Process engineering tools (sensor technology

Theory 4:
Process engineering tools (sensor technology)

- thermal resistance measurement
- pressure and vacuum measurement
- barometric pressure measurement
- metric pressure measurement
- wireless temperature measurement (Amphenol)
- conductometry
- camera systems

Thermal resistance measurement (platinum temperature sensor)

Platinum temperature sensors use the effect of temperature dependence of the electric resistance of the precious metal platinum. The resistance increases at higher temperatures, it is a positive temperature coefficient, such sensors are named PTC (positive temperature coefficient).

Abbildung 6: Temperatursensorproduktion unter Reinraumbedingungen

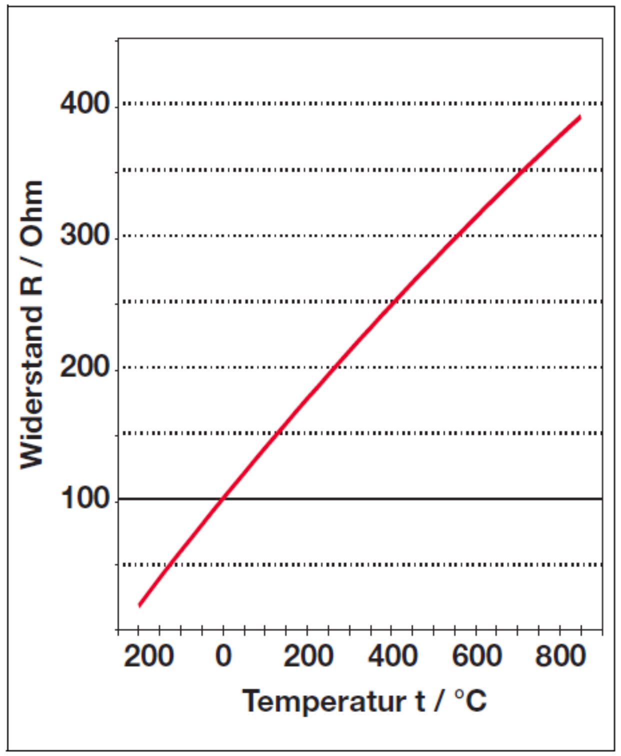


Abbildung 1: Pt100-Kennlinie

Process engineering tools (sensor technology)

Thermal resistance measurement (platinum temperature sensor)

Besides the “standard” PT100 there are temperature sensors with higher nominal values for instance PT500, PT1000.

They have a higher sensitivity, because the increase factor of characteristic curve is directly proportional to the par value R_0.

Their advantage is a larger variation of their resistance depending on the temperature.

Resistance changes (temperature range up to 100 °C)

- 0,4Ω /K at PT100 temperature sensor
- 2,0Ω /K at PT500 temperature sensor
- 4,0Ω /K at PT1000 temperature sensor

Abbildung 12: Laserabgleich der Platin-Chip-Temperatursensoren

Process engineering tools (sensor technology)

Thermal resistance measurement (platinum temperature sensor)

The long-time behavior is another important factor apart from tolerance of temperature sensors. It is responsible for the compliance of measurement uncertainty. The values listed in the data sheets are guide values. They were determined into an oven with normal atmosphere by temperature sensors.

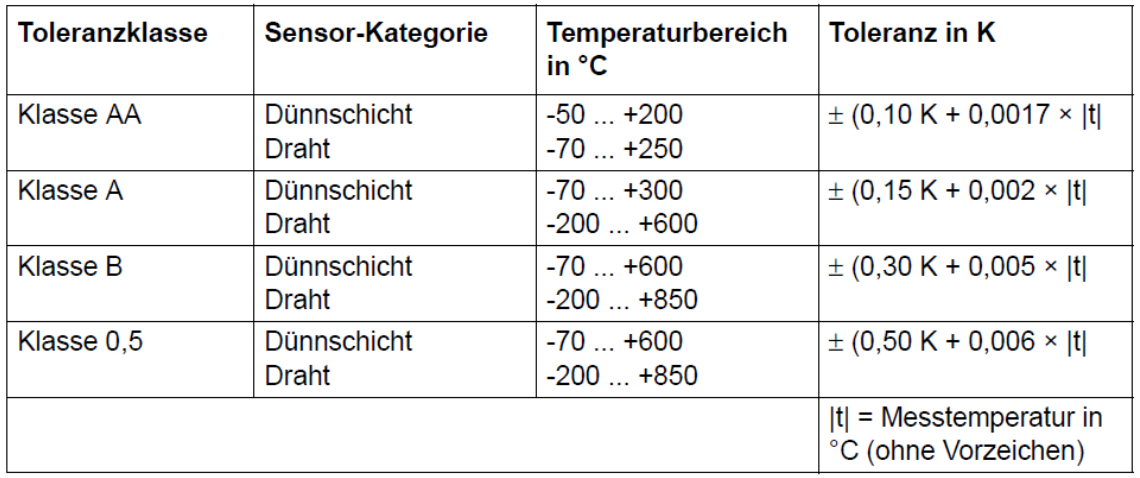
The processing of temperature sensors and the materials with which it comes into contact can influence the long-term stability. In order to determine the long-term stability in each case of the existing construction a regular calibration in their intended conditions of use is necessary.

Abbildung 9: Automatisierte Produktion drahtgewickelter Platin-Glas-Temperatursensoren

Process engineering tools (sensor technology)

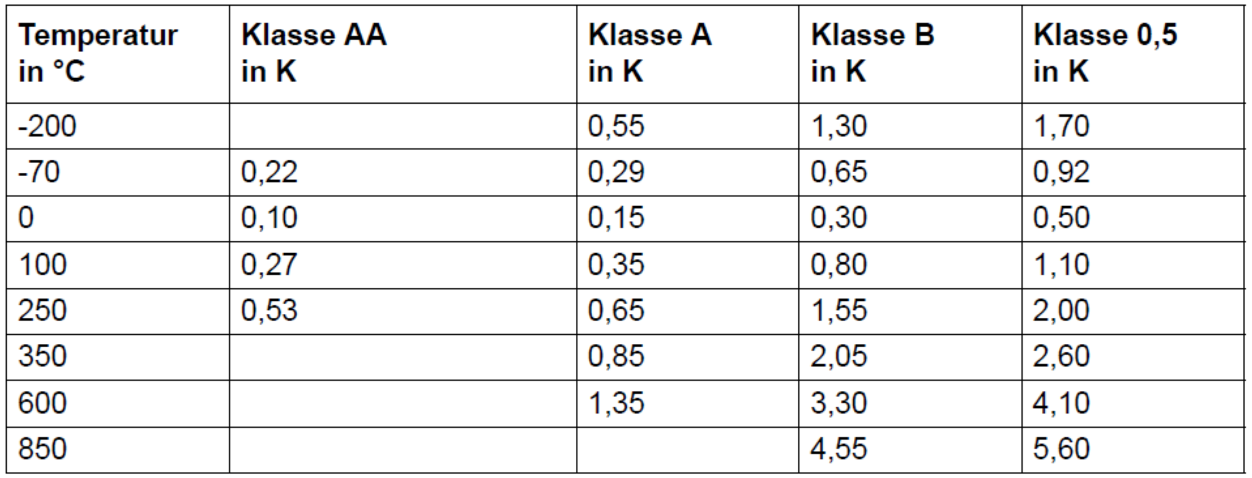
Thermal resistance measurement (platinum temperature sensor)

Tolerance classes



Toleranzklasse	Sensor-Kategorie	Temperaturbereich in °C	Toleranz in K
Klasse AA	Dünnschicht Draht	-50 ... +200 -70 ... +250	± (0,10 K + 0,0017 × |t|
Klasse A	Dünnschicht Draht	-70 ... +300 -200 ... +600	± (0,15 K + 0,002 × |t|
Klasse B	Dünnschicht Draht	-70 ... +600 -200 ... +850	± (0,30 K + 0,005 × |t|
Klasse 0,5	Dünnschicht Draht	-70 ... +600 -200 ... +850	± (0,50 K + 0,006 × |t|
			|t| = Messtemperatur in °C (ohne Vorzeichen)

Tabelle 1: Toleranzklassen - Temperaturgültigkeitsbereich



Temperatur in °C	Klasse AA in K	Klasse A in K	Klasse B in K	Klasse 0,5 in K
-200		0,55	1,30	1,70
-70	0,22	0,29	0,65	0,92
0	0,10	0,15	0,30	0,50
100	0,27	0,35	0,80	1,10
250	0,53	0,65	1,55	2,00
350		0,85	2,05	2,60
600		1,35	3,30	4,10
850			4,55	5,60

Tabelle 2: ±-Toleranz in K je Klasse

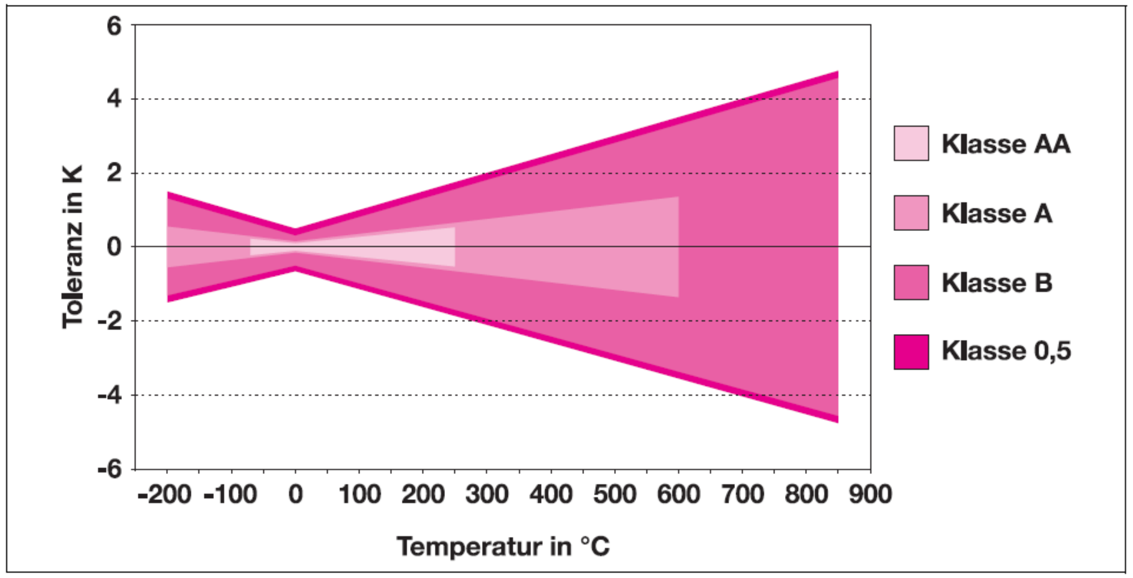


Abbildung 2: Toleranzverlauf in Abhängigkeit von der Temperatur

Process engineering tools (sensor technology)

Thermal resistance measurement (platinum temperature sensor)

Construction PT-sensor

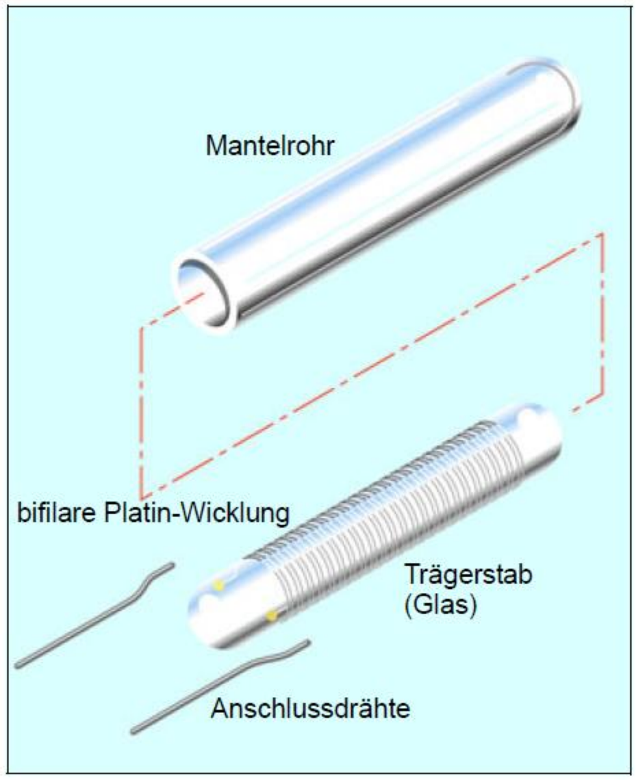


Abbildung 7: Prinzipieller Aufbau von Platin-Glas-Temperatursensoren

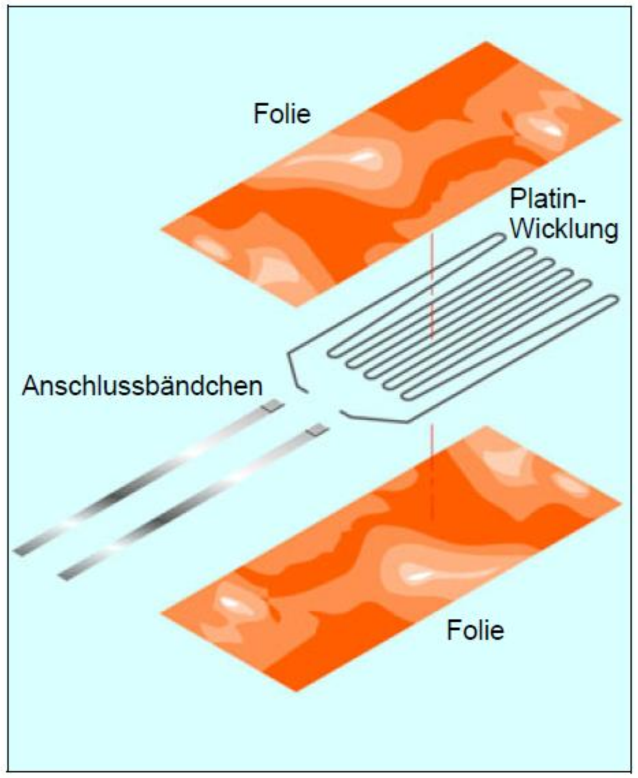


Abbildung 11: Prinzipieller Aufbau von Platin-Folien-Temperatursensoren

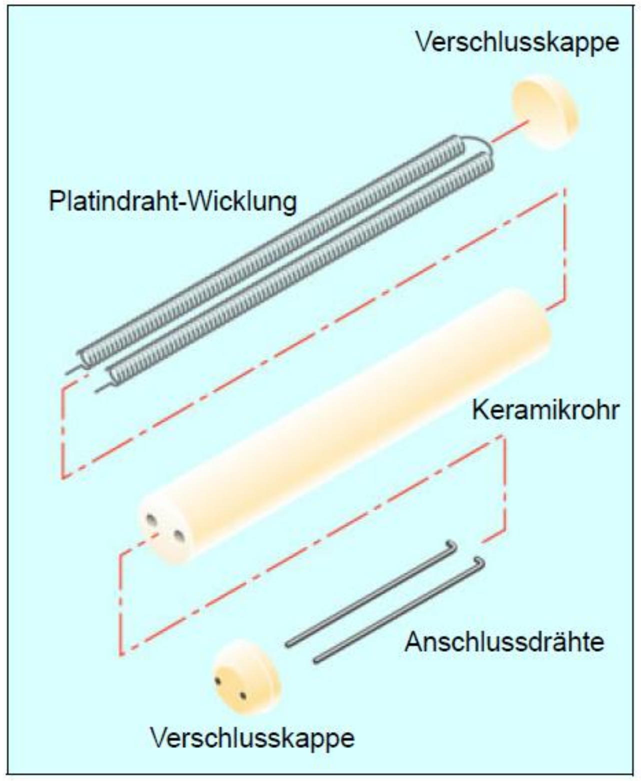


Abbildung 10: Prinzipieller Aufbau von Platin-Keramik-Temperatursensoren

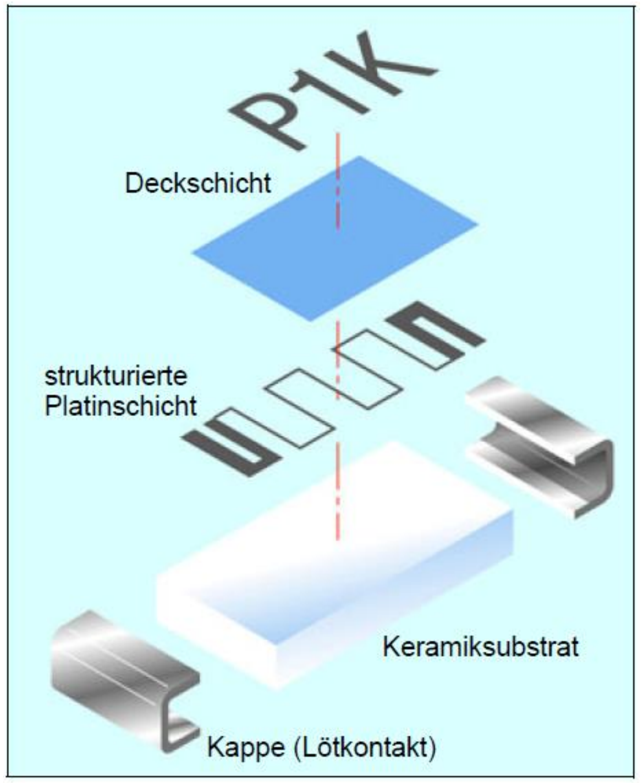


Abbildung 16: Prinzipieller Aufbau von Platin-Chip-Temperatursensoren in SMD-Bauform

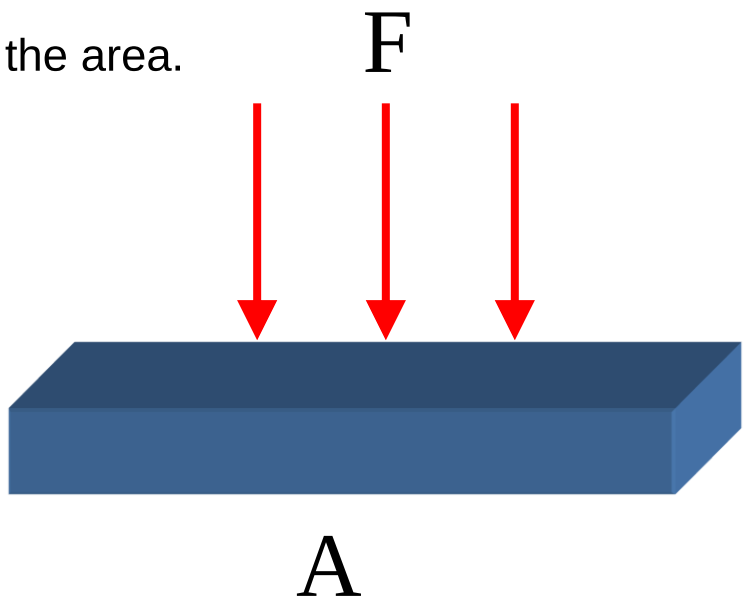
Process engineering tools (sensor technology)

Definition

How is pressure defined?

Pressure p is defined as the **force F** exerted on an **area A** divided by the size of the area.

$$p = \frac{F}{A}$$



Separate technical units of pressure:

newtons per square (*n/m2*), **Pascal** (*Pa*), **bar** (*bar*) und **Pound-Force per square inch** (*Psi*).

Furthermore **outdated units** are still in use: **technical atmosphere** (at) and **physical atmosphere** (atm) and **Torr.**

Each unit can be transferred to another:

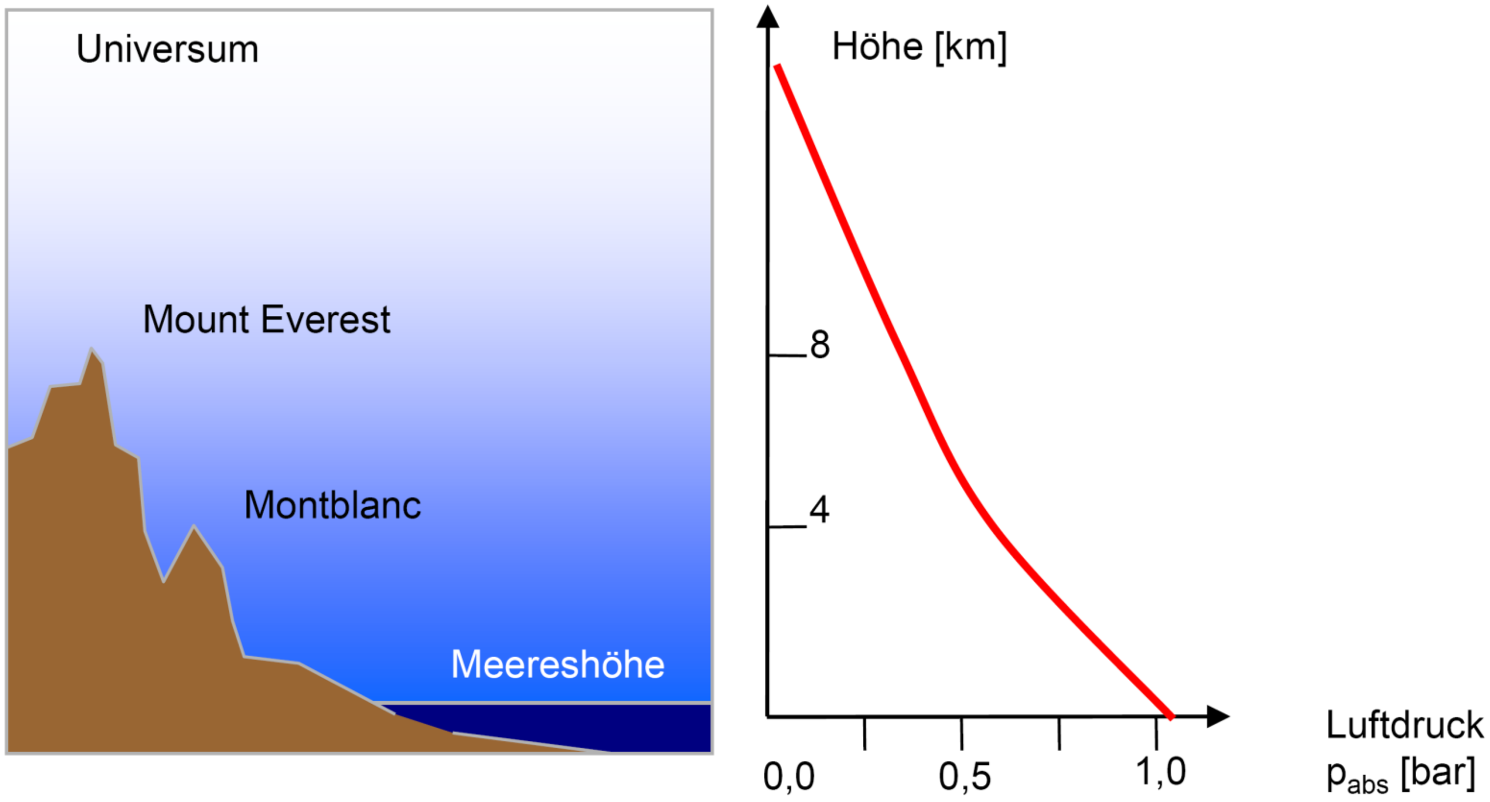
1 bar = 100 000 pa ~ 14,504 psi ~ 1,0197 at ~ 0,98692 atm ~ 750,06 Torr.

Process engineering tools (sensor technology)

Definition

P_{abs}

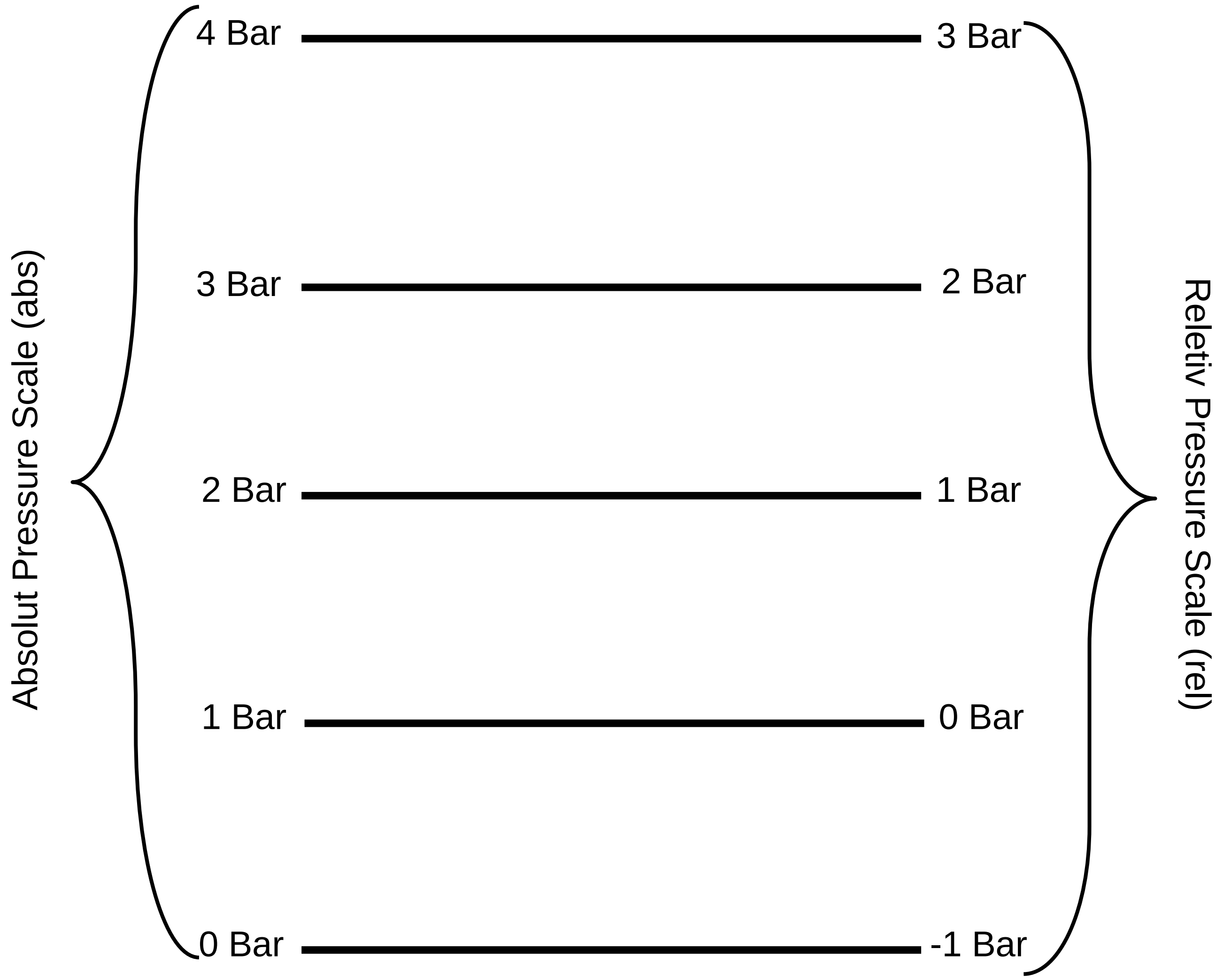
Referenz Pressure (Universe)



The Referenz Pressure will be generaded by Vacuumpumps

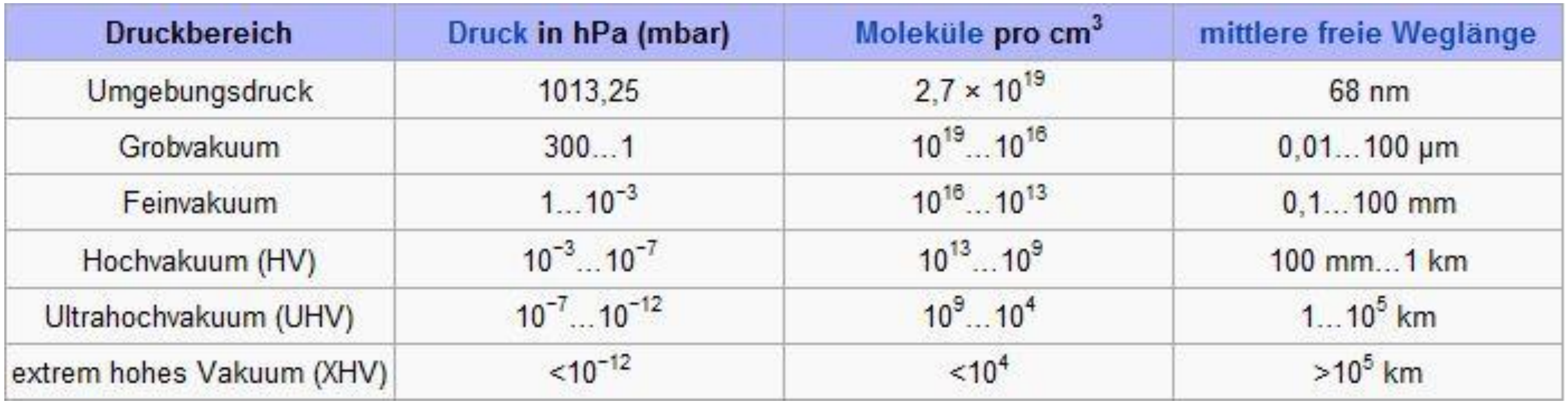
Process engineering tools (sensor technology)

Pressure scale



Absolut Pressure Scale (abs)	Reletiv Pressure Scale (rel)
4 Bar	3 Bar
3 Bar	2 Bar
2 Bar	1 Bar
1 Bar	0 Bar
0 Bar	-1 Bar

Process engineering tools (sensor technology)



Druckbereich	Druck in hPa (mbar)	Moleküle pro cm^3	mittlere freie Weglänge
Umgebungsdruck	1013,25	$2{,}7 \times 10^{19}$	68 nm
Grobvakuum	300…1	$10^{19}…10^{16}$	0,01…100 µm
Feinvakuum	$1…10^{-3}$	$10^{16}…10^{13}$	0,1…100 mm
Hochvakuum (HV)	$10^{-3}…10^{-7}$	$10^{13}…10^{9}$	100 mm…1 km
Ultrahochvakuum (UHV)	$10^{-7}…10^{-12}$	$10^{9}…10^{4}$	$1…10^{5}$ km
extrem hohes Vakuum (XHV)	$<10^{-12}$	$<10^{4}$	$>10^{5}$ km

- rough vacuum: vacuum cleaner (> 0,5 bar)
- fine vacuum: low-pressure gas discharge lamps
- high vacuum: electron tubes, particle accelerator
- ultra-high vacuum: particle accelerator, near-earth space, frequent at equipment in the semiconductor industry
- extremely high vacuum: space, semiconductor industry

Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

One of the most important parameters is the pressure measurement

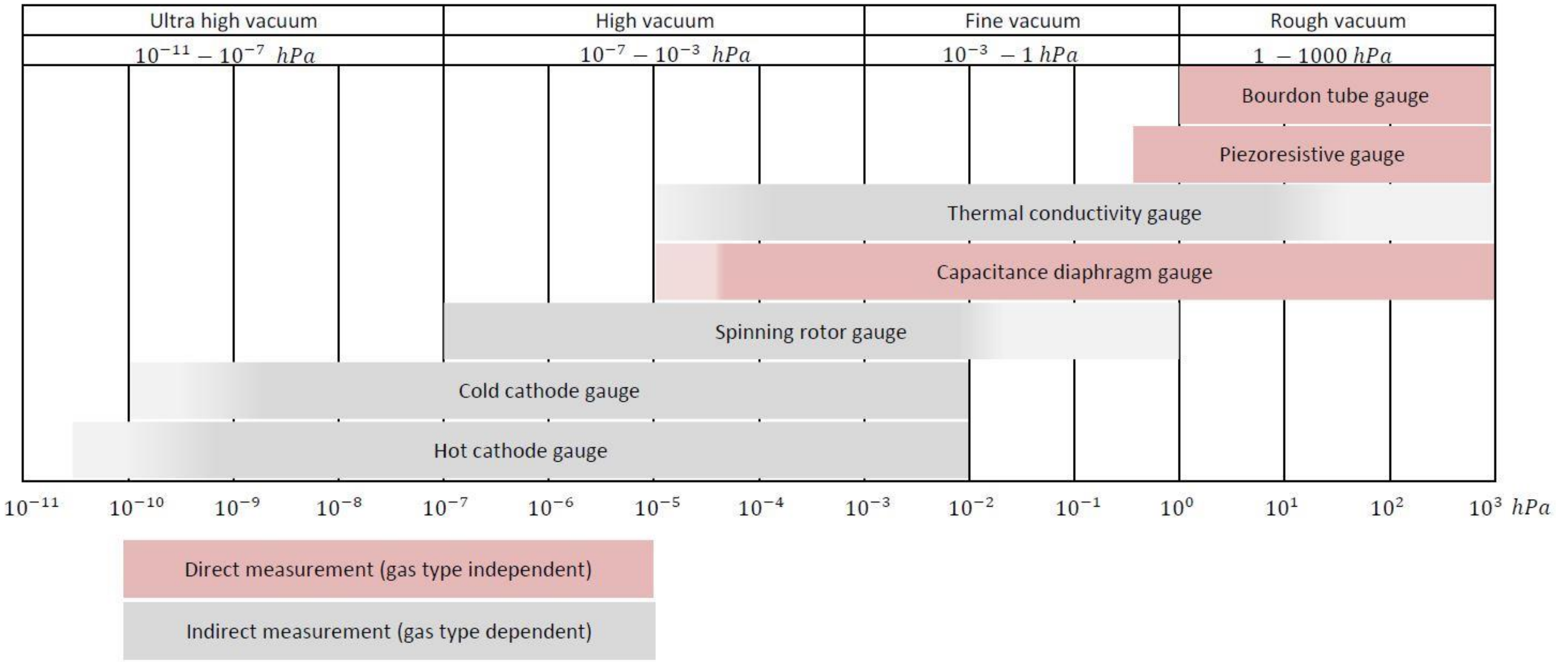
- during a running process the pressure measuring device must have a high accuracy (freeze-drying and sterilisation)
- during a freeze-drying the pressure measurement may be used for comparative pressure measurement (capacitive sensor / Pirani)
- during a sterilisation process the pressure measurement may be used for determining saturated steam conditions

Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

The most common vacuum sensors at freeze-drying are:

- conductive pressure measurement systems (Pirani)
- capacitive pressure measurement systems

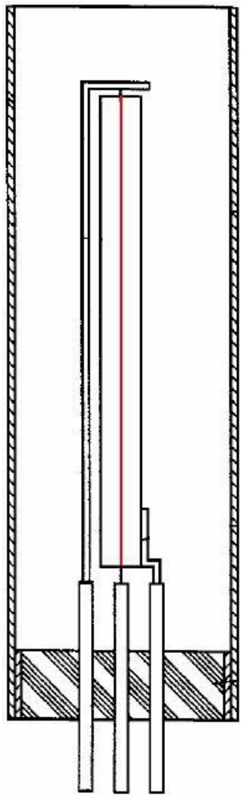


Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

Construction of conductive pressure measurement systems (Pirani)

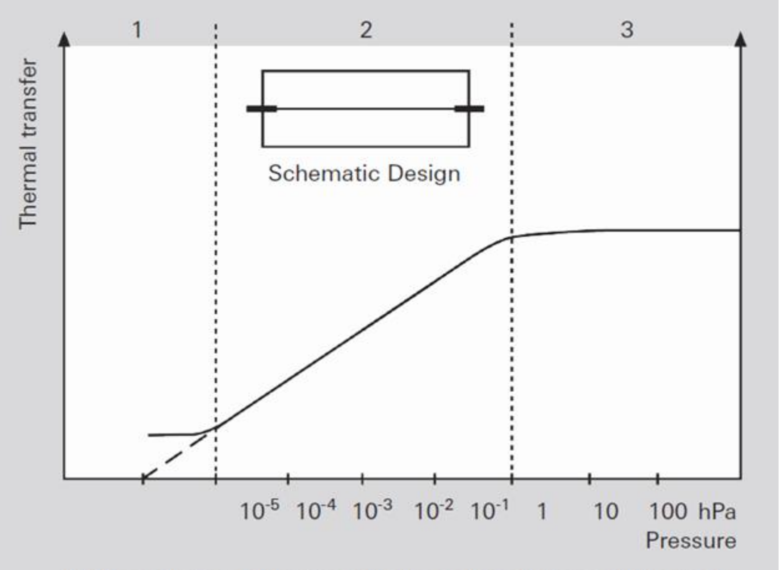
Heat up the wire approximately at a temperature of 110°C to 130°C. The heated wire forms a part of a Wheatstone bridge.



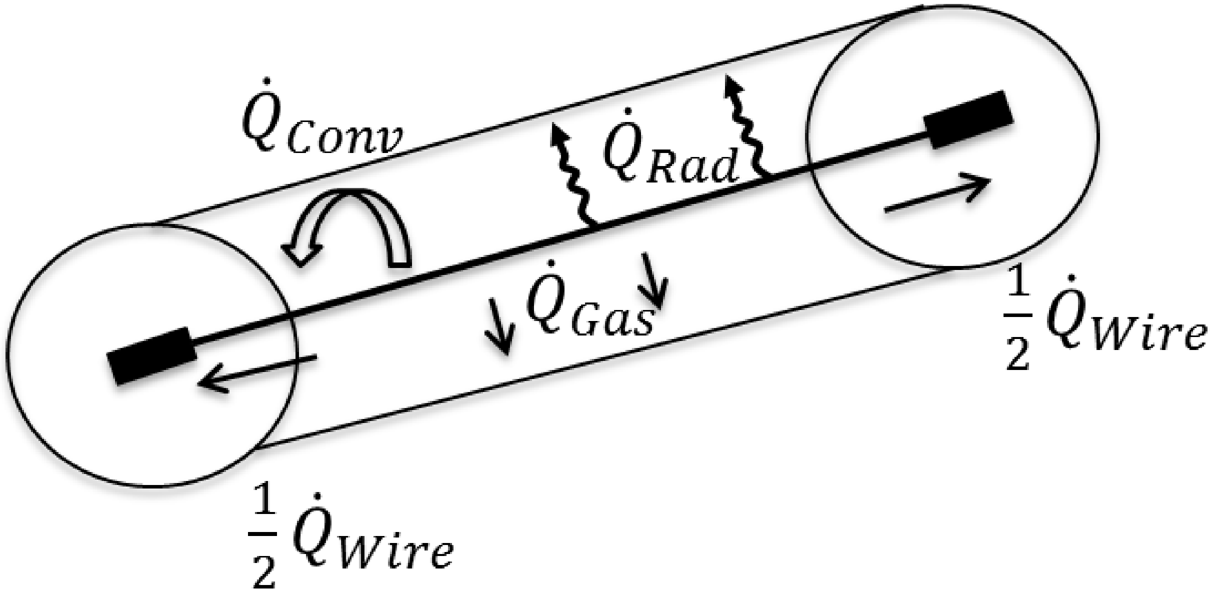
Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

The Pirani sensor works with radiation which changes depending on the available pressure.



1) Thermal transfer to the ends through radiation and thermal conductivity
2) Pressure-dependent thermal transfer through gas
3) Thermal transfer through thermal radiation and convection



Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

Adjustment of Pirani:

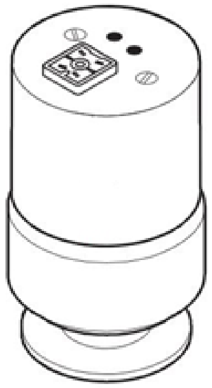
- adjustment of Pirani takes place under real installation conditions
- depending on the age and usage of the Pirani sensor it is necessary to do a zero point calibration (offset)

Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

When using a Pirani you must think about the following:

- vertical installation of the Pirani
- Regular Changing of the Pirani depending on Life Time and Process Turnaround
- depending on the age and usage of the Pirani it is necessary to do a zero point adjustment (offset)
- the accuracy of the Pirani sensor depends on the measured gas

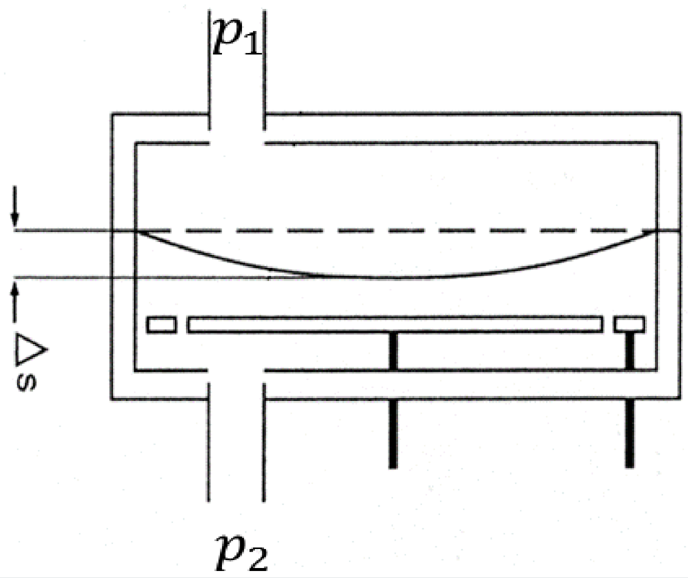


Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

Construction of a capacitive pressure measurement system:

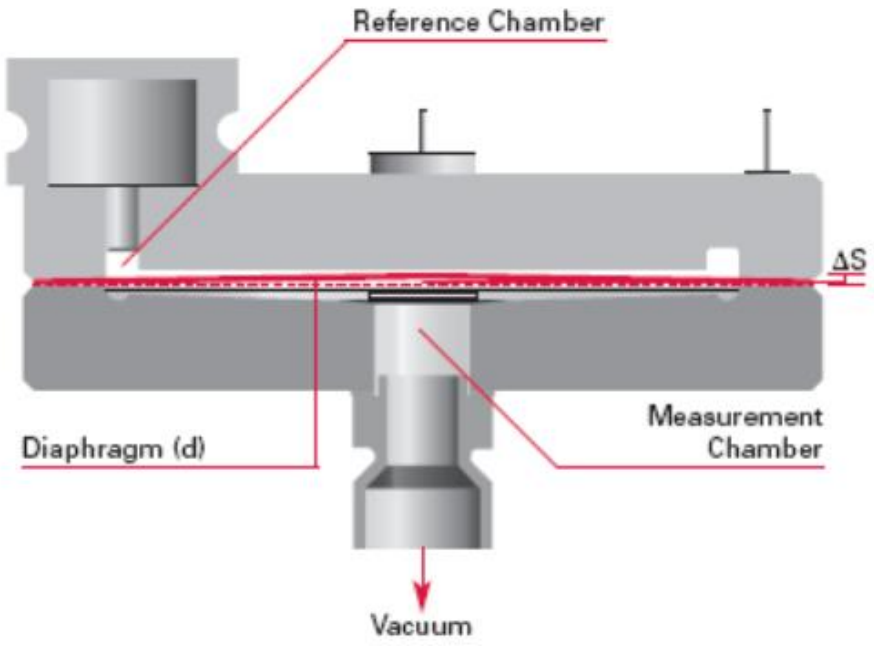
- a capacitive pressure measurement system is independent of the measured gas
- a flexible membrane is mounted inside the Sensor



Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

Construction of a capacitive pressure measurement system:

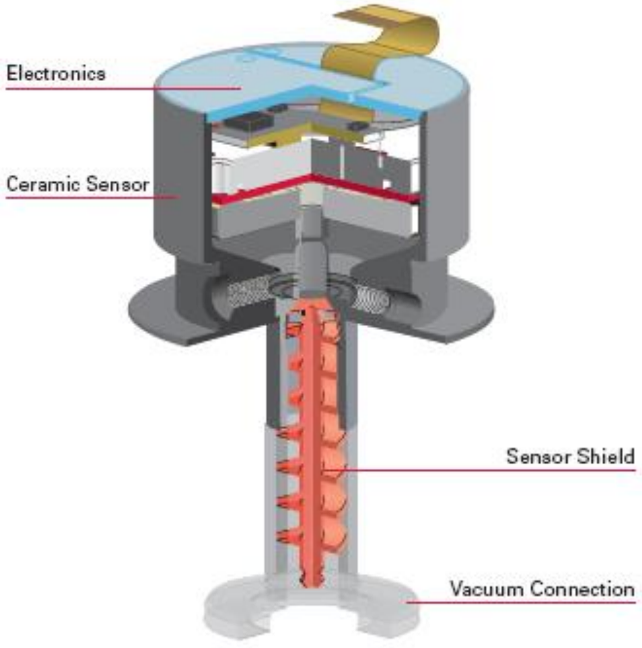


Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

Construction of a capacitive pressure measurement system:

- To avoid a risk of an influence from Temperatures, the capacitive measurement sensors is heated. The temperature of the Sensor is between 45 °C and 200 °C depends on the type of the sensor.
- a freeze dryer which can be sterilized, the capacitive sensors should be heated higher than 150 °C because of the wet sterilisation (Clean Steam).

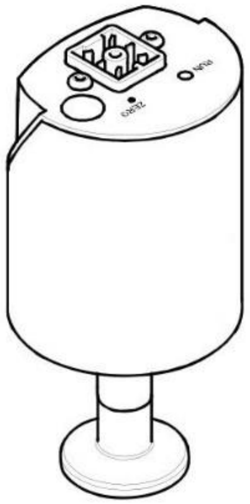


Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

When using a capacitive measurement sensor it should be remembered:

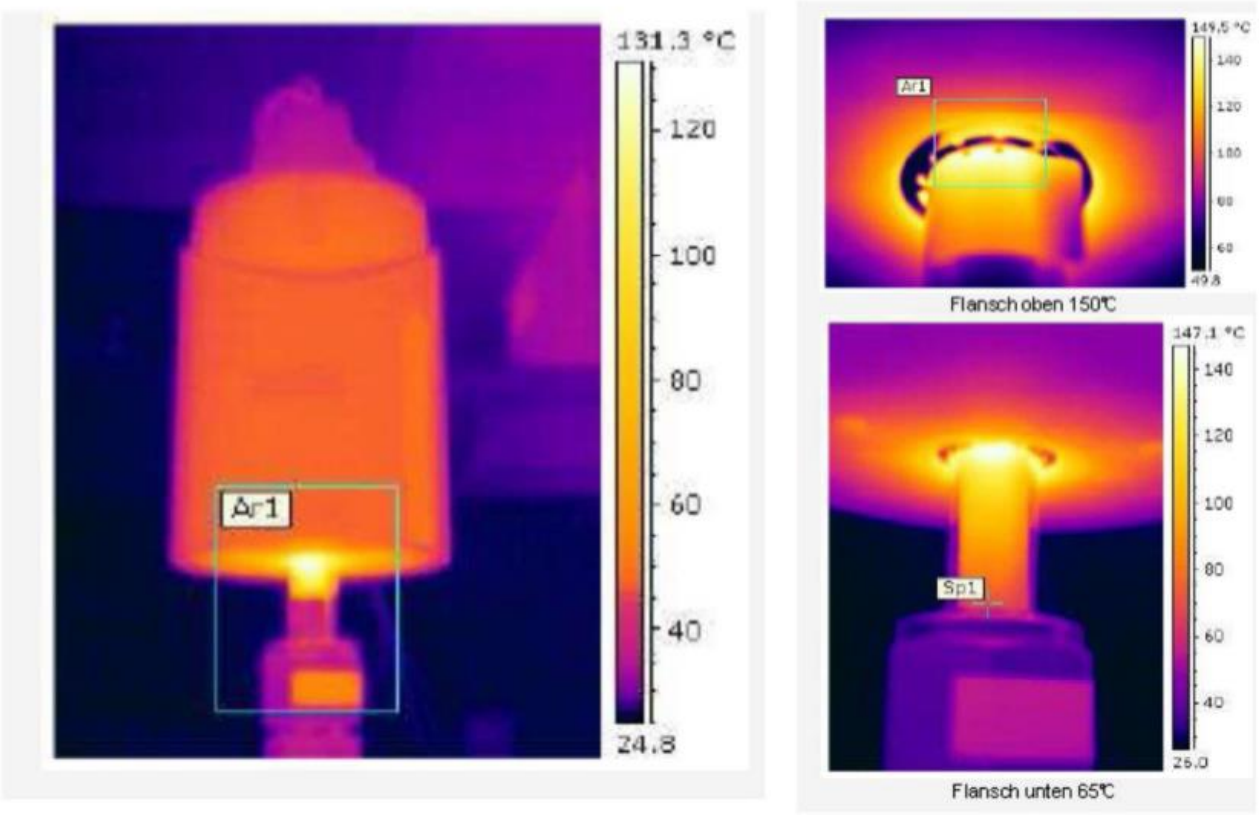
- measurement sensor have a heating up Time (some Sensors around 9h)
- a contaminated membrane have an influence to the accuracy of the Sensor
- Because of the mounted flexible Membrane the installation position is important



Process engineering tools (sensor technology)

Pressure measurement (vacuum and overpressure)

Temperaturverteilung Anschlussrohr der 160°C beheizten CLR 39x



Temperatur in der Nähe der Bodenplatte des Gehäuses: ~ 150°C

Im Inneren der Messröhre sind alle prozessgasführenden Bereiche oberhalb 150°C

Process engineering tools (sensor technology)

Comparative pressure measurement
(Pirani / capacitive pressure measurement)

Pressure measurement

Principle:

pressure measurement for determining the end of main drying

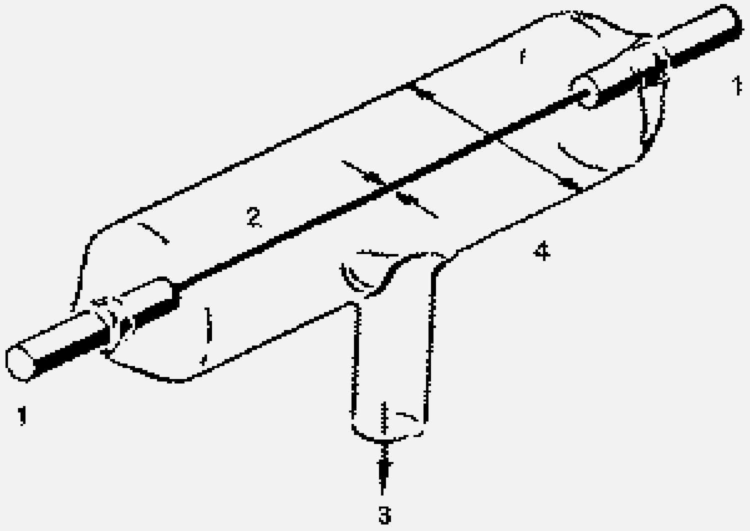
Measurement of camber pressure with

Pirani sensor

based on radiation of heatwire;

depends on the gas inside the Freeze Dryer

Pirani sonde



Process engineering tools (sensor technology)

Comparative pressure measurement
(Pirani / capacitive pressure measurement)

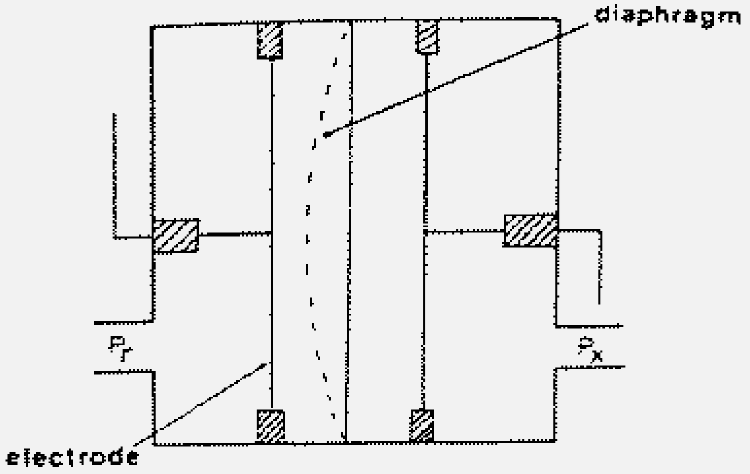
Pressure measurement	capacitive manometer

Measurement of camber pressure with

capacitive sensor

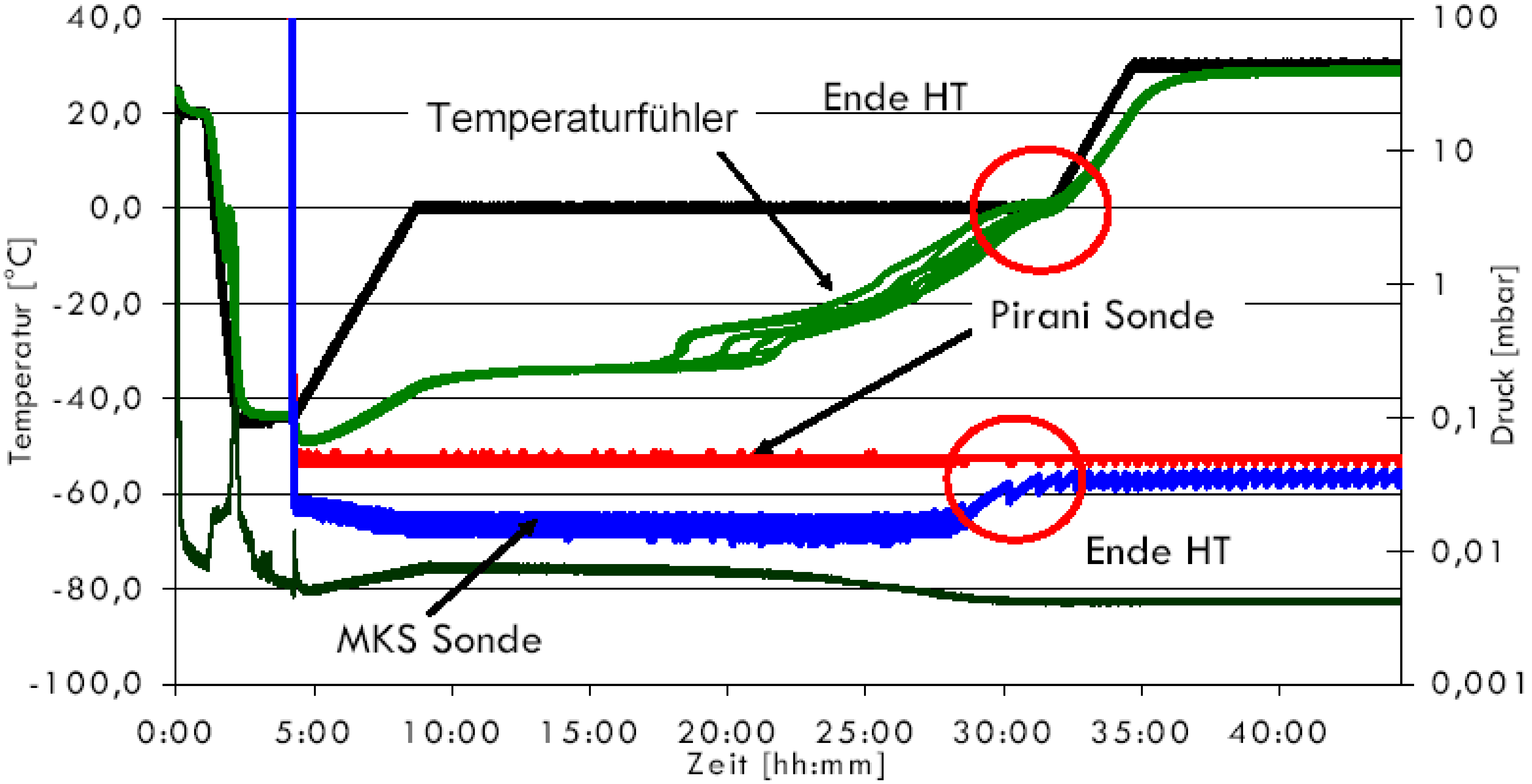
Based on a electrical measurement (Piezo),

independent from gas inside the Freeze Dryer



Process engineering tools (sensor technology)

Comparative pressure measurement
(Pirani / capacitive pressure measurement)



Process engineering tools (sensor technology)

Comparative pressure measurement (Pirani / capacitive pressure measurement)

Comparing pressure measurement

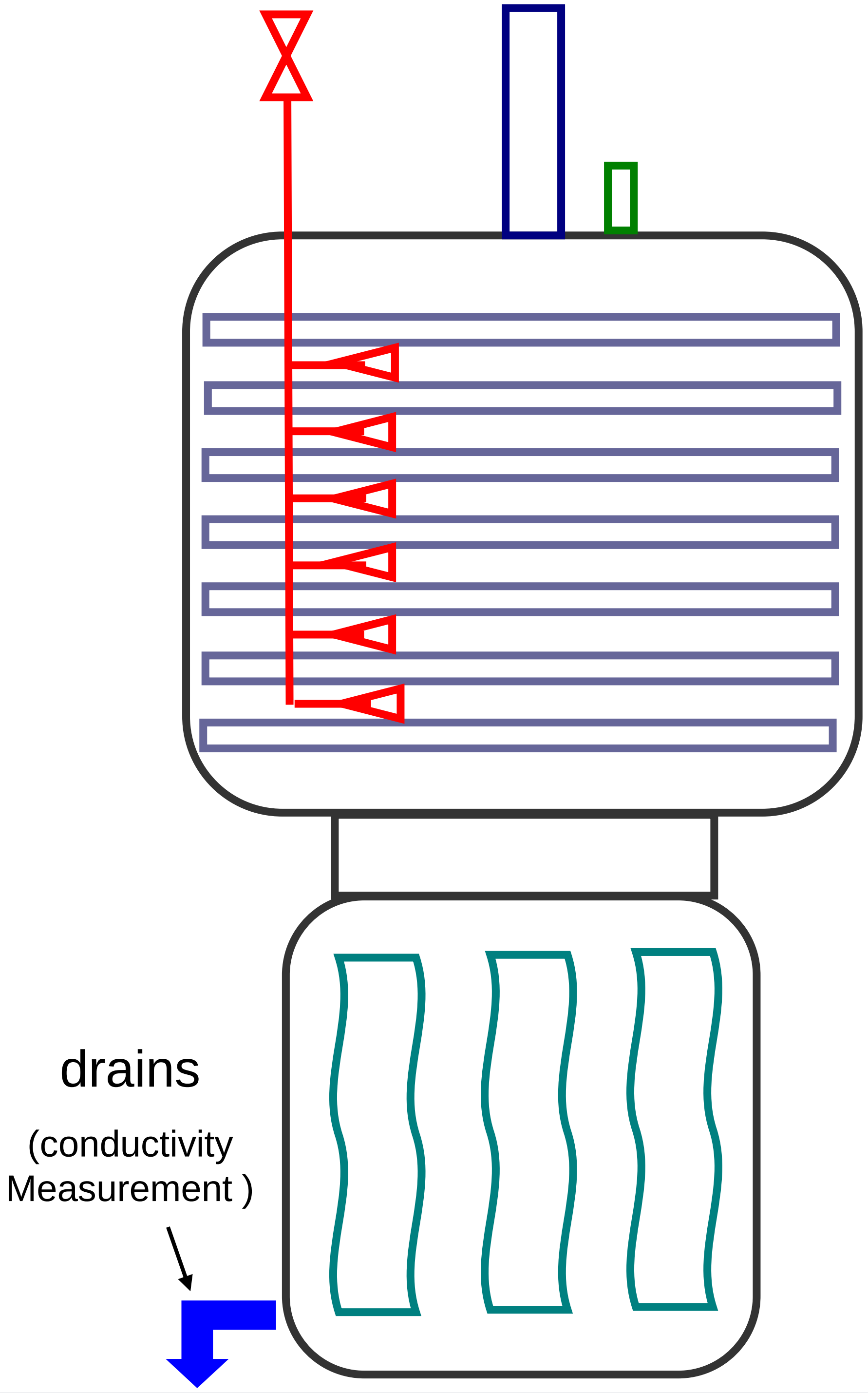
- simultaneous measurement of camber pressure with Pirani and capacitive sensor
- in the beginning the Pirani sensor shows a pressure which is higher than the pressure of the capacitive sensor

(high content of water vapor inside the Freeze Dryer)

- at the end of main drying the measured values of the two sensors approach each other this is an indicator for the end of main drying

(less content of water vapor inside the Freeze Dryer)

Process control tools (sensor technology)



Conductivity Measurement

to check the efficiency of a CIP Cycle a conductivity sensor is usually used.

the conductivity sensor should be fit to the relevant requirements e.g. WFI.

the Sensor should be designed for the expected temperatures of the measuring point (usually the sensor is located inside of the sterile boundary and will be charge with clean steam).

Process control tools (sensor technology)

- the cleaning Media e.g. Concentrate Base or acid are injected with dosing valves into the CIP System. A conductivity sensor is mounted in circulation loops or in the vesele to monitor the dosing of the cleaning Medias.

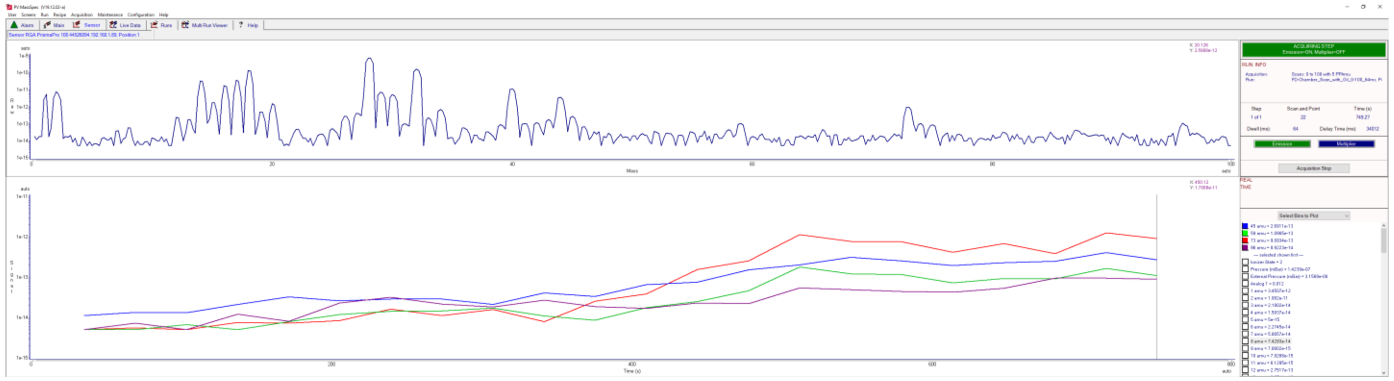
- after a CIP Cycle with cleaning Medias the cleaning Medias must be completely removed from the Freeze Dryer. These include that the complete system must be rinsed with WFI. The rinsing process is monitored a conductivity sensor at drain

Mass Spectrometer

Content of the training:

- Basics mass spectrometer
- Chemical background
- Interpretation of the measurement result

- Hands-On Part



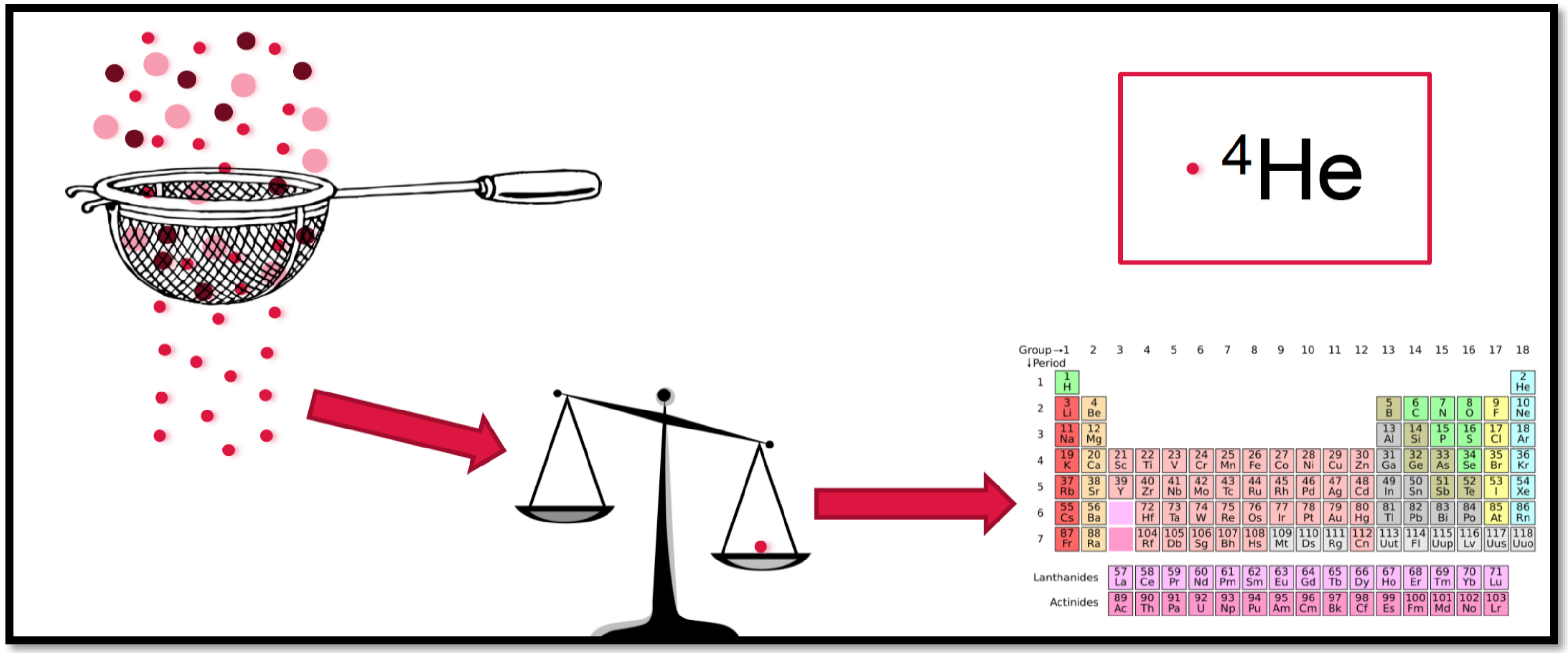
Mass Spectrometer

Applications of mass spectrometry:

- For analysis of chemical products in laboratories
- Process analysis in combustion processes, power plant processes, exhaust gas analysis
- Quality control/Vacuumsystems (outgassing, **leak detection**)
- Surface analysis

Mass Spectrometer

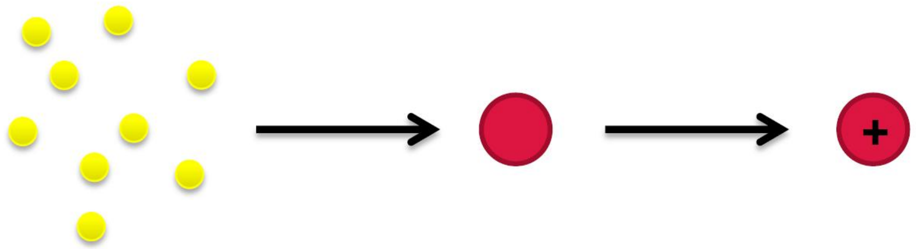
Basic principle of mass spectrometry:



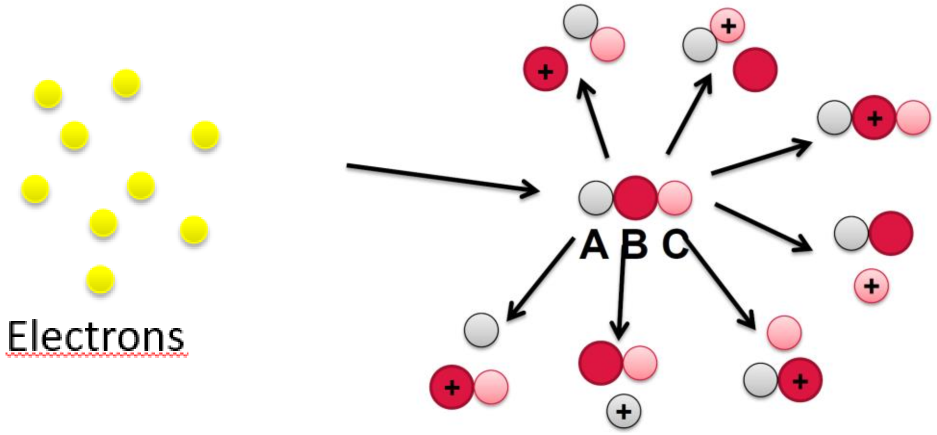
The individual atoms or molecules are separated, the mass/charge ratio is determined and the chemical product is assigned to a specific mass spectrum (fingerprint).

Mass Spectrometer

Ionization of the gases:

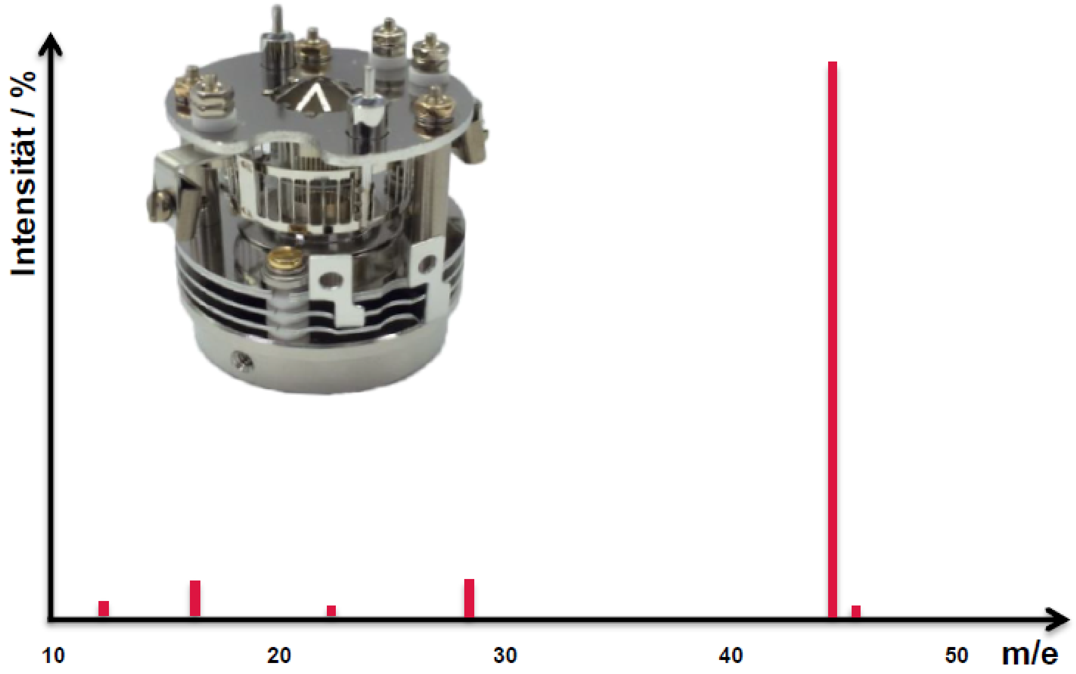


In the ionization process, different fragments are created. Some fragments with high and others with low probability.



Mass Spectrometer

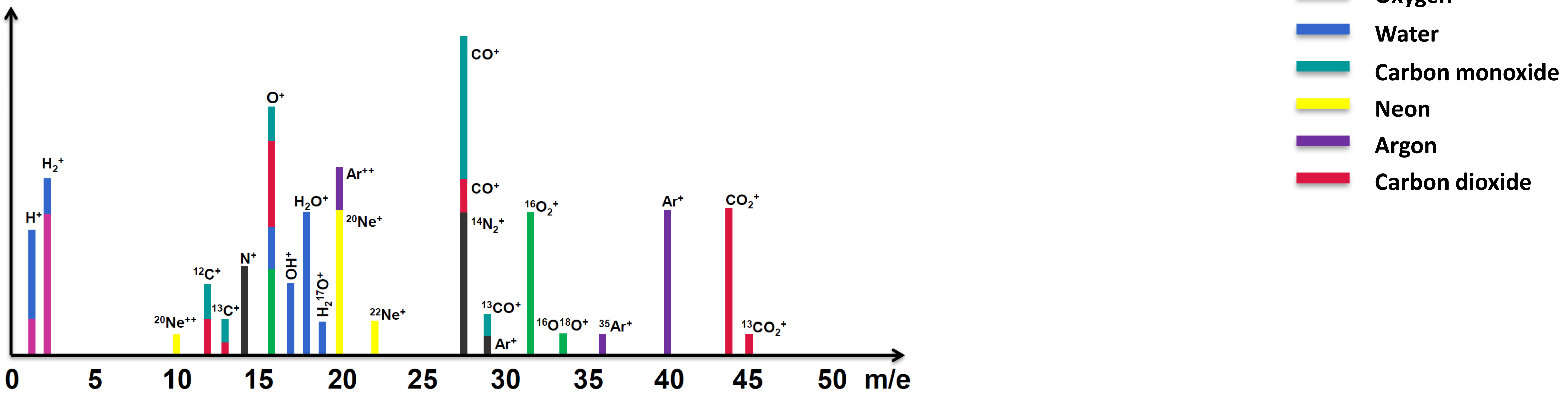
CO2 fragmentation



m/e	Intensität	Ion
12	2,46	$^{12}C^+$
16	6,24	$^{16}O^+$
22	1,78	$^{12}C^{16}O_2^{++}$
28	6,55	$^{12}C^{16}O^+$
29	0,06	$^{13}C^{16}O^+$
44	**100,00**	$\mathbf{^{12}C^{16}O_2^+}$
45	1,16	$^{13}C^{16}O_2^+$
46	0,41	$^{12}C^{16}O^{18}O^+$

Mass Spectrometer

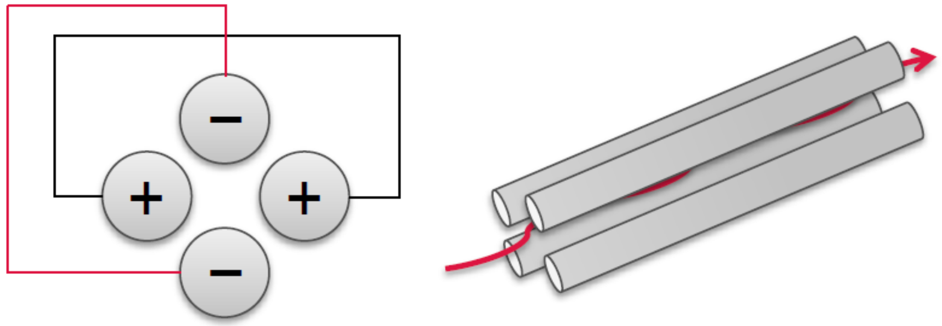
Applications of mass spectrometry:



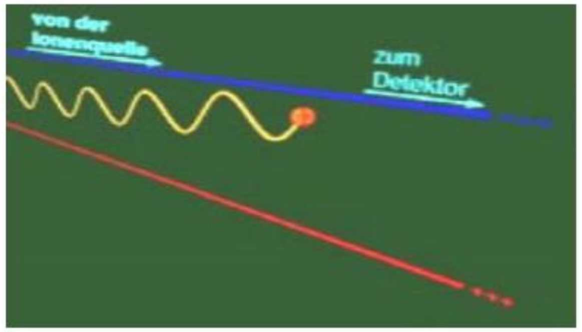
Due to the Gaussian normal distribution, a unique mass spectrum is created for each molecule

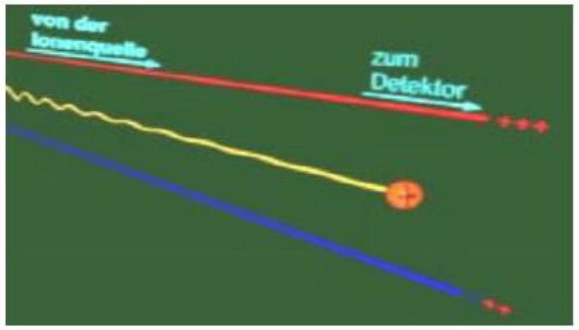
Mass Spectrometer

Separation of masses:



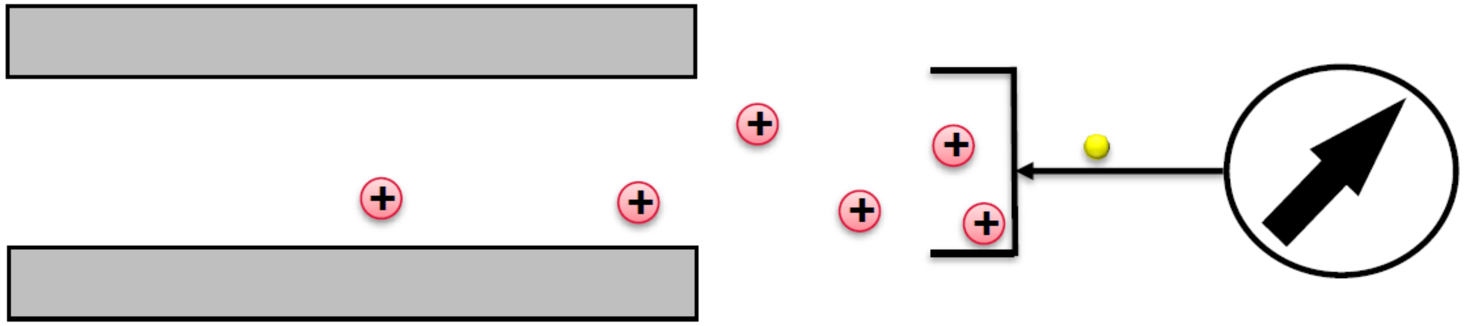
- 4 cylindrical metal bars
- opposite bars are electrically connected
- an AC voltage field is applied to a DC voltage field
- stable flight paths for certain ions
- with a suitable m/e- relation, the ion reaches the detector
- if the relation does not fit, the ion is deflected before it hits the detector





Mass Spectrometer

Detector:

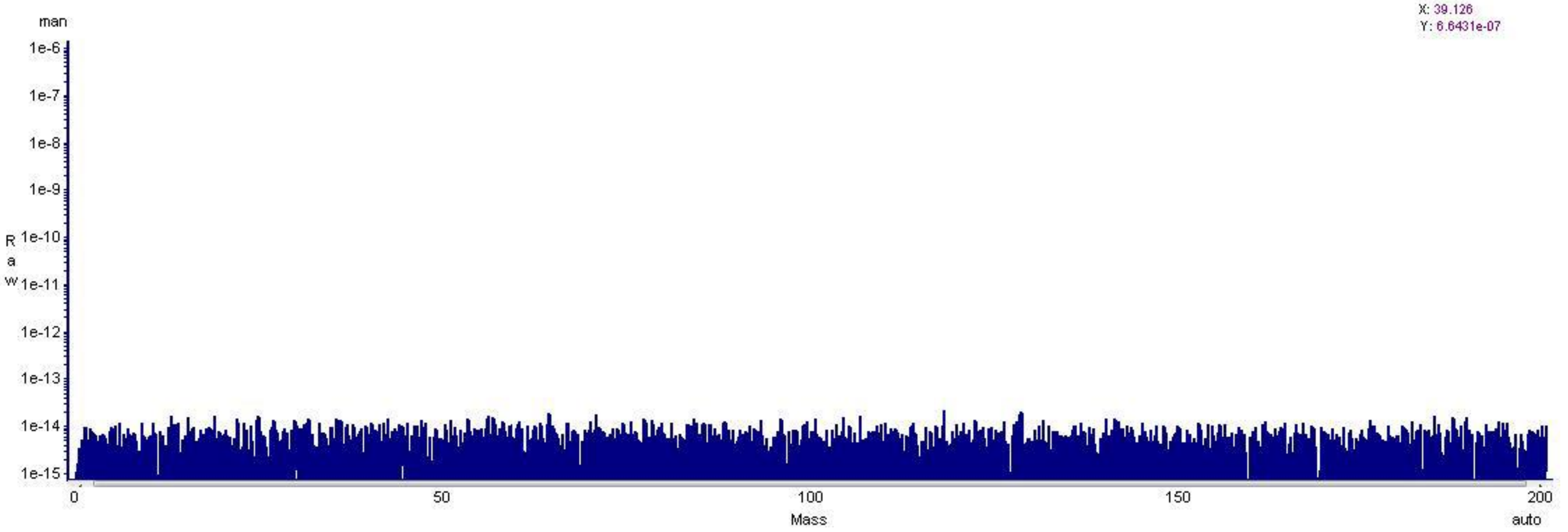


- If the m/e- relation is correct, the corresponding ion flies through the magnetic field and hits the detector.
- The relation m/e- is adjusted for each mass, so that only the corresponding mass crosses the path.

Mass Spectrometer

Detector:

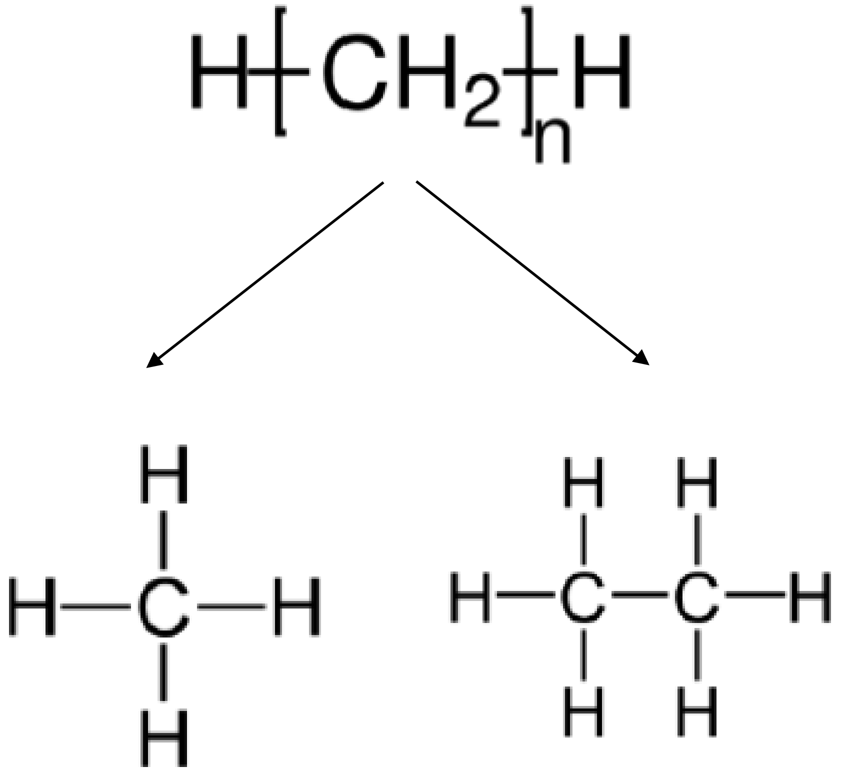
Background signal of the detector



- The detector outputs a minimum intensity independent of the gas analysis
- This signal is called “ground” and results from minimal voltage changes

Mass Spectrometer

Alkanes (hydrocarbons)

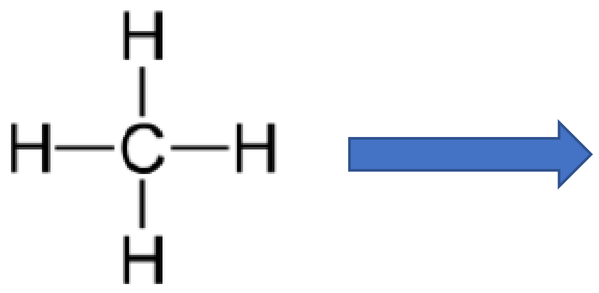


In the following we will have a look at which fragments are produced during ionization and which mass spectrum results from it

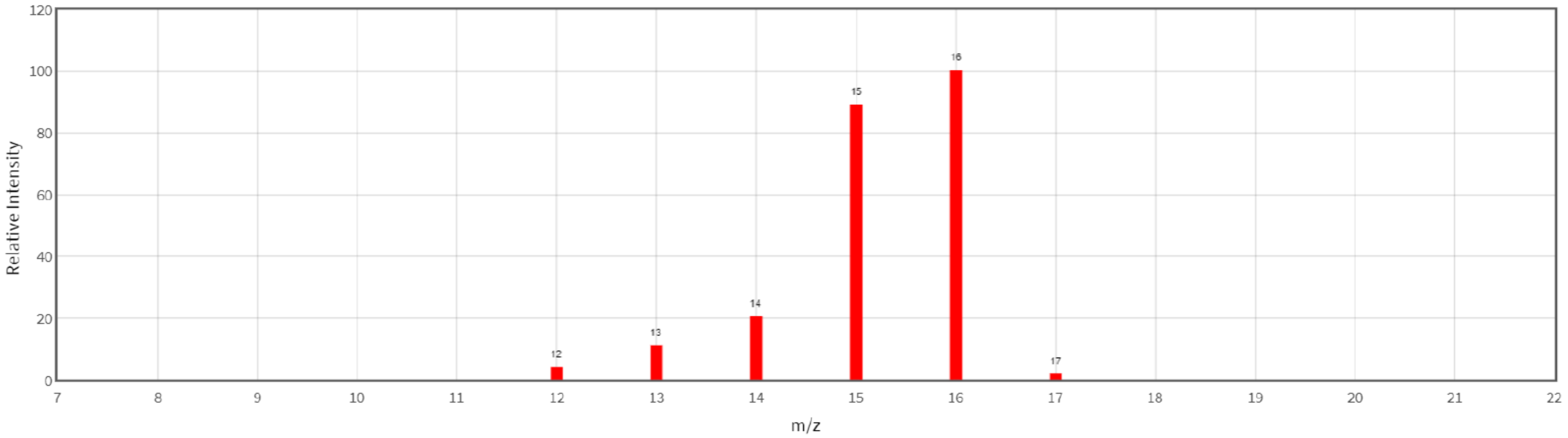
The fragments occur with different probabilities, the most frequently occurring fragment is set to intensity 100% and the others are set in relation to it

Mass Spectrometer

Methan



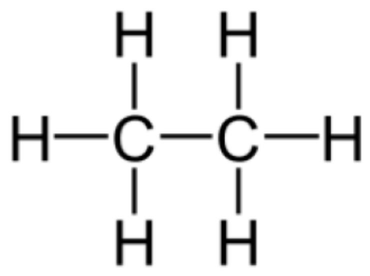
CH_4^+ → 17 amu
CH_4 → 16 amu
CH_3 → 15 amu
CH_2 → 14 amu
CH → 13 amu
C → 12 amu
H_2 → 2 amu
H → 1 amu



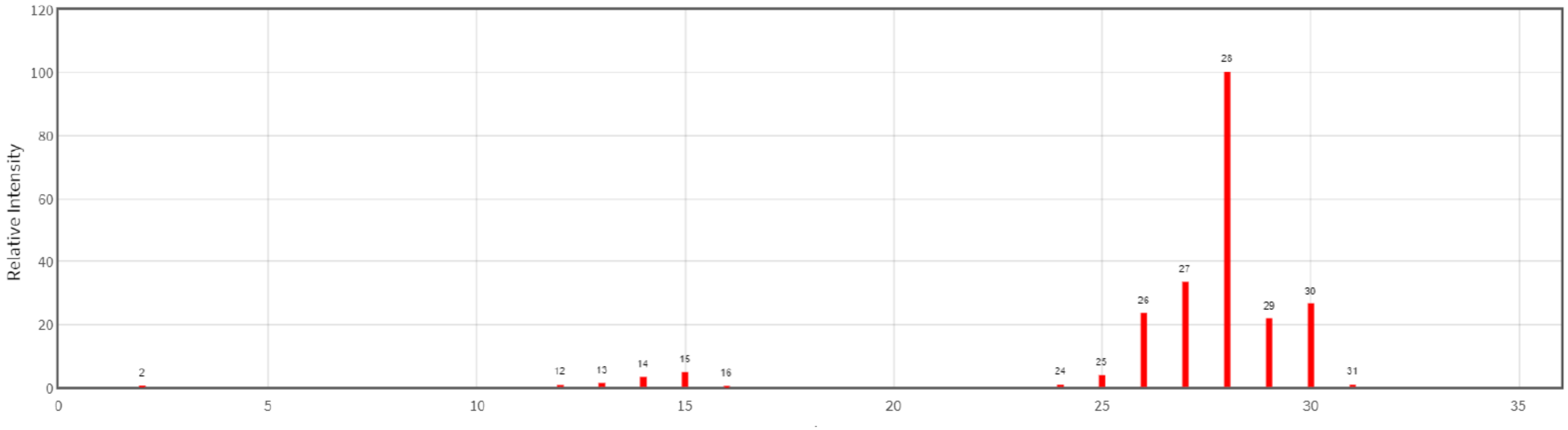
Due to the different probability of the resulting fragments, a unique mass spectrum results like a fingerprint

Mass Spectrometer

Ethan

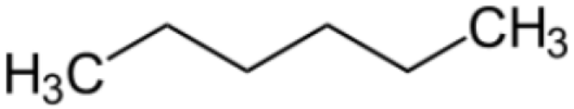


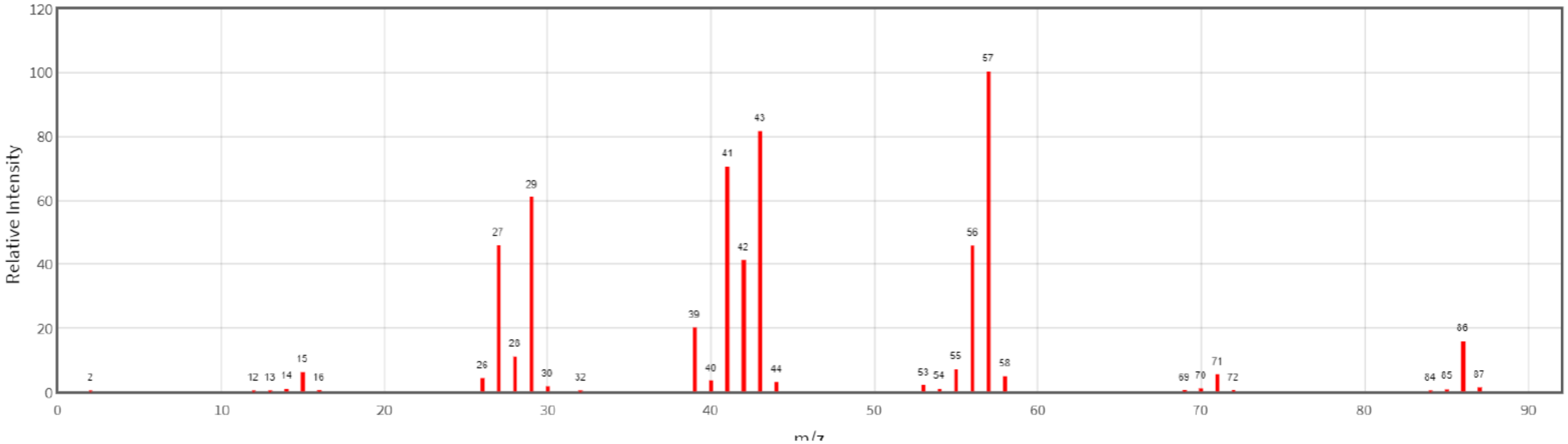
$$H_3C{-}CH_3$$



Mass Spectrometer

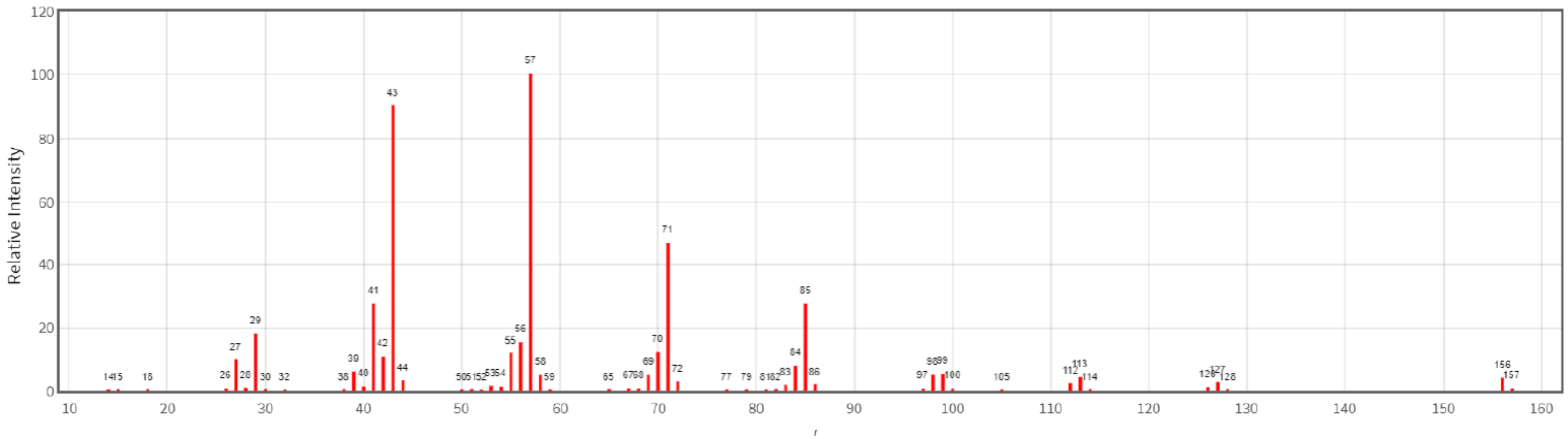
n-Hexan





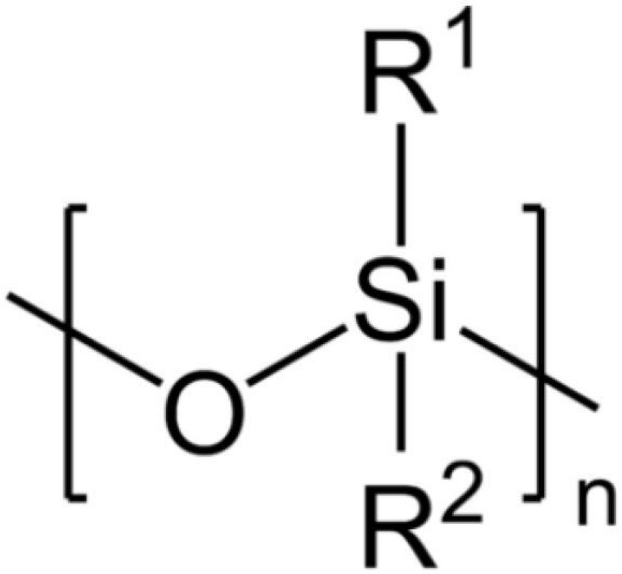
Mass Spectrometer

n-Hexan



Mass Spectrometer

Silicone oils



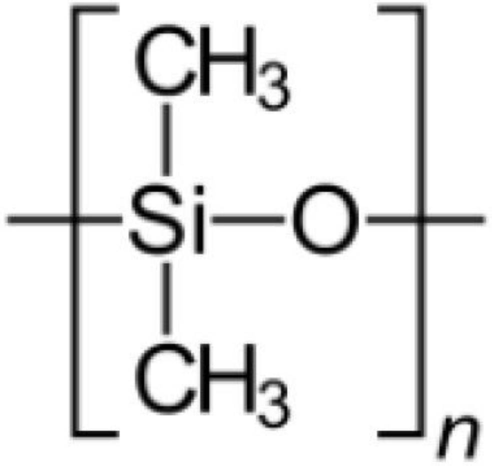
- Siloxane Polymer

- Silicone oils are clear, colorless, nontoxic, neutral, odorless, tasteless, chemically inert, temperature-stable over a wide range, hydrophobic liquids with a molecular mass of 162 to 150,000 g/mol

The repeating unit of the siloxane polymer

Mass Spectrometer

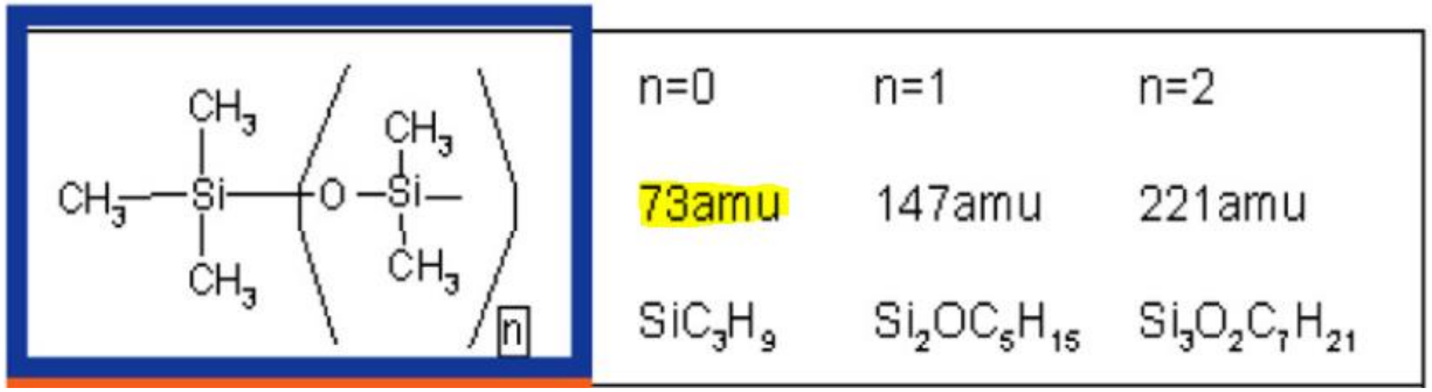
Polydimethylsiloxane (C2H6OSi)



Masses

- H – 1
- C – 12
- O – 16
- Si – 28

Sum formula: $SiOC_2H_6$

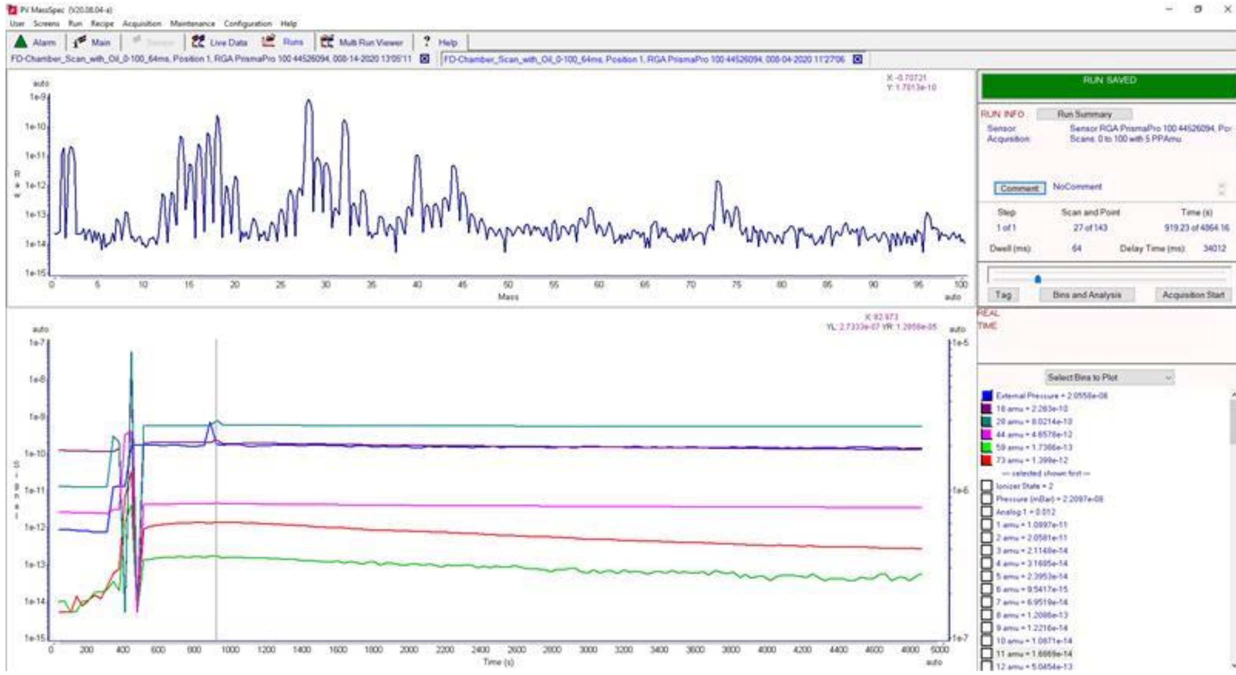


n=0	n=1	n=2
73amu	147amu	221amu
SiC_3H_9	$Si_2OC_5H_{15}$	$Si_3O_2C_7H_{21}$

Mass Spectrometer

Scan of the chamber with silicone oil

- During the scan over all masses, all fragments are detected which are created during the ionization of the air molecules
- If there are traces of evaporated silicone oil in the atmosphere, these fragments are also detected
- The indicators for silicone oil are mainly 45 amu, 59 amu and 73,74,75 amu
- During the scan over all masses, each mass is sampled several times, resulting in parabolic peaks
- The intensity is always relative to the main peak N_2 Intesity = 10
- If the limited sample of silicone oil evaporates, the intensity decreases over time until finally all the oil has evaporated
- In the case of a leak, no decrease in intensity will be seen, as it is not a limited quantity here
- When the chamber is clean, only the fragments of air can be seen



Process control tools (sensor technology)

Wireless temperature measurement

These sensors are used for:

- temperature measurement
- relative humidity
- pressure measurement

Process control tools (sensor technology)

Wireless temperature measurement

Freeze Dryer Logger - 85C to +140C

Cryologger

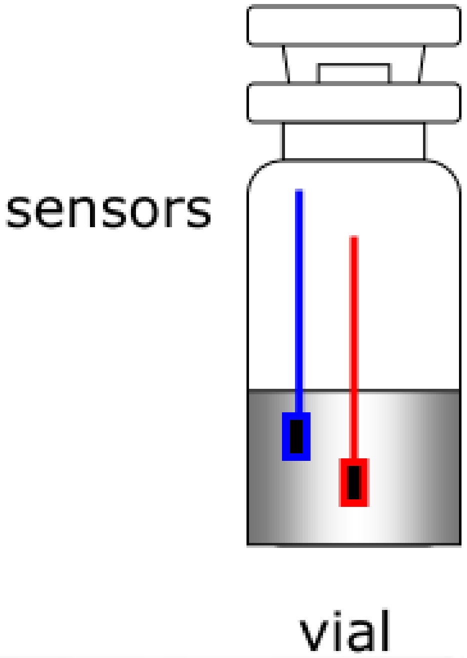
-85C to +140C

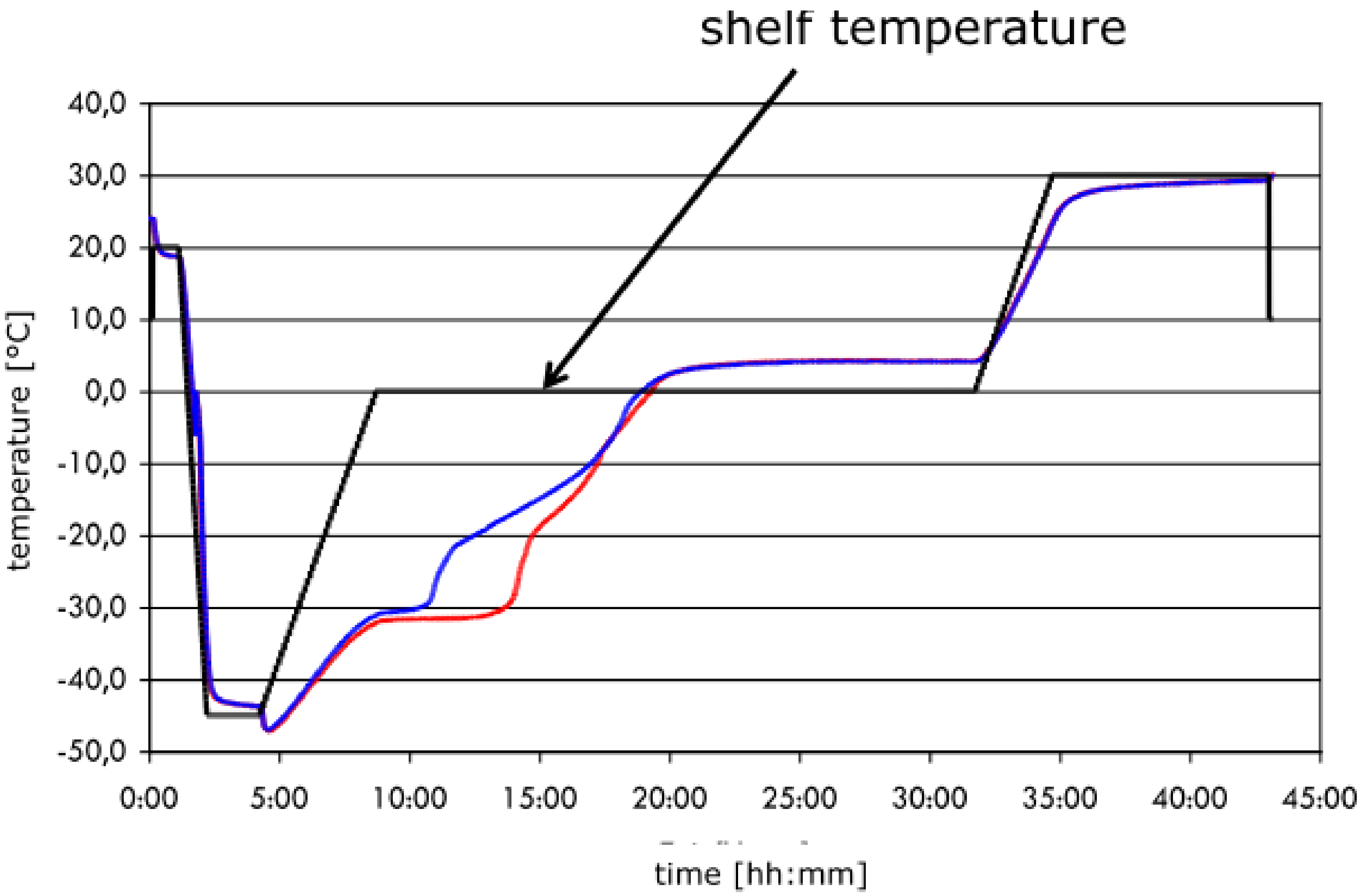
Process control tools (sensor technology)

Wireless temperature measurement

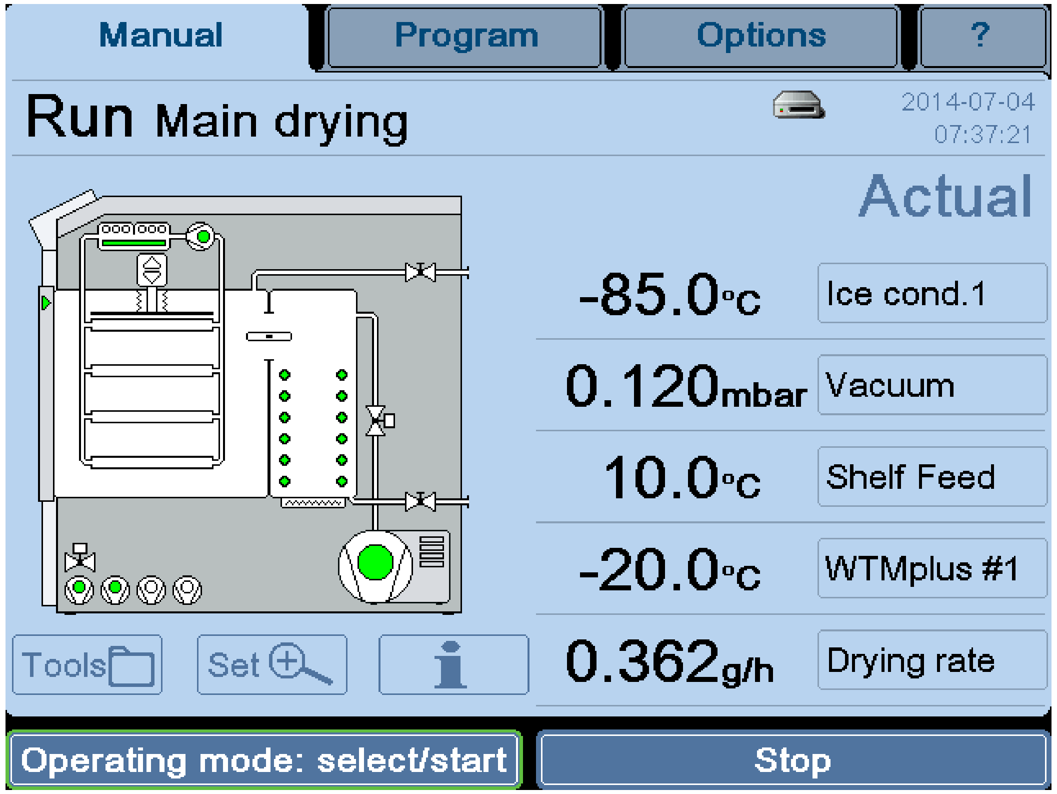
positioning equipment

Process control tools (sensor technology)





Process control tools (sensor technology)

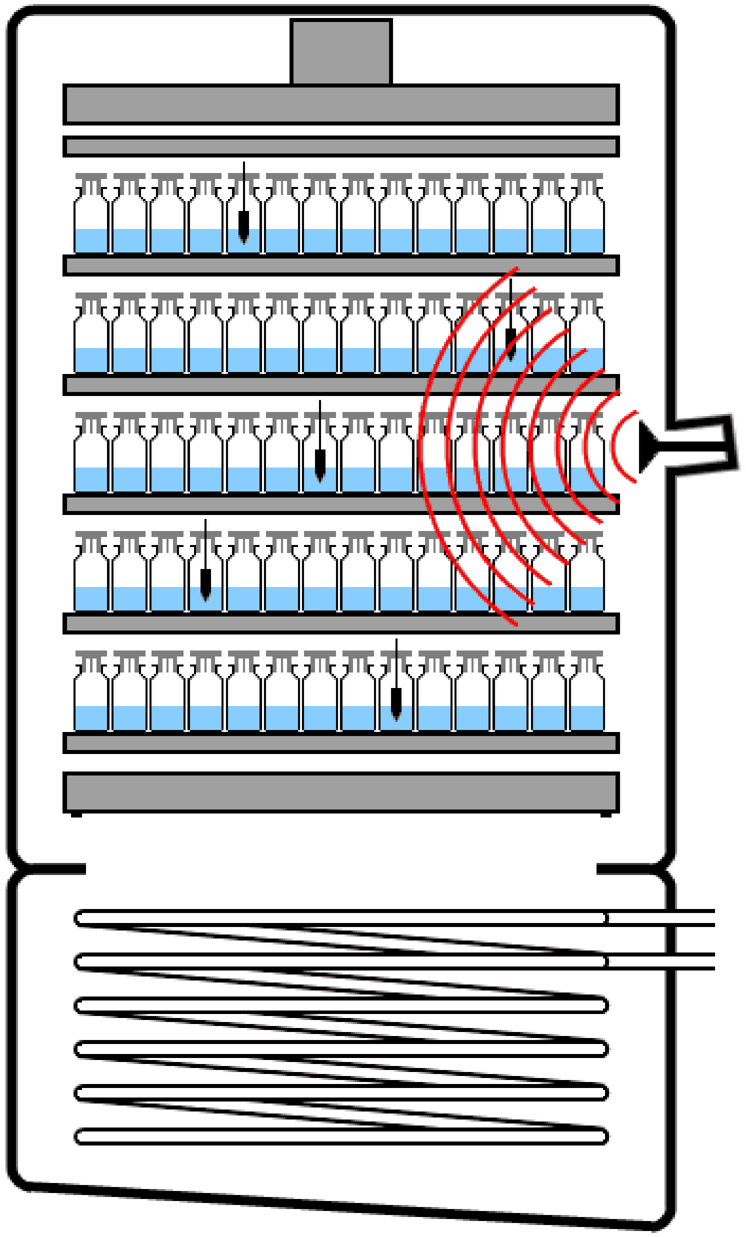


Run Main drying

2014-07-04
07:37:21

Actual

-85.0°C	Ice cond.1
0.120mbar	Vacuum
10.0°C	Shelf Feed
-20.0°C	WTMplus #1
0.362g/h	Drying rate



Functional principle WTMplus

- energy supply of the sensors by means of a radio frequency within in the 2.4 GHz range, i.e. no battery or other energy storing device necessary
- intermediate storage of energy by stimulation of a quartz crystal
- high precision temperature-dependent detuning of quartz-oscillation frequency
- transmission of frequency modulation via an antenna to the evaluation electronics for temperature determination

Process control tools (sensor technology)

WTMplus

easy sensor positioning

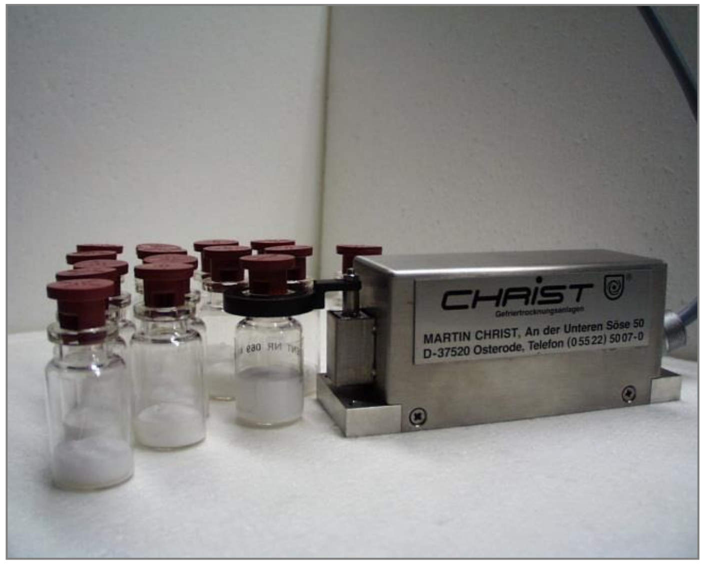
small, robust sensors

Process control tools (sensor technology)

Features

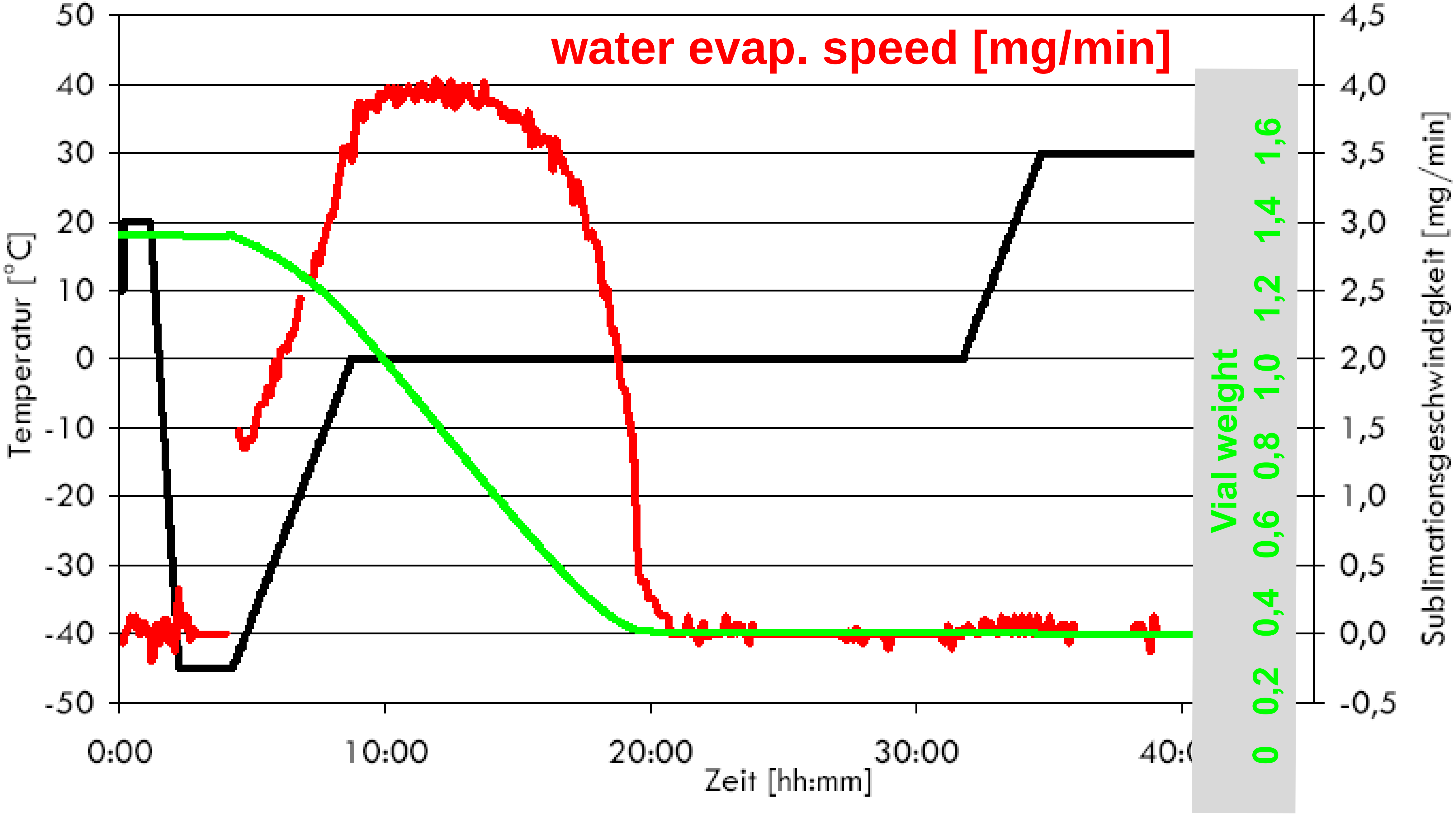
- small and robust, also for 2R vials and bulk
- no plugs and wires with cleaning and contact problems, GMP-design
- small and robust, also for 2R vials and bulk
- product temperature in the vial not influenced by energy input of conventional sensors
- high accuracy ± 0.5 K , resolution 0.1 K
- covers the entire lyophilization cycle (liquid, solid/frozen and dry)
- free sensor positioning on shelves or in pre-defined grid square
- fully integrated in system controller and process documentation

Measurement of drying rates

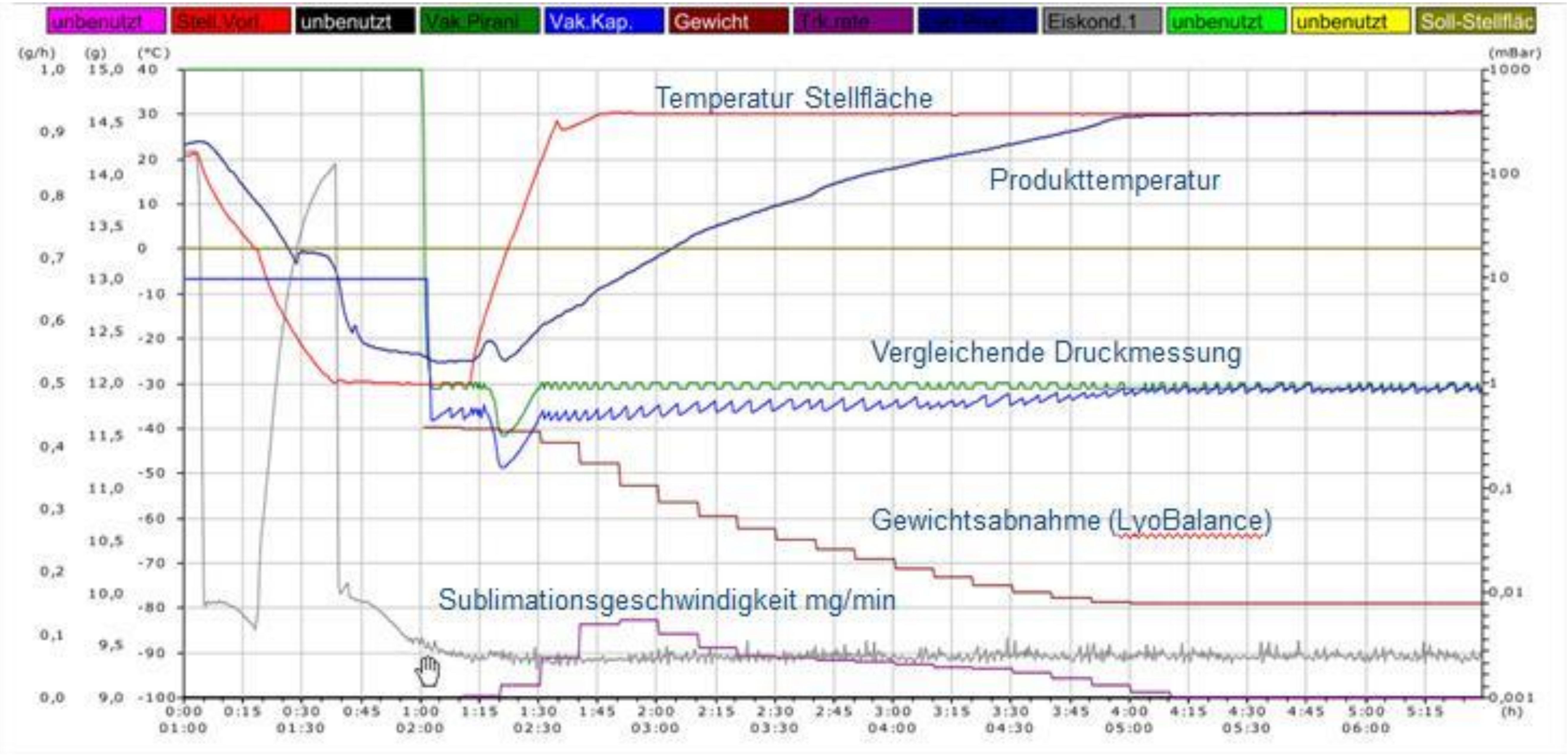


function principle	electromagnetic force compensation
weight determination	▪ via gripping arm, which can be lifted/unlifted in certain - customer defined - time cycles ▪ the weight of the vial is therefore detected periodically
application range	▪ temperatures of -40°C to +40°C ▪ resolution up to 30g vial weight: 0,001g
advantages	▪ can be placed onto every shelve position in the drying chamber ▪ drying process is not disturbed ▪ automatic documentation of the data ▪ can be used as controlling parameter for the process (main drying - final drying)

Speed of the sublimation from analysis with weight cell



Idealized determination of end drying



Inline camera LyoCam

- monitor and analyze freeze drying processes
- intelligent data storage based on
  - process steps
  - process data (limits, alarms, …)
- fully integrated in process visualization LPCplus
- integrated in process data base (identical time stamp)
- equipped with LED lamps for low energy impact into the product
- up to 4 cameras in LPCplus
- standard sight glasses useable