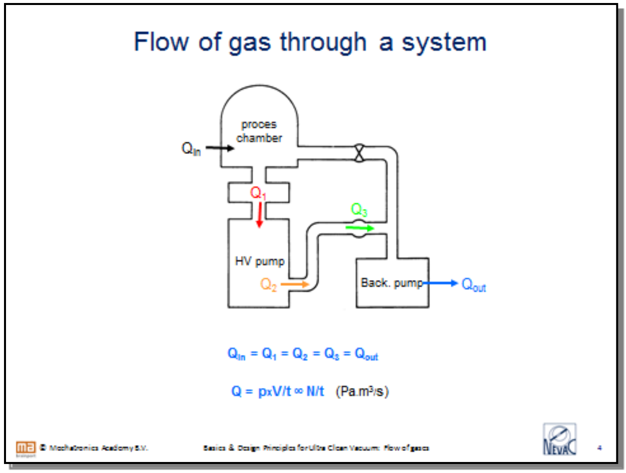
Condensation only occurs at sufficiently low T, when the cohesion between the layers is stronger than the thermal energy

Example: water on windows in wintertime, or ice in the freezer.

Day 1 (afternoon)



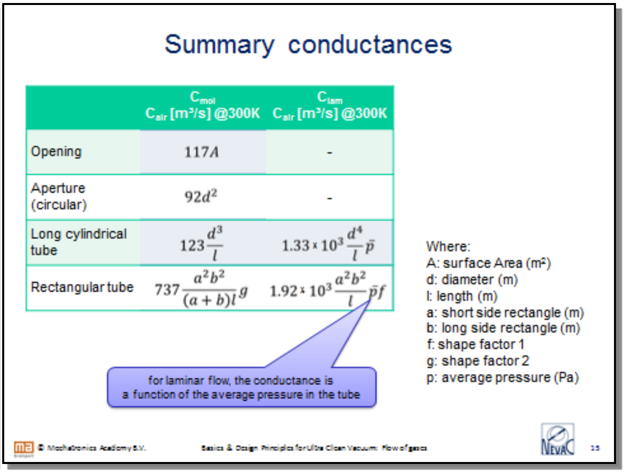
Flow of gases



Flow of gas through a system

$Q_{in} = Q_1 = Q_2 = Q_3 = Q_{out}$

$Q = pxV/t \propto N/t$ (Pa.m³/s)

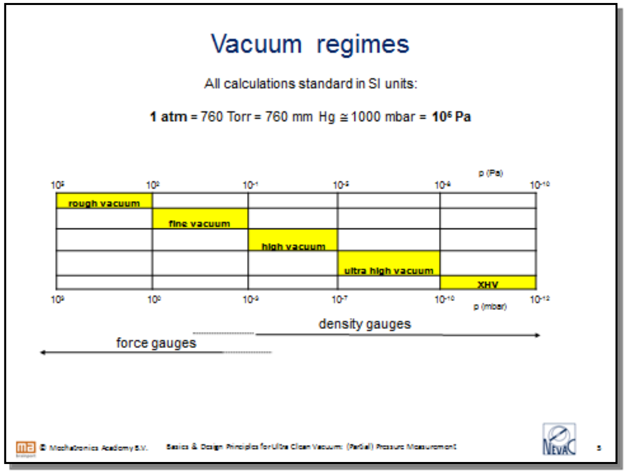


Summary conductances

	C_{mol} C_{air} [m³/s] @300K	C_{lam} C_{air} [m³/s] @300K
Opening	$117A$	-
Aperture (circular)	$92d^2$	-
Long cylindrical tube	$123\frac{d^3}{l}$	$1.33 \times 10^3 \frac{d^4}{l}\bar{p}$
Rectangular tube	$737\frac{a^2b^2}{(a+b)l}g$	$1.92 \times 10^3 \frac{a^2b^2}{l}\bar{p}f$

for laminar flow, the conductance is a function of the average pressure in the tube

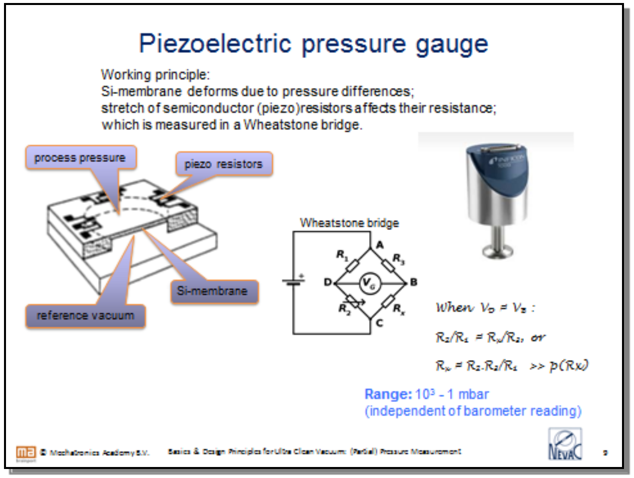
Where:
A: surface Area (m²)
d: diameter (m)
l: length (m)
a: short side rectangle (m)
b: long side rectangle (m)
f: shape factor 1
g: shape factor 2
p: average pressure (Pa)



Vacuum regimes

All calculations standard in SI units:

1 atm = 760 Torr = 760 mm Hg ≅ 1000 mbar = **10^5 Pa**



Piezoelectric pressure gauge

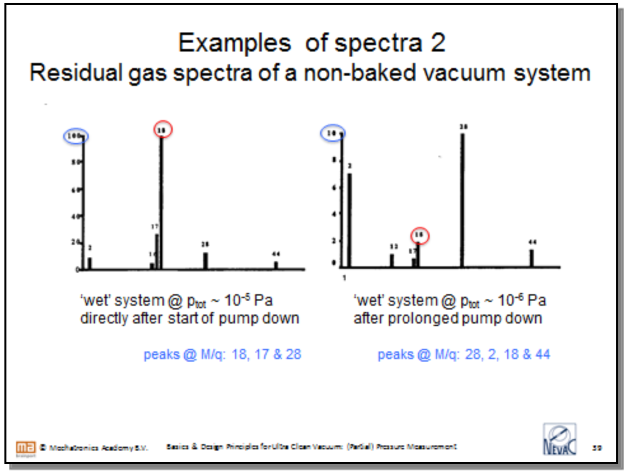
Working principle:
Si-membrane deforms due to pressure differences;
stretch of semiconductor (piezo)resistors affects their resistance;
which is measured in a Wheatstone bridge.

When $V_D = V_B$:

$R_2/R_1 = R_x/R_3$, or

$R_x = R_2.R_3/R_1$ >> $p(R_x)$

Range: 10^3 - 1 mbar
(independent of barometer reading)



Examples of spectra 2
Residual gas spectra of a non-baked vacuum system

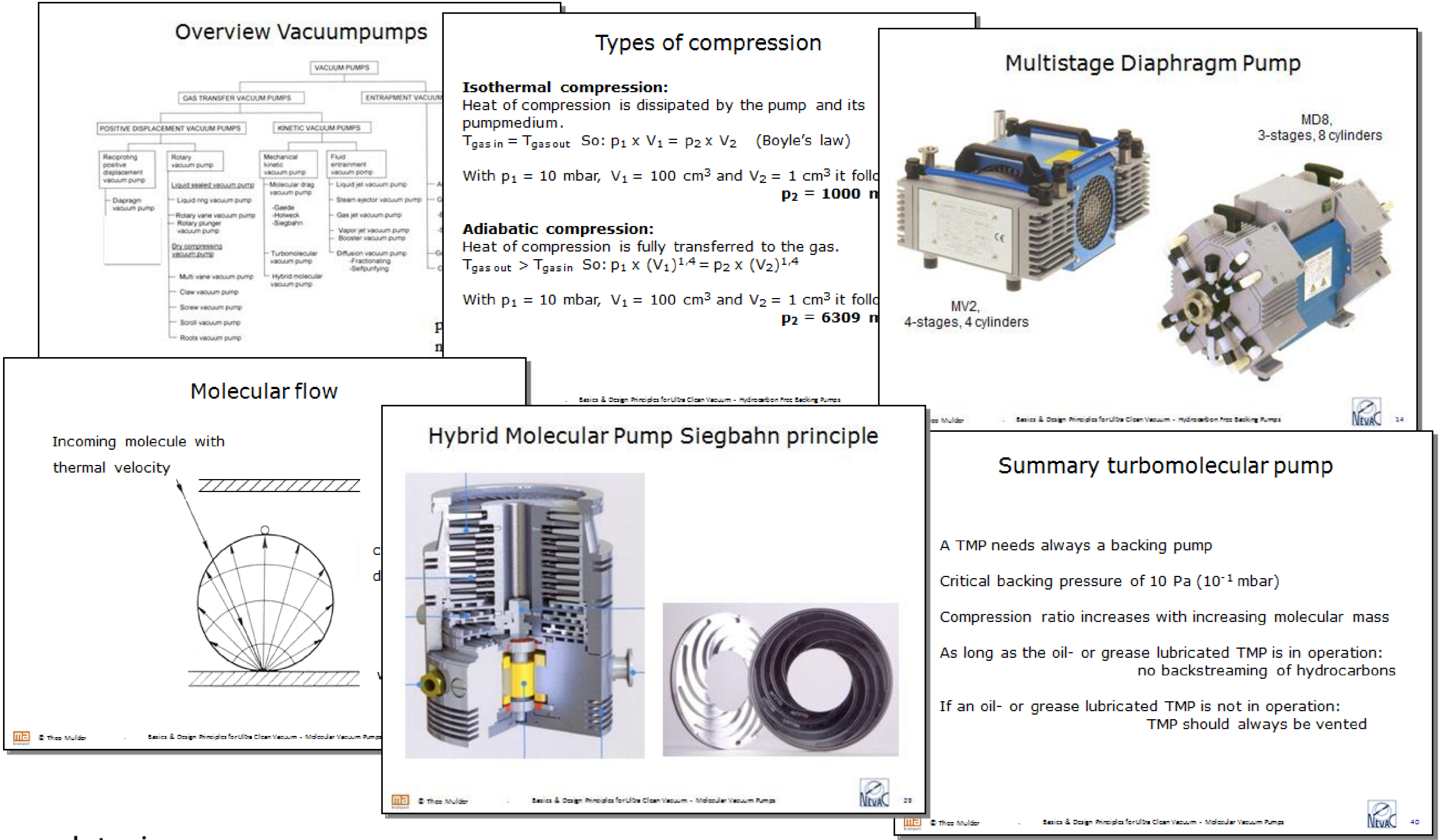
'wet' system @ p_{tot} ~ 10^{-5} Pa
directly after start of pump down

peaks @ M/q: 18, 17 & 28

'wet' system @ p_{tot} ~ 10^{-6} Pa
after prolonged pump down

peaks @ M/q: 28, 2, 18 & 44

Day 2 (morning)



Overview Vacuumpumps

VACUUM PUMPS

GAS TRANSFER VACUUM PUMPS

ENTRAPMENT VACUUM

POSITIVE DISPLACEMENT VACUUM PUMPS

- Reciproting positive displacement vacuum pump
  - Diapragm vacuum pump
- Rotary vacuum pump
  - Liquid sealed vacuum pump
    - Liquid ring vacuum pump
    - Rotary vane vacuum pump
    - Rotary plunger vacuum pump
  - Dry compressing vacuum pump
    - Multi vane vacuum pump
    - Claw vacuum pump
    - Screw vacuum pump
    - Scroll vacuum pump
    - Roots vacuum pump

KINETIC VACUUM PUMPS

- Mechanical kinetic vacuum pump
  - Molecular drag vacuum pump
    - -Gaede
    - -Holweck
    - -Siegbahn
  - Turbomolecular vacuum pump
  - Hybrid molecular vacuum pump
- Fluid entrainment vacuum pomp
  - Liquid jet vacuum pump
  - Steam ejector vacuum pump
  - Gas jet vacuum pump
  - Vapor jet vacuum pump
  - Booster vacuum pump
  - Diffusion vacuum pump
    - -Fractionating
    - -Selfpurifying

Types of compression

Isothermal compression:
Heat of compression is dissipated by the pump and its pumpmedium.
$T_{gas\ in} = T_{gas\ out}$ So: $p_1 \times V_1 = p_2 \times V_2$ (Boyle's law)

With p_1 = 10 mbar, V_1 = 100 cm^3 and V_2 = 1 cm^3 it follo
p_2 = 1000 m

Adiabatic compression:
Heat of compression is fully transferred to the gas.
$T_{gas\ out} > T_{gas\ in}$ So: $p_1 \times (V_1)^{1,4} = p_2 \times (V_2)^{1,4}$

With p_1 = 10 mbar, V_1 = 100 cm^3 and V_2 = 1 cm^3 it follo
p_2 = 6309 m

Basics & Design Principles for Ultra Clean Vacuum - Hydrocarbon Free Backing Pumps

Multistage Diaphragm Pump

MD8,
3-stages, 8 cylinders

MV2,
4-stages, 4 cylinders

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Molecular flow

Incoming molecule with
thermal velocity

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Hybrid Molecular Pump Siegbahn principle

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Summary turbomolecular pump

A TMP needs always a backing pump

Critical backing pressure of 10 Pa (10^{-1} mbar)

Compression ratio increases with increasing molecular mass

As long as the oil- or grease lubricated TMP is in operation:
no backstreaming of hydrocarbons

If an oil- or grease lubricated TMP is not in operation:
TMP should always be vented

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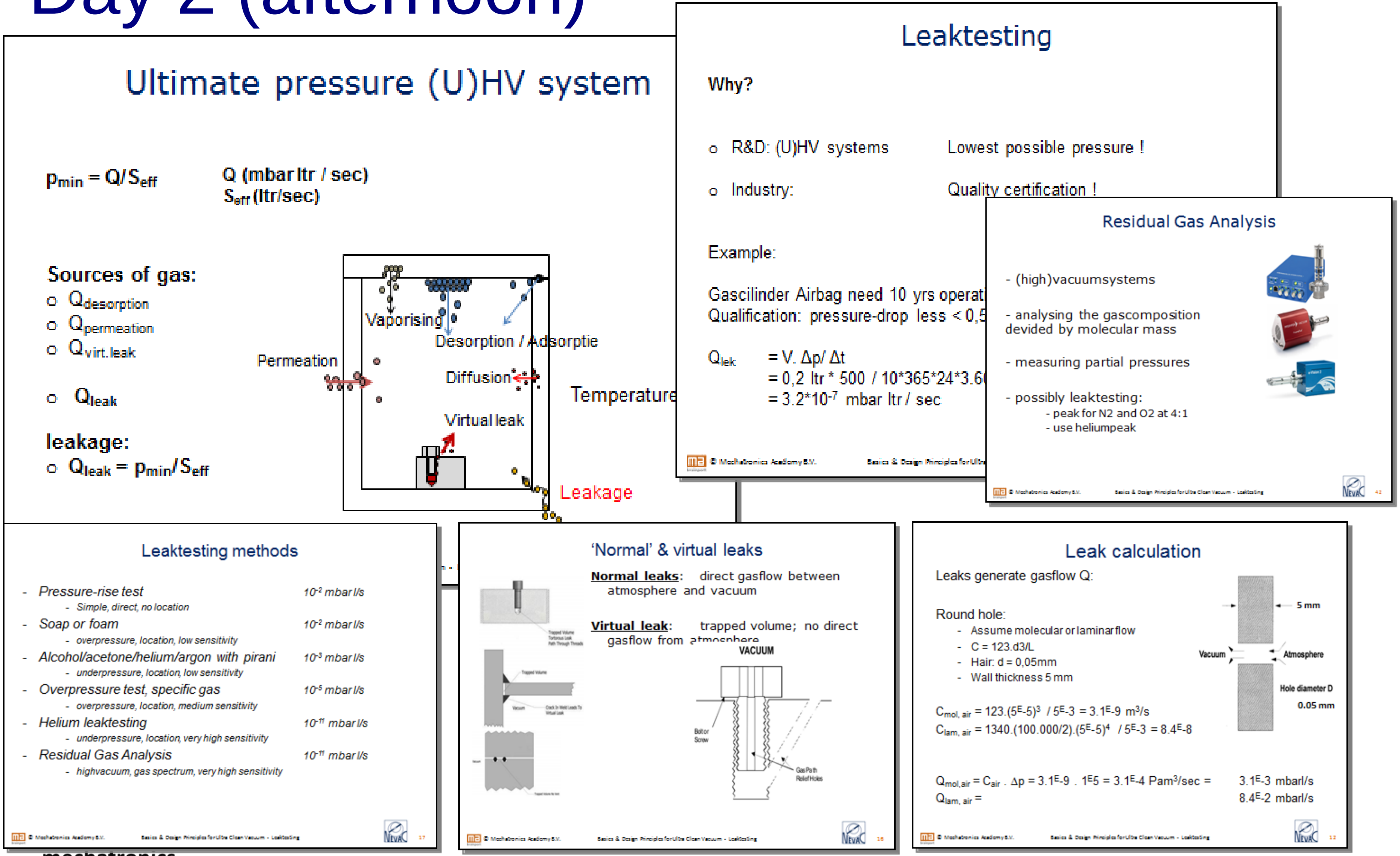
Day 2 (afternoon)



Ultimate pressure (U)HV system

$p_{min} = Q/S_{eff}$

Q (mbar ltr / sec)
S_{eff} (ltr/sec)

Sources of gas:

- ○ $Q_{desorption}$
- ○ $Q_{permeation}$
- ○ $Q_{virt.leak}$
- ○ Q_{leak}

leakage:

- ○ $Q_{leak} = p_{min}/S_{eff}$

Leaktesting

Why?

- ○ R&D: (U)HV systems — Lowest possible pressure !
- ○ Industry: — Quality certification !

Example:

Gascilinder Airbag need 10 yrs operat
Qualification: pressure-drop less < 0,5

Q_{lek} = V. Δp/ Δt
= 0,2 ltr * 500 / 10*365*24*3.6
= 3.2*10^{-7} mbar ltr / sec

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Residual Gas Analysis

- (high)vacuumsystems
- analysing the gascomposition devided by molecular mass
- measuring partial pressures
- possibly leaktesting:
  - peak for N2 and O2 at 4:1
  - use heliumpeak

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Leaktesting methods

- *Pressure-rise test*	*10^{-2} mbar l/s*
- *Simple, direct, no location*	
- *Soap or foam*	*10^{-2} mbar l/s*
- *overpressure, location, low sensitivity*	
- *Alcohol/acetone/helium/argon with pirani*	*10^{-3} mbar l/s*
- *underpressure, location, low sensitivity*	
- *Overpressure test, specific gas*	*10^{-5} mbar l/s*
- *overpressure, location, medium sensitivity*	
- *Helium leaktesting*	*10^{-11} mbar l/s*
- *underpressure, location, very high sensitivity*	
- *Residual Gas Analysis*	*10^{-11} mbar l/s*
- *highvacuum, gas spectrum, very high sensitivity*	

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‘Normal’ & virtual leaks

Normal leaks: direct gasflow between atmosphere and vacuum

Virtual leak: trapped volume; no direct gasflow from atmosphere

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Leak calculation

Leaks generate gasflow Q:

Round hole:

- Assume molecular or laminar flow
- C = 123.d3/L
- Hair: d = 0,05mm
- Wall thickness 5 mm

$C_{mol,\,air}$ = 123.(5E-5)^3 / 5E-3 = 3.1E-9 m^3/s
$C_{lam,\,air}$ = 1340.(100.000/2).(5E-5)^4 / 5E-3 = 8.4E-8

$Q_{mol,air} = C_{air}$. Δp = 3.1E-9 . 1E5 = 3.1E-4 Pam^3/sec = 3.1E-3 mbarl/s
$Q_{lam,\,air}$ = 8.4E-2 mbarl/s

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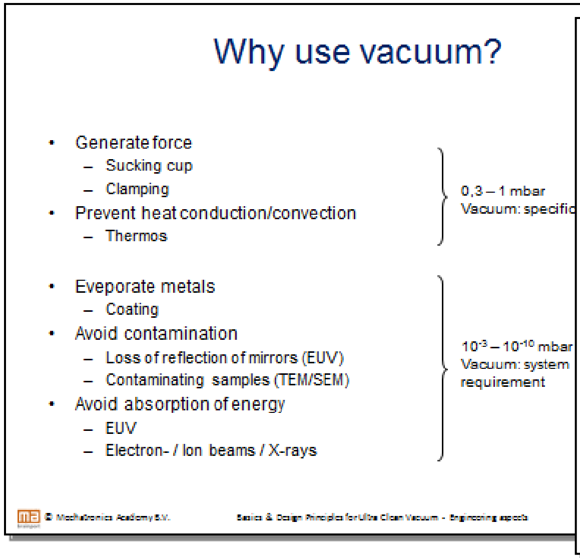
Day 3 (morning)



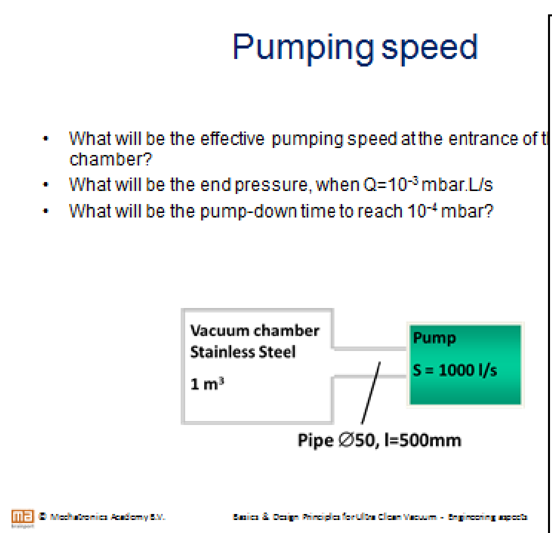
Why use vacuum?

- Generate force
  - Sucking cup
  - Clamping
- Prevent heat conduction/convection
  - Thermos

0,3 – 1 mbar
Vacuum: specific

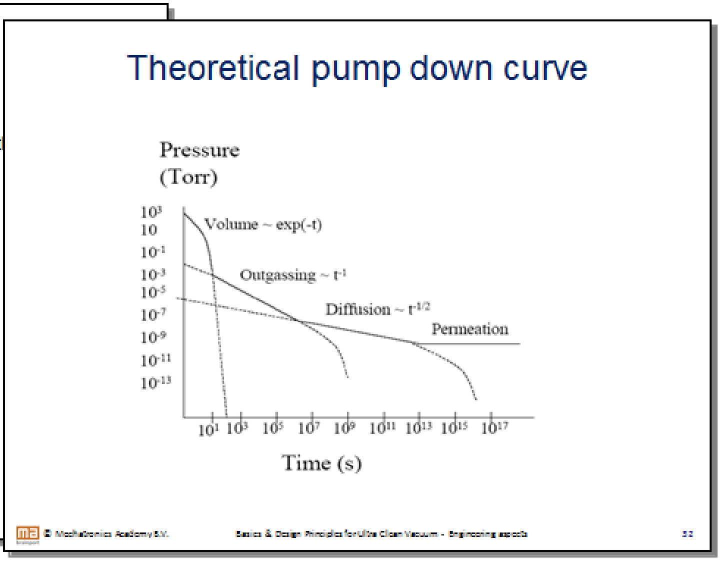
- Eveporate metals
  - Coating
- Avoid contamination
  - Loss of reflection of mirrors (EUV)
  - Contaminating samples (TEM/SEM)
- Avoid absorption of energy
  - EUV
  - Electron- / Ion beams / X-rays

$10^{-3} – 10^{-10}$ mbar
Vacuum: system requirement

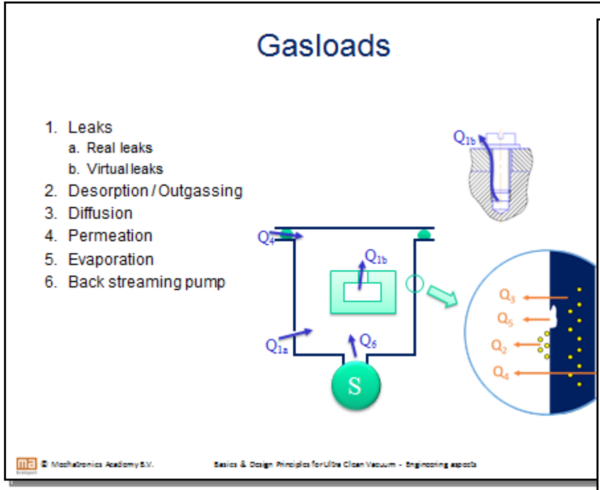


Pumping speed

- What will be the effective pumping speed at the entrance of t chamber?
- What will be the end pressure, when Q=10^{-3} mbar.L/s
- What will be the pump-down time to reach 10^{-4} mbar?

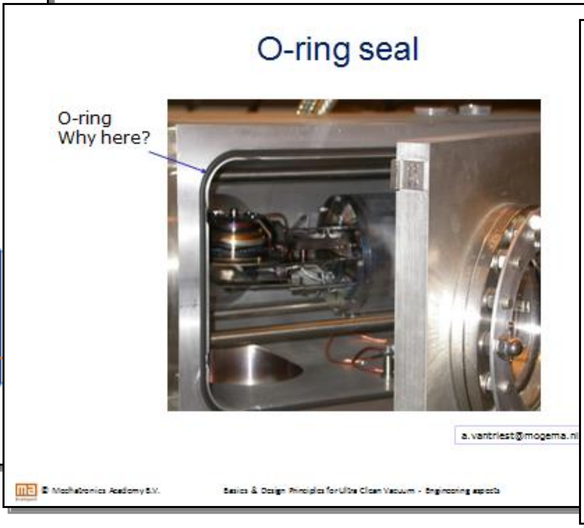


Theoretical pump down curve



Gasloads

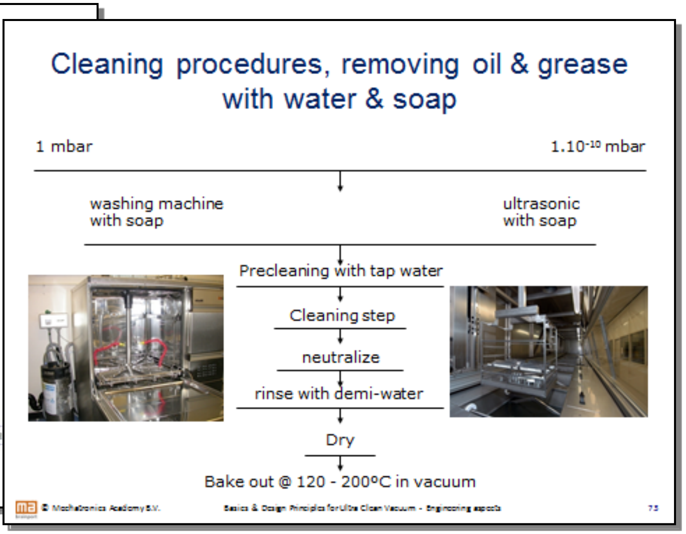
1. Leaks
   a. Real leaks
   b. Virtual leaks
2. Desorption / Outgassing
3. Diffusion
4. Permeation
5. Evaporation
6. Back streaming pump



O-ring seal

O-ring
Why here?

a.vantriest@mogema.nl



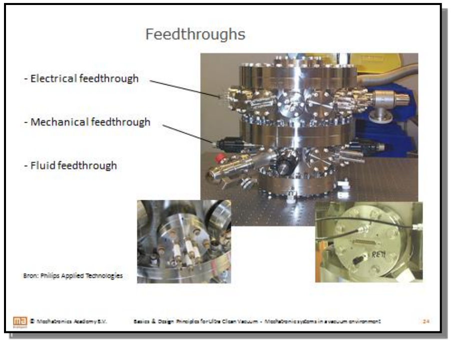
Cleaning procedures, removing oil & grease with water & soap

1 mbar
1.10^{-10} mbar

washing machine with soap
ultrasonic with soap

Precleaning with tap water
Cleaning step
neutralize
rinse with demi-water
Dry
Bake out @ 120 - 200ºC in vacuum

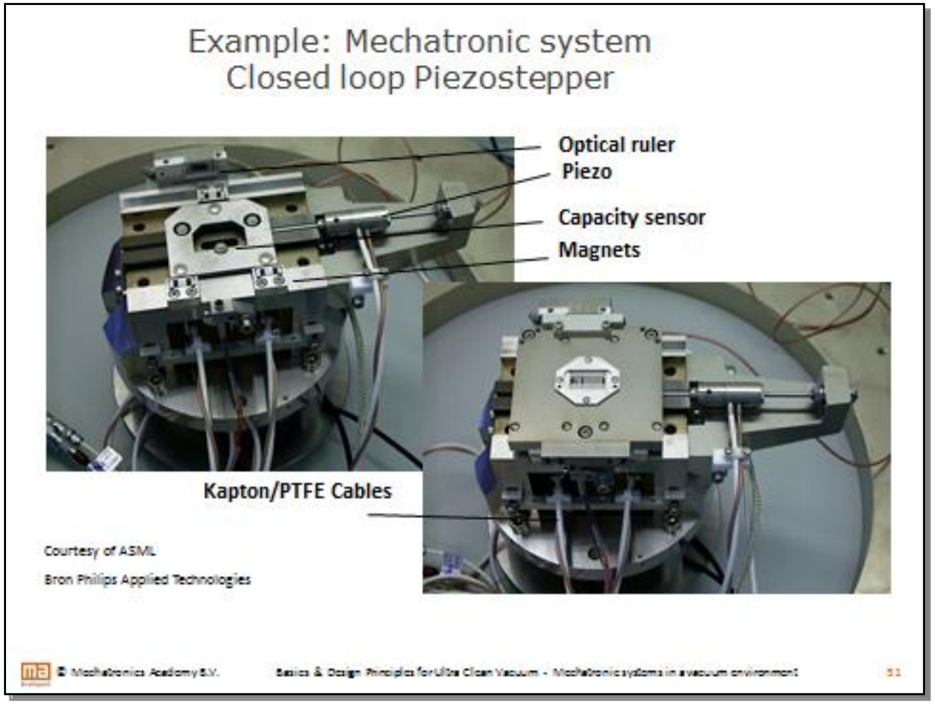
Day 3 (afternoon)



Feedthroughs

- Electrical feedthrough
- Mechanical feedthrough
- Fluid feedthrough

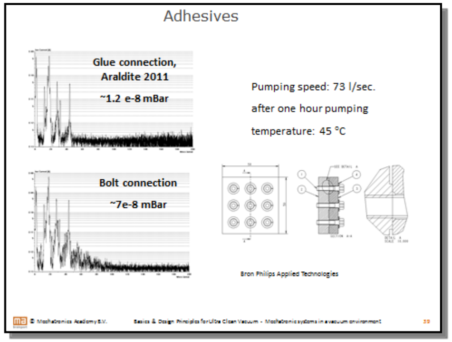
Bron: Philips Applied Technologies



Example: Mechatronic system Closed loop Piezostepper

Courtesy of ASML

Bron Philips Applied Technologies



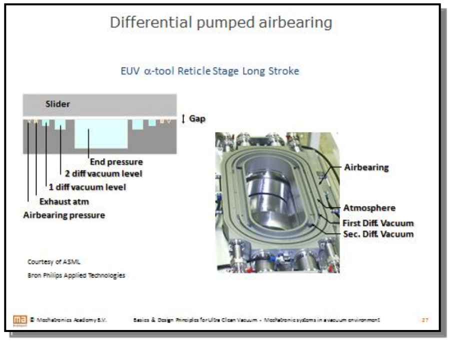
Adhesives

Pumping speed: 73 l/sec.

after one hour pumping

temperature: 45 °C

Bron Philips Applied Technologies

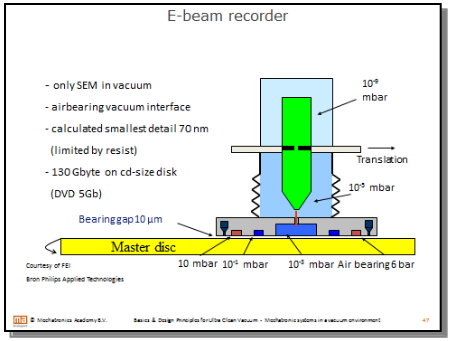


Differential pumped airbearing

EUV α-tool Reticle Stage Long Stroke

Courtesy of ASML

Bron Philips Applied Technologies

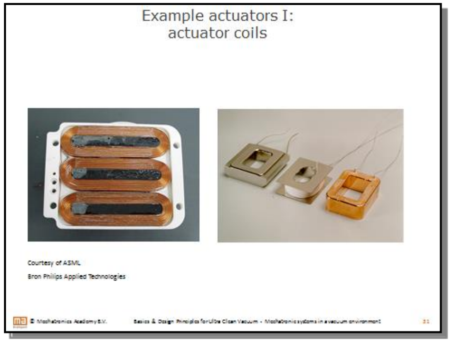


E-beam recorder

- only SEM in vacuum
- airbearing vacuum interface
- calculated smallest detail 70 nm (limited by resist)
- 130 Gbyte on cd-size disk (DVD 5Gb)

Courtesy of FEI

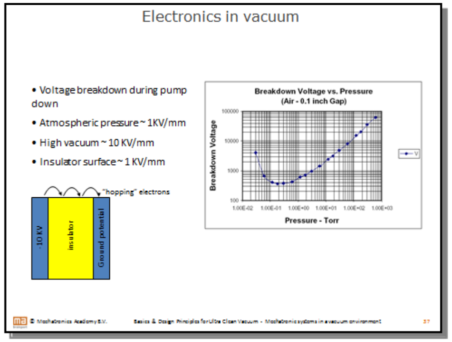
Bron Philips Applied Technologies



Example actuators I: actuator coils

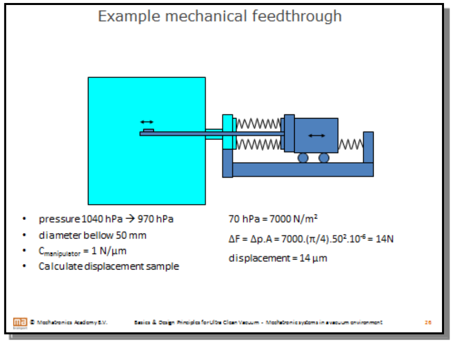
Courtesy of ASML

Bron Philips Applied Technologies



Electronics in vacuum

- Voltage breakdown during pump down
- Atmospheric pressure ~ 1KV/mm
- High vacuum ~ 10 KV/mm
- Insulator surface ~ 1 KV/mm



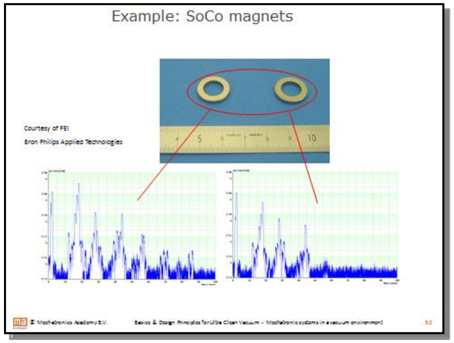
Example mechanical feedthrough

- pressure 1040 hPa → 970 hPa
- diameter bellow 50 mm
- $C_{manipulator} = 1\ N/\mu m$
- Calculate displacement sample

70 hPa = 7000 N/m²

$\Delta F = \Delta p.A = 7000.(\pi/4).50^2.10^{-6} = 14N$

displacement = 14 µm



Example: SoCo magnets

Courtesy of FEI

Bron Philips Applied Technologies

Day 4 (morning)

Qualification

- Medium RGA qualification system Philips Apptech
- Typical application: (sub)assemblies
- Background ≈1% of product specification
  - $p_{H_2O} \approx 10^{-10} mbar$

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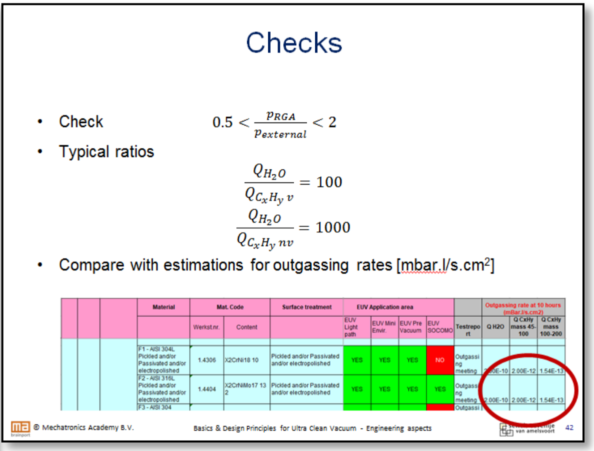

Checks

- Check $0.5 < \frac{p_{RGA}}{p_{external}} < 2$
- Typical ratios

$$\frac{Q_{H_2O}}{Q_{C_xH_y\,v}} = 100$$

$$\frac{Q_{H_2O}}{Q_{C_xH_y\,nv}} = 1000$$

- Compare with estimations for outgassing rates [mbar.l/s.cm^2]

			Material	Mat. Code		Surface treatment	EUV Application area					Outgassing rate at 10 hours (mBar.l/s.cm2)		
				Werkst.nr.	Content		EUV Light path	EUV Mini Envir.	EUV Pre Vacuum	EUV SOCOMO	Testreport	Q H2O	Q CxHy mass 45-100	Q CxHy mass 100-200
			F1 - AISI 304L Pickled and/or Passivated and/or electropolished	1.4306	X2CrNi18 10	Pickled and/or Passivated and/or electropolished	YES	YES	YES	NO	Outgassing meeting	2.00E-10	2.00E-12	1.54E-13
			F2 - AISI 316L Pickled and/or Passivated and/or electropolished	1.4404	X2CrNiMo17 13 2	Pickled and/or Passivated and/or electropolished	YES	YES	YES	YES	Outgassing meeting	2.00E-10	2.00E-12	1.54E-13
			F3 - AISI 304								Outgassi			

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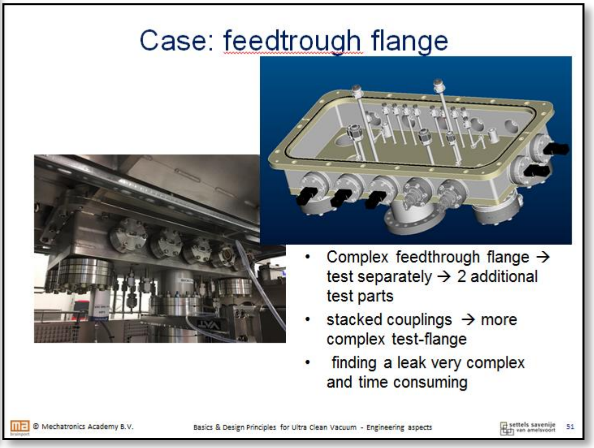

Case: feedtrough flange

- Complex feedthrough flange → test separately → 2 additional test parts
- stacked couplings → more complex test-flange
- finding a leak very complex and time consuming

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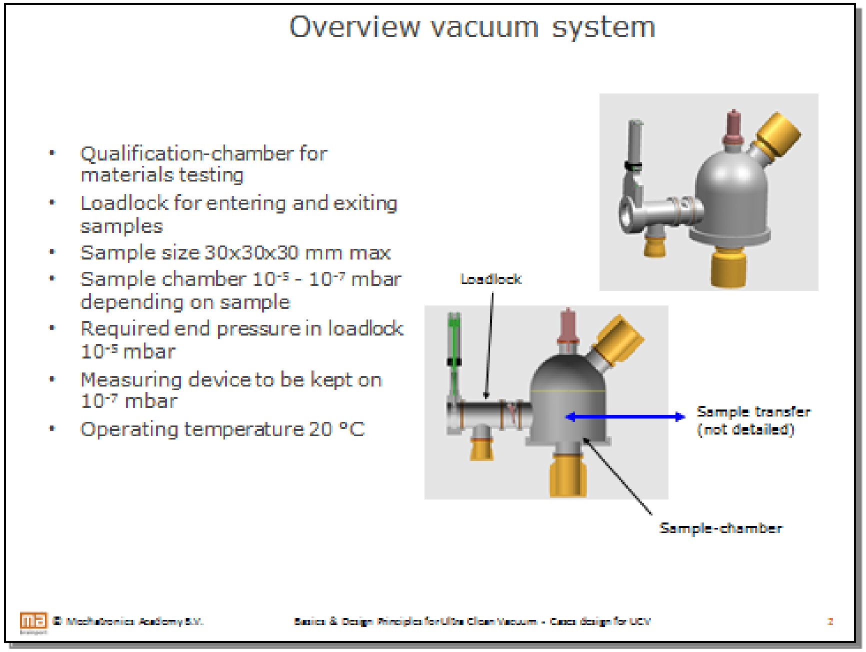
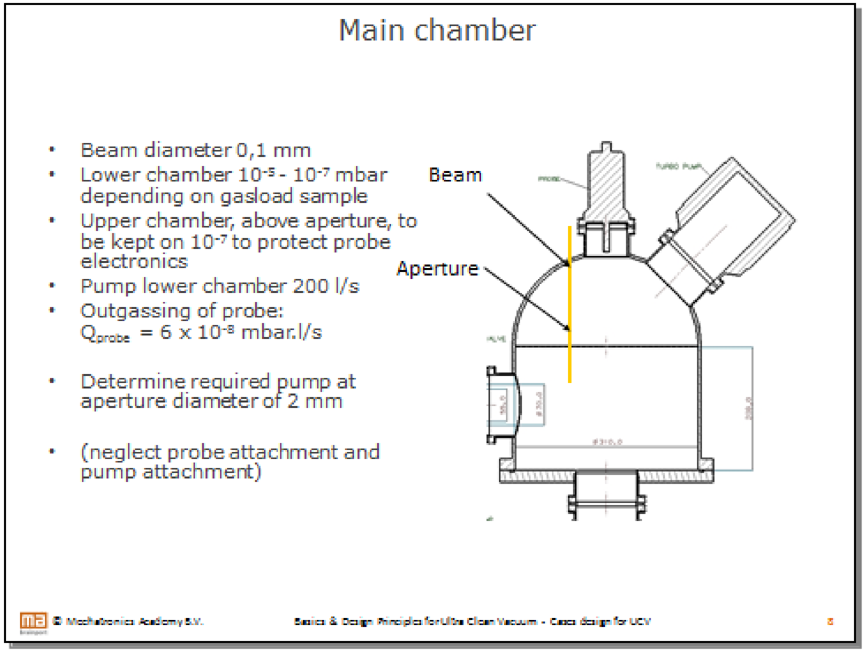
Day 4 (afternoon)



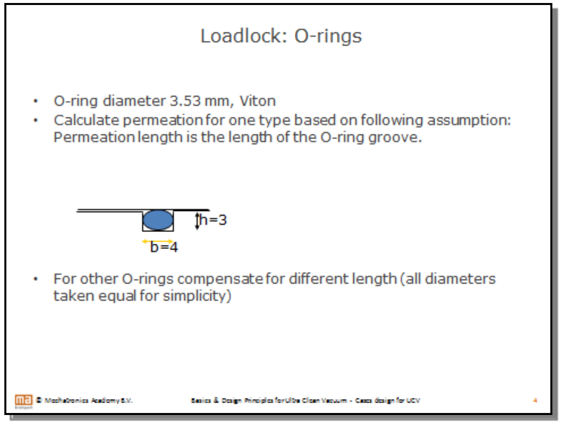
Overview vacuum system

- Qualification-chamber for materials testing
- Loadlock for entering and exiting samples
- Sample size 30x30x30 mm max
- Sample chamber 10^{-5} - 10^{-7} mbar depending on sample
- Required end pressure in loadlock 10^{-5} mbar
- Measuring device to be kept on 10^{-7} mbar
- Operating temperature 20 °C



Main chamber

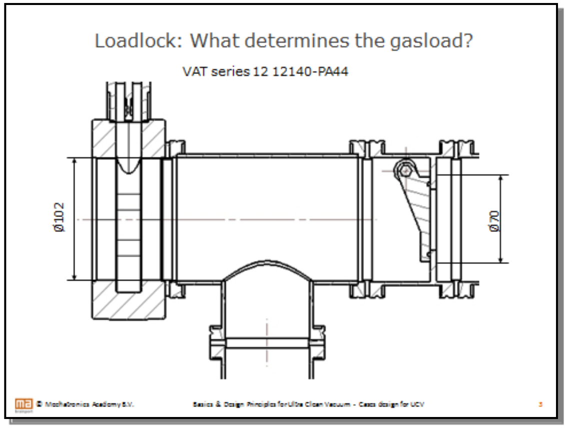
- Beam diameter 0,1 mm
- Lower chamber 10^{-5} - 10^{-7} mbar depending on gasload sample
- Upper chamber, above aperture, to be kept on 10^{-7} to protect probe electronics
- Pump lower chamber 200 l/s
- Outgassing of probe: Q_{probe} = 6 x 10^{-8} mbar.l/s
- Determine required pump at aperture diameter of 2 mm
- (neglect probe attachment and pump attachment)



Loadlock: O-rings

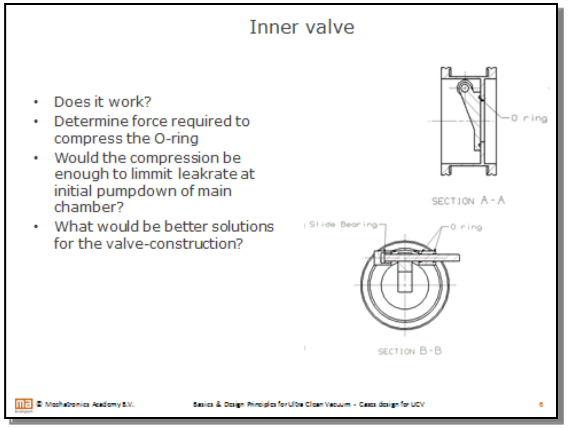
- O-ring diameter 3.53 mm, Viton
- Calculate permeation for one type based on following assumption: Permeation length is the length of the O-ring groove.

- For other O-rings compensate for different length (all diameters taken equal for simplicity)



Loadlock: What determines the gasload?

VAT series 12 12140-PA44



Inner valve

- Does it work?
- Determine force required to compress the O-ring
- Would the compression be enough to limmit leakrate at initial pumpdown of main chamber?
- What would be better solutions for the valve-construction?

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