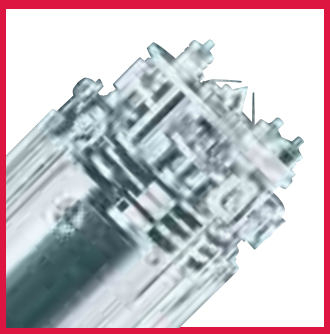
PFEIFFER VACUUM

Mass spectrometer







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Vacuum is nothing, but everything to us

- Analytical instruments
- Biotechnology
- Research and Development
- Glass coating
- Semiconductor industry
- Medicine and Life Science
- Pharmaceuticals
- Process technology
- Tool coating
- Additional markets such as packaging and automotive industries

Contents

1 Fundamentals of mass spectrometry

Contents


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1 Fundamentals of mass spectrometry

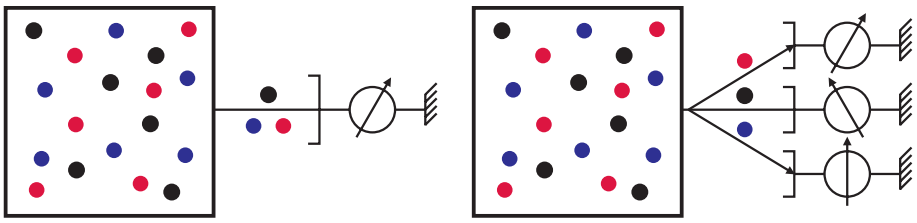
1.1 Introduction

Mass spectrometric measuring methods have become an indispensable diagnostic aid in numerous branches of process engineering, technology and product development, medicine and basic scientific research.

Conversely, development of vacuum technologies has increasingly required the utilization of small high performance mass spectrometers.

Mass and Charge

- The total pressure is the sum of all pressures of a given gas mixture
- To determine the partial pressure of a certain gas component, this component must be isolated from the mixture
  - ✡ Thus prior separation of the gas mixture is necessary
- This takes place according to the ratio of mass to charge: m/e



No separation
✡ Total pressure

Separation in **time** or **space**
✡ Individual partial pressures

Fig. 1:
In contrast to total pressure measurements, in mass-selective measuring methods detection is according to the mass/charge ratio of the ions.

Typical applications are:

- mass-selective leak testing of serial production components in the automotive industry
- quantitative determination of the composition and purity of process gases
- complex analysis of catalytic reactions on the surface of solid bodies
- the investigation of biochemical substance transformations.

In view of this wide range of applications it is not surprising that in the course of recent decades numerous physical methods for mass separation of particles have been developed and implemented in matured practical measuring instruments.

In spite of the considerable difference of the methods, they all have a common feature. A vacuum must be generated for operating mass spectrometers, in many cases with several pressure ranges. Con-

Some examples are:

- leak detection
- partial pressure measurements in high vacuum systems
- monitoring of the gas composition in vacuum coating processes
- end point determination in vacuum etching
- mass-resolved determination of neutral particles and ions in plasma processes
- determination of gas-specific desorption and adsorption rates of materials for vacuum system components.

Chiefly *quadrupole mass filters* (Fig. 2) are used today particularly for these measuring tasks. The properties of quadrupole mass filters which are especially useful for these applications are the simple manner of scanning the entire mass range, high sensitivity, high measuring and repetition

1 Fundamentals of mass spectrometry

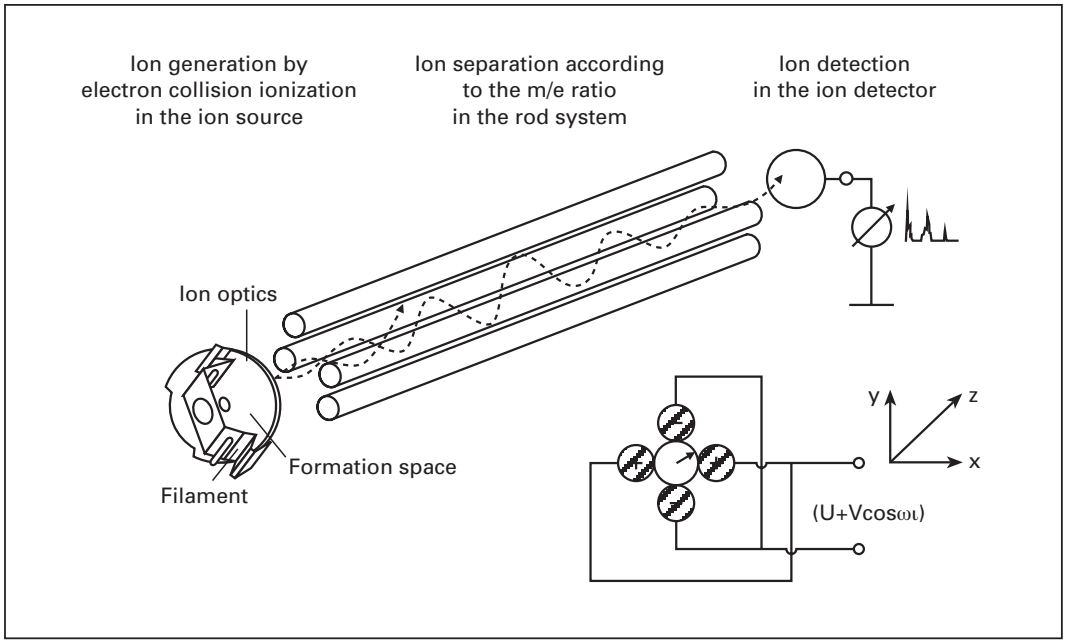


Fig 2:
Functional principle
of a quadrupole mass
spectrometer.

rate, large measuring range (up to 10 decades) and compatibility with the general requirements of vacuum technology such as relatively small dimensions, arbitrary mounting position and low outgassing rates.

A quadrupole mass spectrometer intended for partial pressure measurements is in principle an ionization vacuum gauge equipped with an additional device, the rod system, which first of all separates the types of ions produced by the ionization process according to their mass/charge ratio (m/e) before measuring them with an ion detector.

The ions are separated in a high frequency electric quadrupole field between the four rod electrodes with field radius r_0. The voltage between the electrodes consists of a high frequency alternating voltage Vcos ωt and a superimposed direct voltage U. When ions are trapped in the direction of the field axis perpendicular to the plane of the diagram, they perform

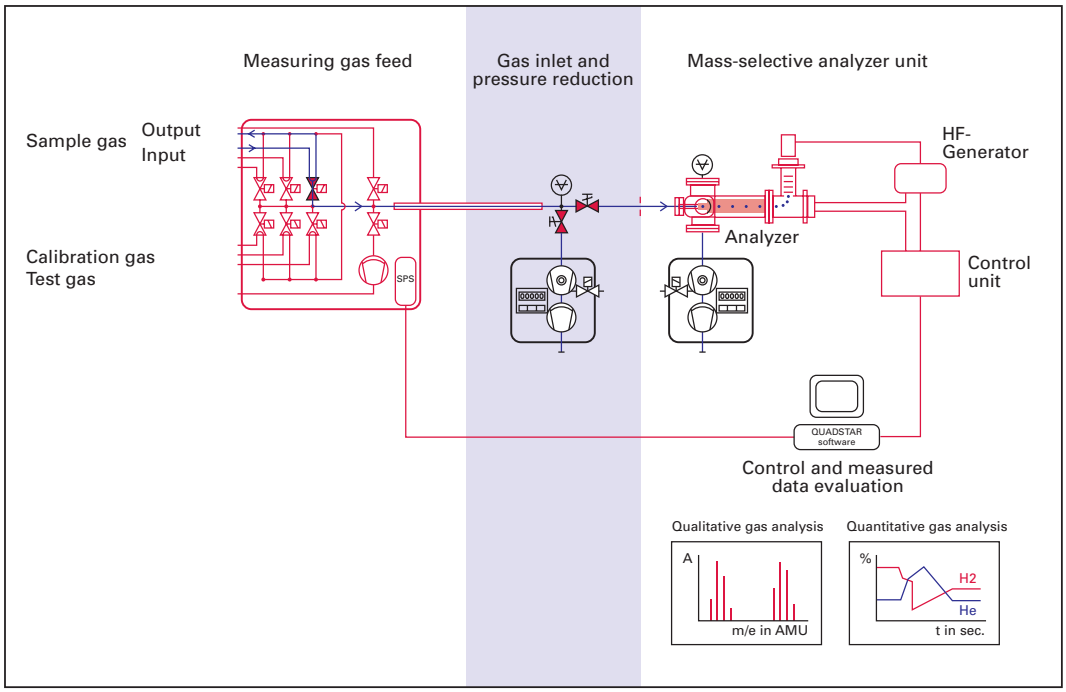


Fig. 3:
Components for
gas analysis
The associated pump
systems are described
in detail in the catalog
Pfeiffer Vacuum,
Vacuum Technology
2002–2004.

oscillations perpendicular to the field axis under the influence of the high frequency field. For certain values of U,V, ω and r_0 only ions with a particular ratio m/e can pass through the separating field and reach the ion detector. Ions which have a different mass/charge ratio are rejected by the quadrupole field and therefore cannot reach the detector. Mass/charge ratio scanning can be achieved by varying the frequency ($m/e \sim 1/\omega^2$) or, as is for technical reasons almost always the case, by varying the voltages ($m/e \sim V$) . This gives a linear mass scale by simple means. It is also possible to adjust the resolution capability ($\Delta m/m$) of a quadrupole mass spectrometer via the ratio of the magnitude U of the direct voltage component to the amplitude V of the high frequency component. It must be pointed out already at this juncture that it is always necessary to find a compromise between best possible mass resolution and high sensitivity.

Specific optimized application solutions (Fig. 3) are possible only by combining high performance mutually matched components for sample gas feed, for pressure reduction, for the actual mass spectrometer system and for the respective vacuum generating systems.

1.2 The quadrupole mass spectrometer

A first technically realizable variant of a quadrupole mass spectrometer was described in 1953 by W. Paul and H. Steinwedel [1, 2, 3]. The chief functional components of the mass spectrometers presented in this catalog are:

- analyzer unit (QMA) with ion source, rod system and detector
- HF generator (QMH)
- electrometer preamplifier (EP) or a pulse preamplifier (CP)
- control unit (QMS,QMI) with the quadrupole electronics (QC)
- power supply for the ion source (IS) and the high voltage power supply for a SEM detector (HV) and the computer interfaces (RS 232 C and LAN ArcNet)
- control and evaluation software (QuadStar™)

The modular construction with the various functional groups permits technically optimised equipment variants with good price to performance ratio for numerous applications, through combination of various analysers, different HF generators and specific equipment variants for the control unit. This also facilitates subsequent modification for other applications. QuadStar™ software is the common platform for the diversity of equipment versions, giving the operator a standardised user interface and the facilities for transferring measured data, measuring parameter sets and complete measuring sequences even for very different QMG systems.
Only the analyzer unit is under vacuum. It is attached via a CF flange connection, whereby the ion source (and the ion optics) as well as a part of the rod system project into the analysis chamber.

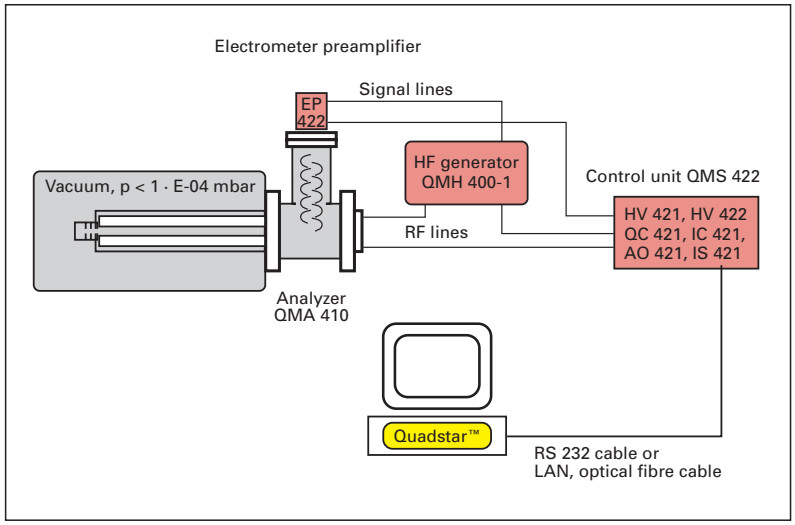


Fig. 4:
Functional component units of a QMG 422.

The mounting orientation of a quadrupole analyser can be arbitrary, i.e. it can be optimally adapted to the particular application. The preamplifier is connected directly to the signal output of the ion detector via a plug connection, to minimise signal losses. The length of the HF lines and thus the possible distance between the analyzer and the HF generator is usually limited, because the parasitic capacitances of the connecting leads make a considerable contribution to the total capacitance of the HF resonant circuit. The attachment orientation of the HF generator is arbitrary, but it is necessary to ensure adequate air circulation for cooling. The control units are constructed as slide-in modules for racking systems and can accommodate further modules for analog and digital signal input/output (AO 421, AI 421, DO 421, DI 421). In addition to an internal bus system which interconnects all system components, the control units also contain their own data and parameter memories, so that the current operating mode (including set alarm points) can still run even when communication with the computer is interrupted. A local operator console CS 422 permitting operation without computer support is available for the control unit QMS 422.
In the compact units of the Prisma™ series (Fig. 5), the electronic components comprising the HF generator, the electrometer preamplifier, the quadrupole electronics, the ion source power supply, the high voltage power supply and the data interface, are combined in a housing and directly connected to the analyzer via a disconnectable plug connection. The direct coupling of the HF generator to the rod system leads to significantly smaller HF power loss when coupling-in the high frequency field. This permits smaller power rating of the HF module for the same performance quality of the mass filter, and thus a space saving and cost effective constructional design of the entire electronics. However, there are limits to the possible utilisation of such a design if high ambient temperatures (> 40 °C) or increased radiation stress, for example in direct attachment to elementary particle accelerators, can arise. Utilization of the Prisma™ devices down to the region of very small pressures ($p < 1 \cdot 10^{-10}$ mbar) is possible without problems by virtue of the degassing function of the ion source, the use of suitable materials for the components under vacuum and the maximum bakeout temperature of 300 °C for the analyzer when the electronics is detached.

Fig. 5:
Mass spectrometer Prisma™ M1.

1.2.1 The ionization process

Ionization is the part of the procedure for analysing neutral particles which has the greatest effect upon the sample gas [4, 5]. A small fraction of the atoms or molecules present in the gas phase are converted into an ionized state by bombarding them with low energy electrons. This produces singly and multiply charged positive ions. The energy of the collision electrons has a strong effect on the number and on the type of ions which are produced (Fig. 6). The ionization process of the neutral particles commences at a minimum energy (the "appearance potential") of the electrons. The number of ions produced increases rapidly with increasing electron energy, reaching a maximum at 50 – 150 eV depending on the type of gas, then falling slowly again as the energy is increased further. The yield of ions – and therewith the sensitivity – should be as great as possible, therefore electron energies in the range 70–100 eV are used in most cases. The ionic current i^+_k of a gas component k can be calculated according to the following formula:

$$i^+_k = i^- \cdot l \cdot s \cdot p_k \ [A]$$

where

i^- = Electron (emission) current [A]
l = Mean free path of the electrons [cm]
s = Differential ionization of k $\frac{1}{[cm \cdot mbar]}$
p_k = Partial pressure of k [mbar]

For the ionization of molecules, the number of possible kinds of ions increases rapidly with increasing complexity of the molecules. Fragment ions appear in addition to singly and multiply charged molecular ions.

$$\begin{aligned} ABC + e^- \rightarrow\ & ABC^+ + 2e^- \\ & ABC^{++} + 3e^- \\ & AB^+ + C + 2e^- \\ & BC^+ + A + 2e^- \\ & A^+ + BC + 2e^- \\ & C^+ + AB + 2e^- \\ & B^+ + A + C + 2e^- \end{aligned}$$

Rearrangement ions, such as AC^+, can appear in addition to these species. The appearance and relative abundances of the individual species of ions are characteristic for a certain kind of molecule and serve as important clues for identifying the molecule and thus for qualitative gas

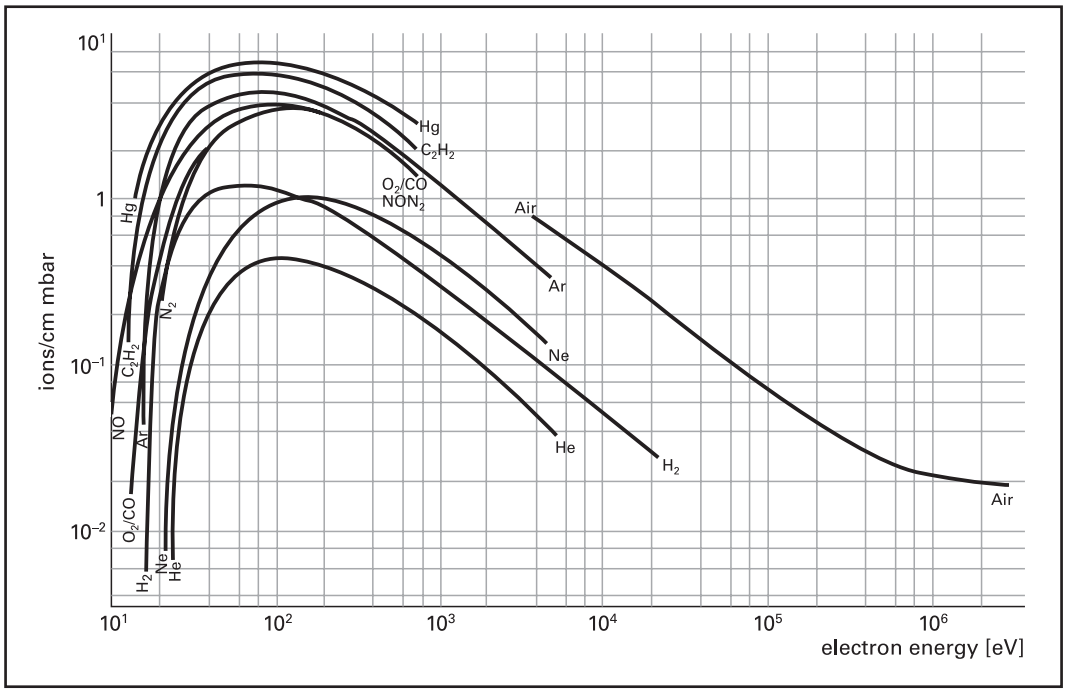


Fig. 6:
Ionization produced by electron impact, as a function of the electron energy.

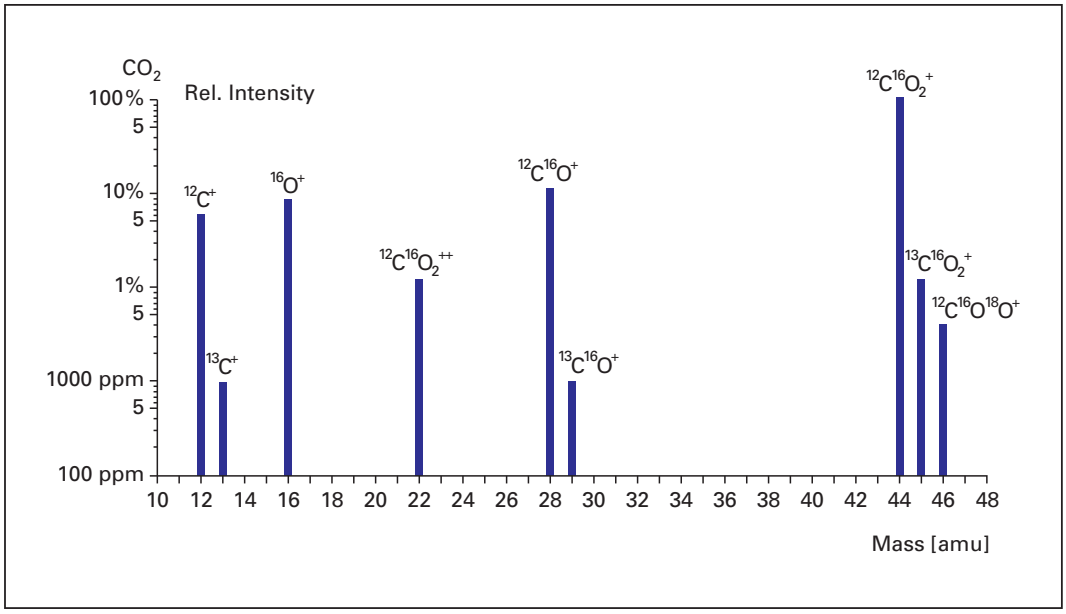


Fig. 7:
The fragment distribution of CO_2.

analysis. Fig. 7 below shows the distribution of fragments (fragment distribution or cracking pattern) of the simple molecule CO_2 recorded with 70 eV electron energy. The spectral library provided in the QuadStar™ software contains further fragment distributions for some gases and compounds which are frequently of interest. These and other distributions taken from spectral libraries can only serve for guidance, because the actual distribution depends on various parameters such as ionization energy, temperature and the transmission characteristics of the mass analyzer.

As shown in Fig. 8, the production of multiply charged ions can be strongly suppressed by using smaller electron energies, here < 43 eV. This effect is exploited, for example, to analyse Ar/Ne mixtures, in order to minimise the contribution to the mass number 20 produced by $^{40}Ar^{++}$ and thus to achieve a lower detection threshold for ^{20}Ne on mass number 20.

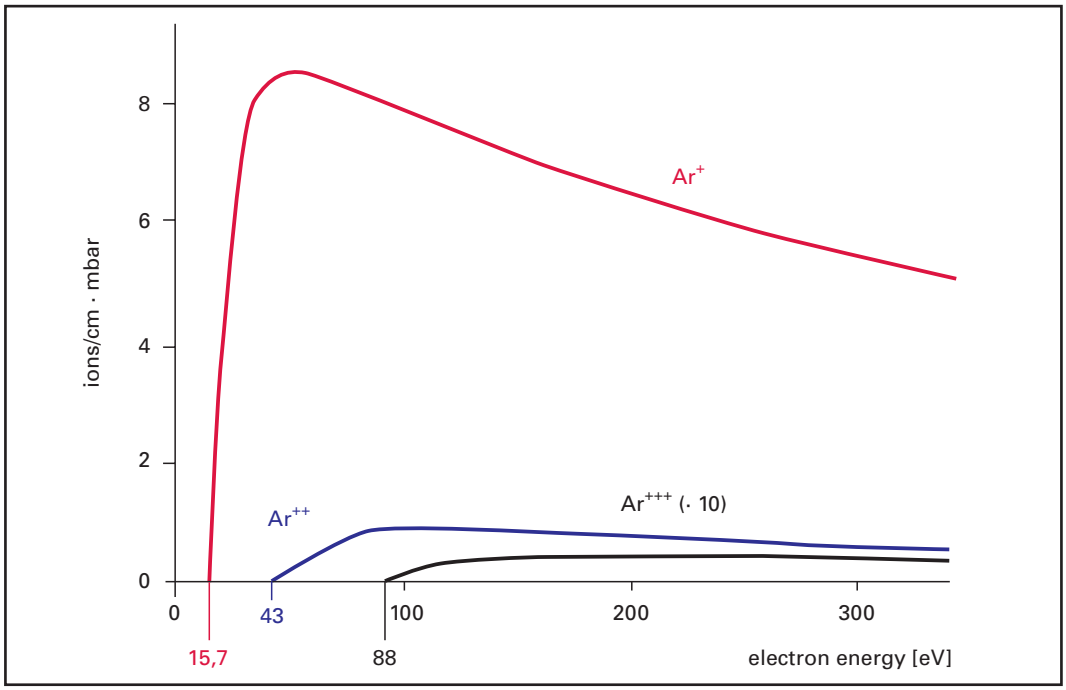


Fig. 8:
Ionization by electron impact as a function of the electron energy for argon.

For all mass spectrometers described in this catalog (except for the QMG 422, QME 125 variants) the energy of the collision electrons can be varied continuously over the range 10 – 150 eV.
The problem of overlapping ion currents of different origin on certain mass numbers is frequently encountered when analysing mixtures of several gas components.
Fig. 9 shows that in this example there are mass numbers whose intensity is determined exclusively by a single gas component (e.g. argon at mass number 40, oxygen at mass number 32, carbon dioxide at mass number 44, water at mass number 18).
For other mass numbers the total intensity of the detected ion current is determined by superimposition of the contributions made by various fragment ions originating from different gas components. In this example the ion current intensity on mass number 16 is determined by fragment ions from oxygen, water, carbon monoxide and carbon dioxide. Therefore this mass number is less suitable for quantitative determination of the oxygen content or oxygen partial pressure. In this example one would use instead the intensity measured at mass number 32. In this example it would be particularly difficult to determine the CO content, which could be calculated only by subtracting from the total ion current intensity at mass number 28 the contributions of N_2 (determined at mass number 14 when the fragment ion ratio N^+/N_2^+ is known) and of CO_2 (determined on the mass number 44 when the fragment ion ratio CO_2^+/CO^+ is known).
Depending on the composition and concentration ratios of the gas mixture which is to be analysed, it is thus possible to devise suitable algorithms and calibrating procedures for a particular measuring task. Before carrying out a quantitative gas analysis, the respective calibration factors for each individual gas component must be determined by feeding suitable calibration gas mixtures with respective non-overlapping components. Thereafter the concentration and partial pressure of these gases can be determined within the scope of a matrix calculation.
The QuadStar™ software supports such matrix calculations and the required gas-specific calibration routines.

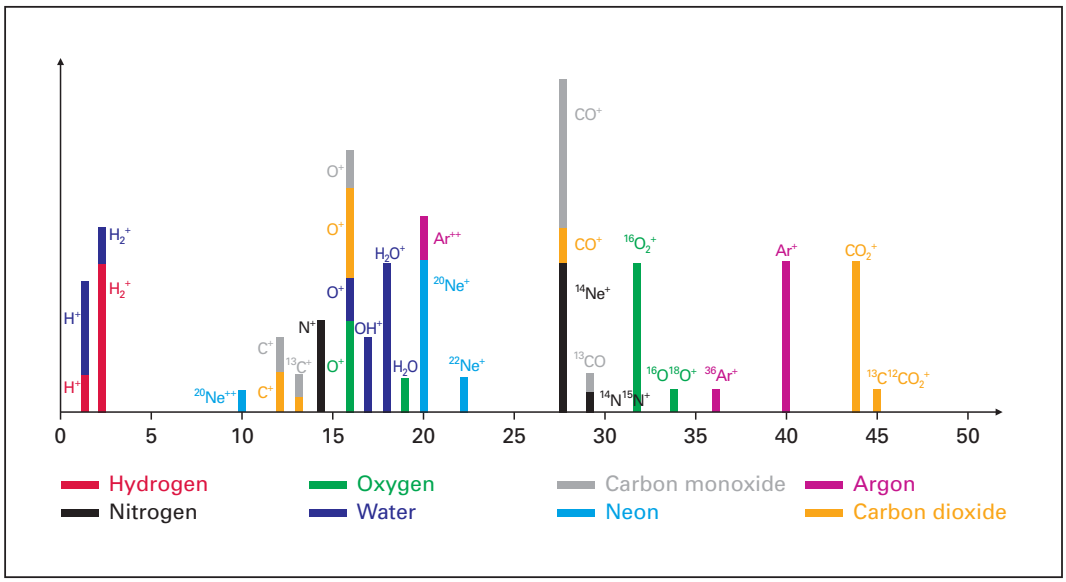


Fig. 9:
Mass spectrum of a gas mixture, recorded with 90 eV ionization energy.

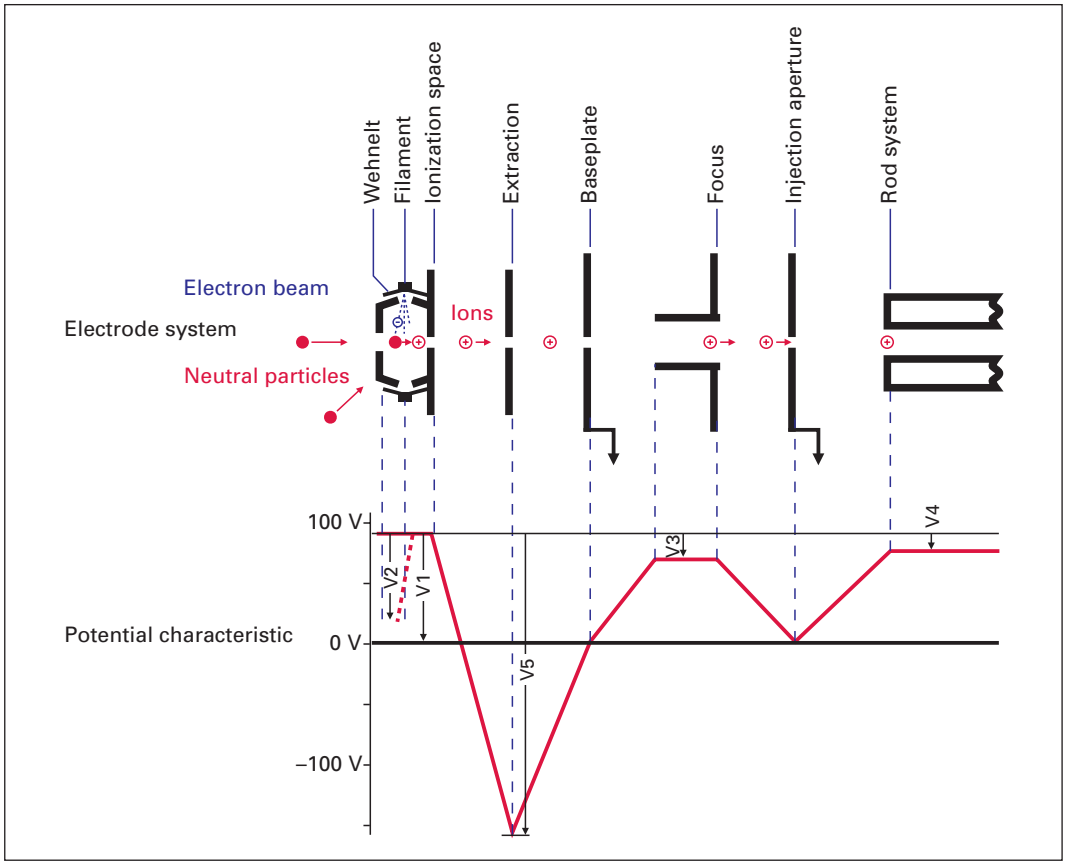


Fig. 10:
Electrode configuration and potential characteristic of a cross-beam ion source taken as example.

Operation of Ion Source (Fig. 10)
The neutral particles arriving in the ionizing space (formation space) are ionized by the electrons which are emitted by the filament and accelerated in the formation space. From the potential characteristics it is evident that a repelling potential always results for the electrons relative to the environment (mass frame potential), so that no electrons are emitted into the environment, and electrons are accelerated only towards the formation space. The produced positive ions are rapidly accelerated out of the formation space and then decelerated by the applied electric field down to the energies corresponding to the field axis potential (V4). This achieves shorter dwell times of the ions in the formation space:

- reduces undisired ion-neutrals-reactions
- faster penetration of transition fields

Except for the QMG 422, with QME 125 mass spectrometers, all voltages on the electrode configurations and the emission current can be varied continuously via the QuadStar™ software, so that optimising the ion source for a particular measuring task is a very simple procedure.
Tungsten (W), rhenium (Re) and yttrium oxide coated iridium are used as coated iridium filament material. Tungsten filaments are preferred in the ultra-high vacuum range, or where the vapor pressure of Re could produce disturbances. It is necessary, however, to bear in mind the brittleness of tungsten filaments produced by the tungsten-carbon-oxygen cycle, i.e. through the formation of W_2C. Yttrium oxide coated iridium is used increasingly instead of the former pure metal filaments. The advantages of these filaments are the considerably lower operating temperature and the relative insensitivity to air in-rush. Consequently the preferred application fields for these filaments are analysis of thermally sensitive substances (such as metal-organic compounds) or the analysis of impurities in gas mixtures which contain a large oxygen fraction.
Different constructional designs of the ion sources have been developed in order to

establish best matched conditions of mass spectrometry for the various measuring tasks. The following illustrations show the chief types of ion sources for the mass spectrometers described in this catalog.

Axial Ion Source (Fig.11)
Electron beam orientation and ion extraction in the axial direction ensure high sensitivity and good injection conditions for the ions into the downstream quadrupole separating field. The preferred application field for this rugged ion source is residual gas analysis. The filament is made of rhenium or tungsten.

Grid Ion Source (Fig.12)
The special selection of materials in conjunction with the open construction give

Fig. 11: Axial ion source.

the grid ion source very low desorption rates. This ion source also has the important advantage of easy degassing by electron bombardment. Possible applications are therefore residual gas analysis and partial pressure determination in the ultra high vacuum field (Fig. 13), as well as desorption measurements. Two filaments are available in the form of the ring cathode with centre tap. By virtue of its low vapor pressure, tungsten is the preferred filament material for this ion source.
During measurements in the pressure range < 10^{-10} mbar the "EID ions" mentioned above can be observed [6]. When surfaces

Fig. 12:
Grid ion source for extreme ultra high vacuum measurements.

are bombarded with electrons, a number of species such as H^+, O^+, F^+, Cl^+ are desorbed directly, often with high yield. EID ions originate from adsorbed layers whose cause is often found in the history of the ultra high vacuum apparatus or of the ion source, and they usually have an initial energy of a few eV. This property can be exploited for distinction with respect to ions from the gas phase (Fig. 13). Based thereon, Redhead has proposed the "extractor" tube for total pressure measurement, giving good discrimination with respect to ions with initial energy [7]. The quadrupole mass spectrometer can be combined with a grid ion source with a similar functional principle. The mass numbers 1, 16, 19, 35, 37, which are typical for EID ions, in most cases have only very limited significance for residual gas analysis. All gases which contribute to these peaks can also be detected on other mass numbers.

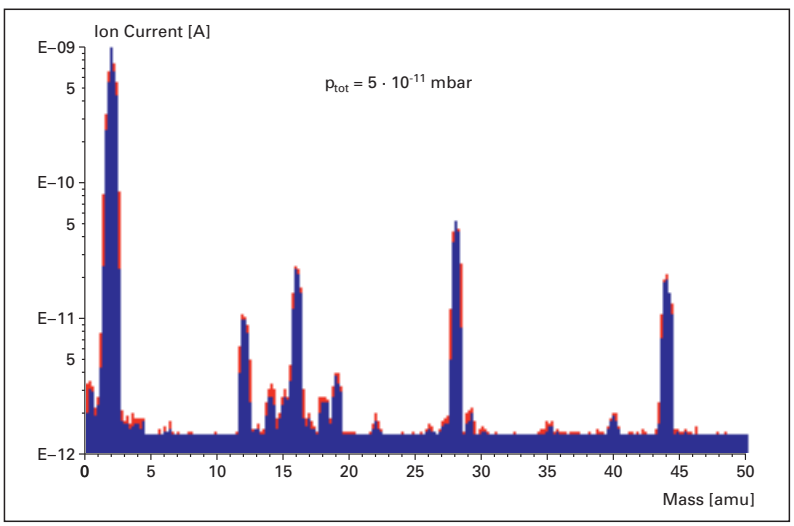


Fig. 13:
UHV spectrum recorded with the QMA 125 grid ion source and 90° off axis SEV and QME 125-1, (1-100 AMU)

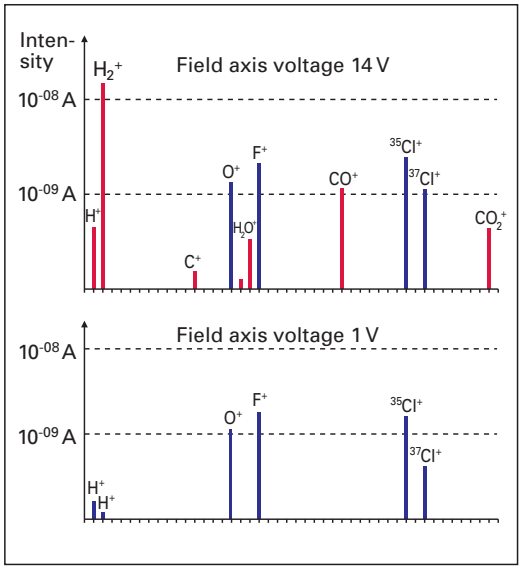


Fig. 14:
The different behaviour of ions from the gas phase (red) and EID ions (blue).

Cross-Beam Ion Source (Fig. 15)
The open construction of the cross-beam ion source (Fig. 15) permits operation with a directed gas jet largely without wall interaction. The particle beam (gas jet), the electron beam and ion extraction are mutually at right angles. The special „thin sheet metal construction“ with low heat loss lets the source interior heat-up to 200°C, so that condensation of vapors is largely prevented. The cross-beam ion source is equipped with two filaments outside the formation space of the ions, so that reactions of the gases to be analysed on the hot surfaces of the filaments are suppressed, giving long service life

Fig. 15:
Cross-beam ion source.

for this construction too. Tungsten as well as rhenium and yttrium oxide coated iridium are used as filament materials. In conjunction with a gas feed pipe it is possible to obtain inlet conditions similar to molecular beam operation for improved signal/background ratio. The application fields for the cross-beam ion source consequently range from general residual gas analysis via analysis of corrosive or condensable gas mixtures to molecular beam measurements and the determination of isotope ratios. As a further constructional variant, the cross-beam ion source is also used in conjunction with a special aperture construction for monitoring material flows and for source control in thermal coating processes.
By virtue of its suitable geometry, this ion source can also be used for detecting laser-induced ions (with switched-off filament) as simple ion transfer optics. With the help of a magnet system the electron density can be increased in the part of the ion source from which the ions can be effectively focussed into the rod system. This can considerably increase the sensitivity of the ion source. The electron-guiding magnet also has the effect that the majority of the electrons impinge on locations of the formation space which are less critical in terms of electron optics. A special version of this ion source is shown in Fig. 16. This version is particularly suitable for analysing gases under high pressure which are fed directly into the ionization space via orifices or gas dosing valves. Utilizing a “gas tight“ ion source achieves low gas consumption (and therewith slight loading of the pumping system), low background pressure in the rest of the analysis vacuum chamber and a very short time constant of the ion source. Typical application fields are consequently trace analysis of ultra pure gases, respiration analysis in human medicine and isotope analysis. However, it must be borne in mind that the danger of possible coating of the inner surfaces of the ion source increases. This is due to the lower effective pumping capacity of the vacuum system in the formation

space of the ion source. The conductance value of a gas tight cross-beam ion source is about 1 l/s for nitrogen. Therefore this constructional form of the cross-beam ion source is only conditionally suitable for analysing strongly condensing gas mixtures. A gas tight ion source is also not recommended for classical residual gas analysis at pressures < $1 \cdot 10^{-6}$ mbar, because of the closed construction.

Prisma Ion Source

Fig. 16 shows the ion source of the Prisma™ family in open and in gas tight form. Both versions have a dual filament configuration, so that two cathodes are available. Tungsten, or yttrium oxide coated iridium in the open version, is used as filament material. The configuration of the electrodes and the potential characteristic are similar to those of the grid ion source.

For the gas tight version of the Prisma™ ion source it must be borne in mind that gas input is possible only in the axial direction, i.e. in the direction of ion extraction. The conductance value is about 1 l/s for nitrogen.

Fig. 16:
Prisma™ ion source
Left: open version
Right: gas tight version.

1.2.2. Mass separation

Ions can be separated according to their mass/charge ratio in a high frequency quadrupole field produced in the ideal case with four hyperbolic rod electrodes with an apex separation of r_0. Cylindrical electrodes are used in most cases for commercial applications because of the technical difficulties involved in making hyperbolic electrodes with the necessary quality. Relatively good approximation of the ideal quadrupole field is achieved by making the rod radius equal to 1.144 times the field radius r_0. The equations of motion for ions injected into a quadrupole field are described by the Mathieu differential equations. Only a brief phenomenological description of the functional principles is given here. See [3, 8, 9] for a detailed description.

1. Only a direct voltage U is applied to the rod electrodes U:
   xz plane: The positive ions experience a repelling potential of the electrodes and can reach the detector.
   yz plane: The positive ions are attracted by the nearest electrode and become neutralised so that they cannot reach the detector.

2. A high frequency voltage of amplitude V is superimposed on the direct voltage electrode potential:
   xz plane: With increasing V the positive ions execute unstable oscillations with increasing amplitude and are neutralised.
   yz plane: With increasing amplitude V the positive ions execute stable oscillations with decreasing amplitude and can reach the detector.

3. For a *fixed mass/charge ratio M* we have:
   xz plane: For $V < V_1$ the ions can reach the detector.
   For $V > V_1$ transmission is suppressed.
   yz plane: For $V < V_1$ transmission is suppressed.
   For $V < V_1$ the ions can reach the detector.

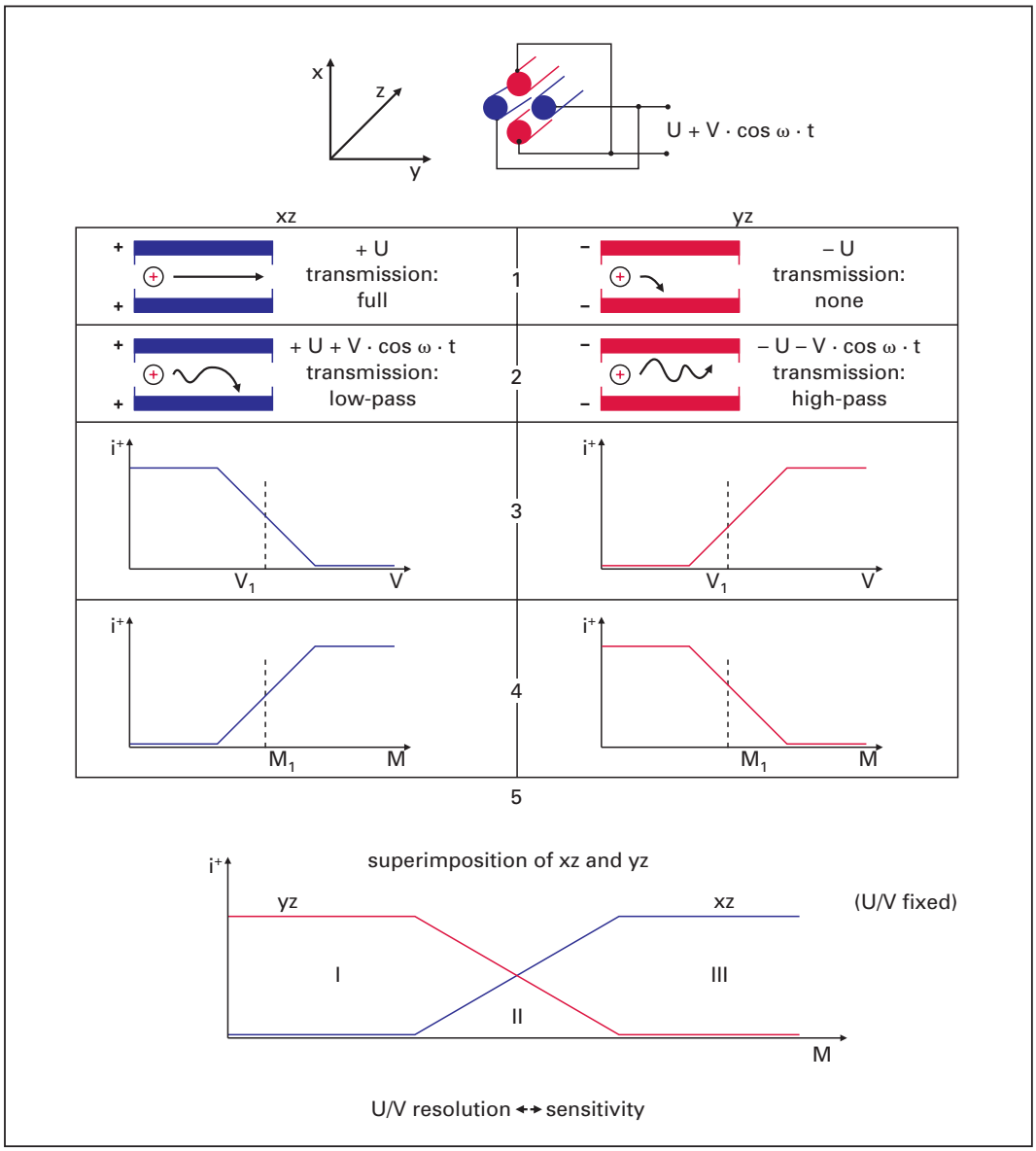


Fig. 17:
The principle of separating the ions according to their m/e ratio.

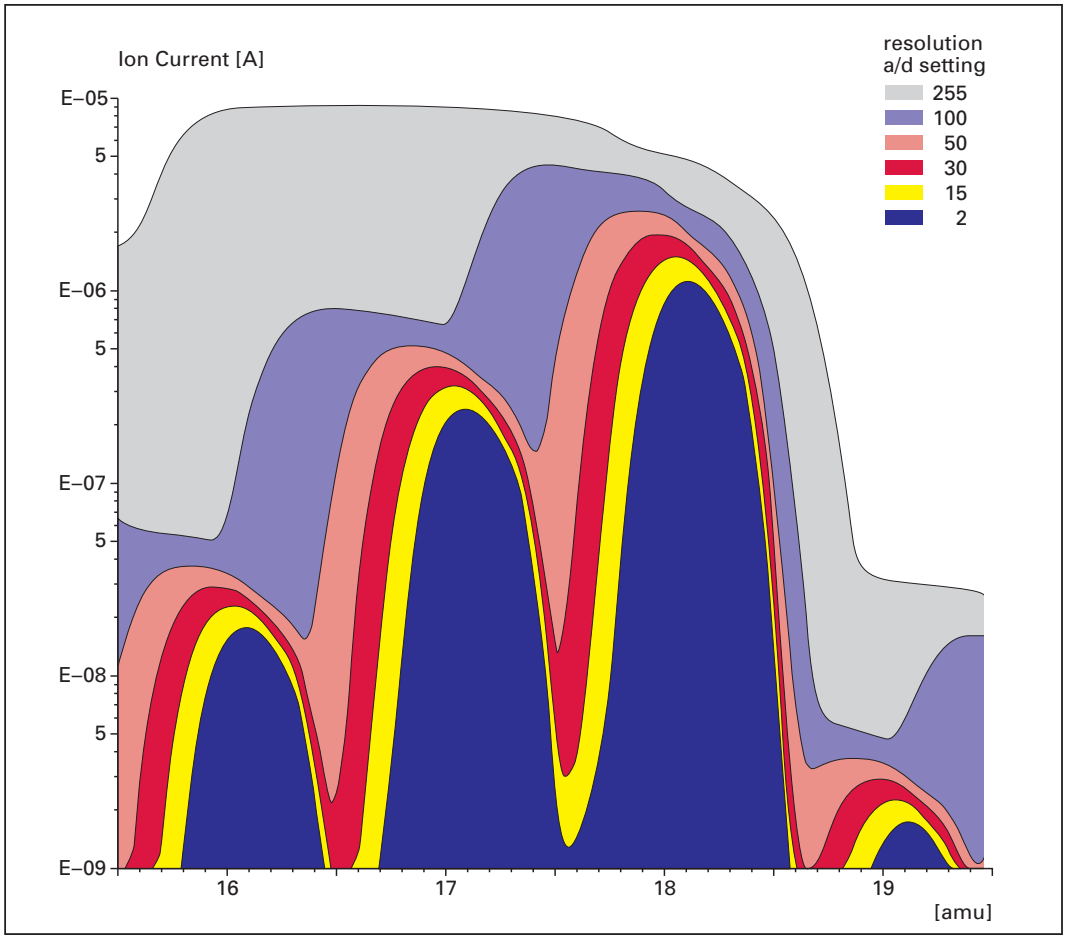


Fig. 18:
Variation of the resolution taking the H_2O group as an example (measurements with Prisma™ M2, field axis = 3.74 V).

4. For a *fixed* U/V ratio we have:
   xz plane: For ions with M < M_1 transmission is suppressed.
   Ions with M > M_1 can reach the detector.
   yz plane: Ions with M < M_1 can reach the detector.
   For ions with M < M_1 transmission is suppressed.
5. For the combination of both planes the resulting ion current i^+ with fixed U/V ratio is:
   Region I: The ions cannot pass through the rod system (xz plane).
   Region III: The ions cannot pass through the rod system (yz plane).
   Region II: The transmission factor for a mass number M is determined by the ratio U/V. A compromise must always be made between the desire for high sensitivity and the desire for high resolution (Fig. 17).

The oscillation amplitudes of the ions in region II remain finite and smaller than r_0. All other ions are rejected. For "stable" ions we have:

$$V = 14.438 \cdot M \cdot f^2 \cdot r_0^2$$

f = HF frequency, when U/V is held just below 0.1678 .
Thus the resolution can easily be varied electrically, by changing the U/V ratio, for adapting to various tasks.
If the direct voltage U is set to zero, the quadrupole operates as high-pass mass filter. With low HF amplitudes the ions of nearly all masses initially move on stable paths and reach the detector (Fig. 18, resolution "255"). This is exploited only for making total pressure measurements. With increasing HF amplitude, commencing with light masses ions with increasing mass number M become unstable and are therefore rejected. Mass number scan is

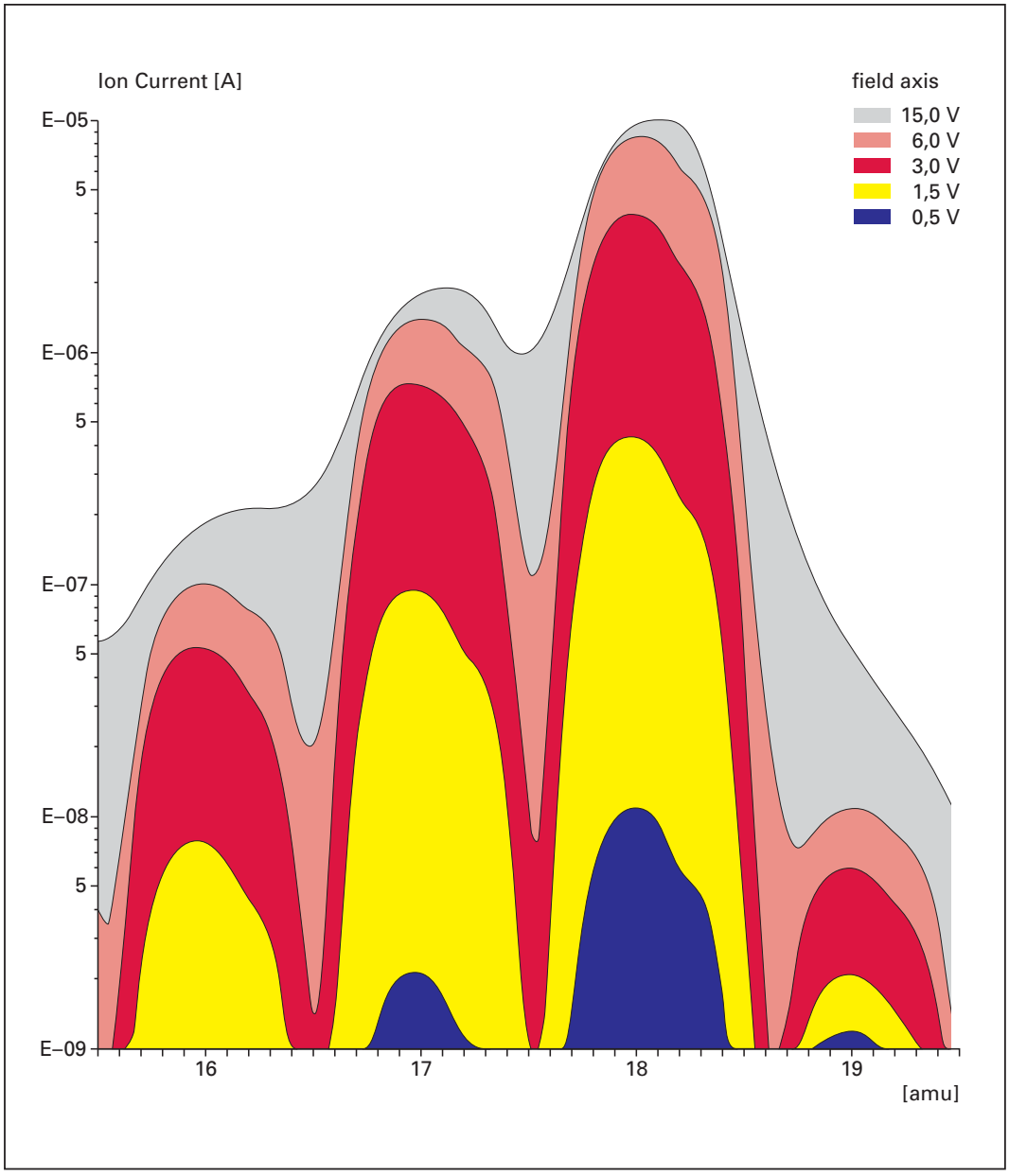


Fig. 19: Modification of the injection conditions by varying the field axis voltage (measurements with Prisma™ M2, resolution = "25").

achieved by varying V, giving a linear mass number scale.
The ratio U/V can be controlled as a function of the mass number such that not the actual resolution m/Δm but instead the line width Δm remains constant. This means increase of resolution proportional to the mass number. In spite of the increasing resolution proportional to the mass number, the reduction of transmission with increasing mass number (mass number discrimination) can be avoided by making the quadrupole rod system sufficiently exact and ensuring that the ion source fulfils the correct conditions for injecting the ions into the rod system. An ion which is only slightly unstable must be allowed sufficient time before it leaves the field, i.e. its velocity must not be too great. The following further requirements exist for the injection conditions in order to enable the ions to pass through the limited quadrupole field:

- Ions parallel to the z axis must be injected within an injection aperture having diameter $D = {}^1/_2 \cdot r_0 \cdot (m/\Delta m)$.
- The maximum injection angle ψ must satisfy the condition $\tan \psi < 11.85 \cdot r_0^2 / L^2$.

The following general conclusions for selection can be drawn for the quality of a quadrupole mass filter from the relationships pointed out above:
The quality of a quadrupole mass filter increases with increasing rod diameter (r) and increasing rod length (L). (Fig. 20, 21)
Furthermore, with greater rod radius it is easier to fulfil the conditions for geometric accuracy (production tolerances and assignments for operating the QMS).
The quality of a quadrupole mass filter increases with increasing frequency f of the high frequency field (Fig. 22)
These considerations are offset by the larger space required for the analyzer and the lower required operating pressure and especially the necessary increased power rating of the HF generator with the corresponding effort needed.

Fig. 20:
Rod systems with diameters of 6 mm, 8 mm and 16 mm for the analyzers QMA 200 (QMA 125), QMA 400 (QMA 430), QMA 410.

The required power rating N of the HF generator is

$$N = \text{Constant} \cdot C \cdot M_{max} \cdot r^4 \cdot f^5$$

where C is the capacitance of the rod system including the connecting leads and M_{max} is the maximum mass number. N increases proportional to high powers of the frequency and of the rod radius.
Fig. 20 shows the rod systems of the mass spectrometers described in this catalog.

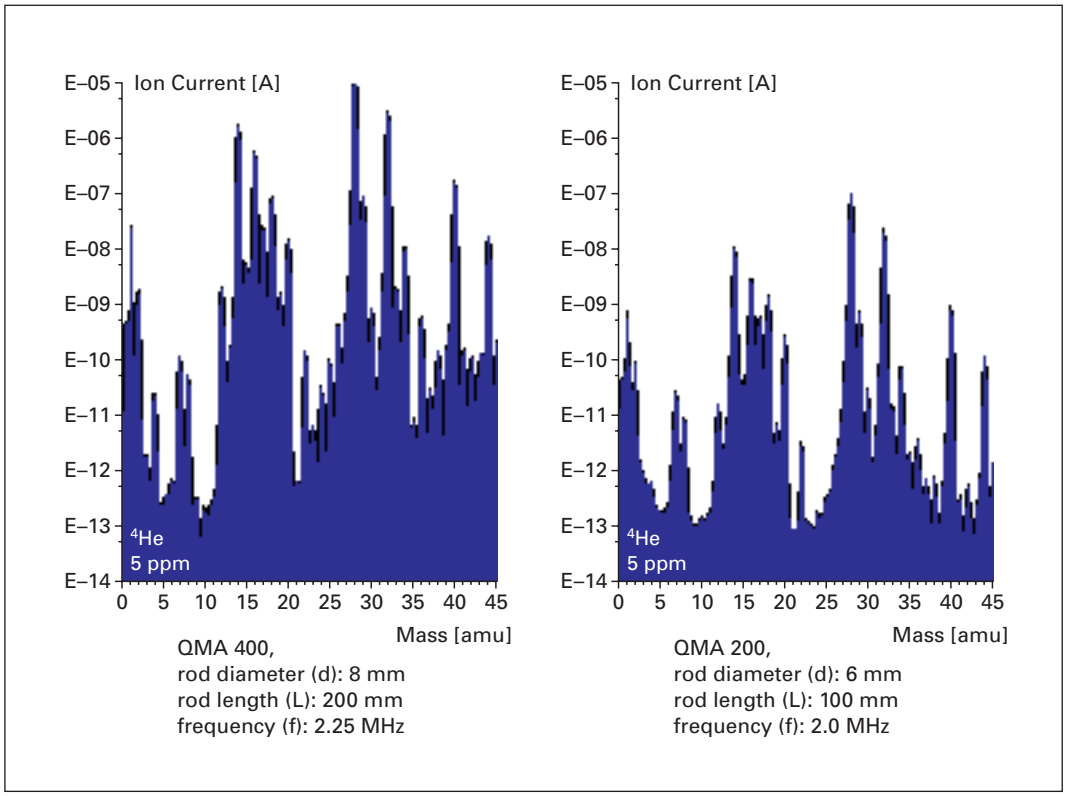


Fig. 21:
Air spectra; the input pressure was about $5 \cdot 10^{-6}$ mbar in each case.

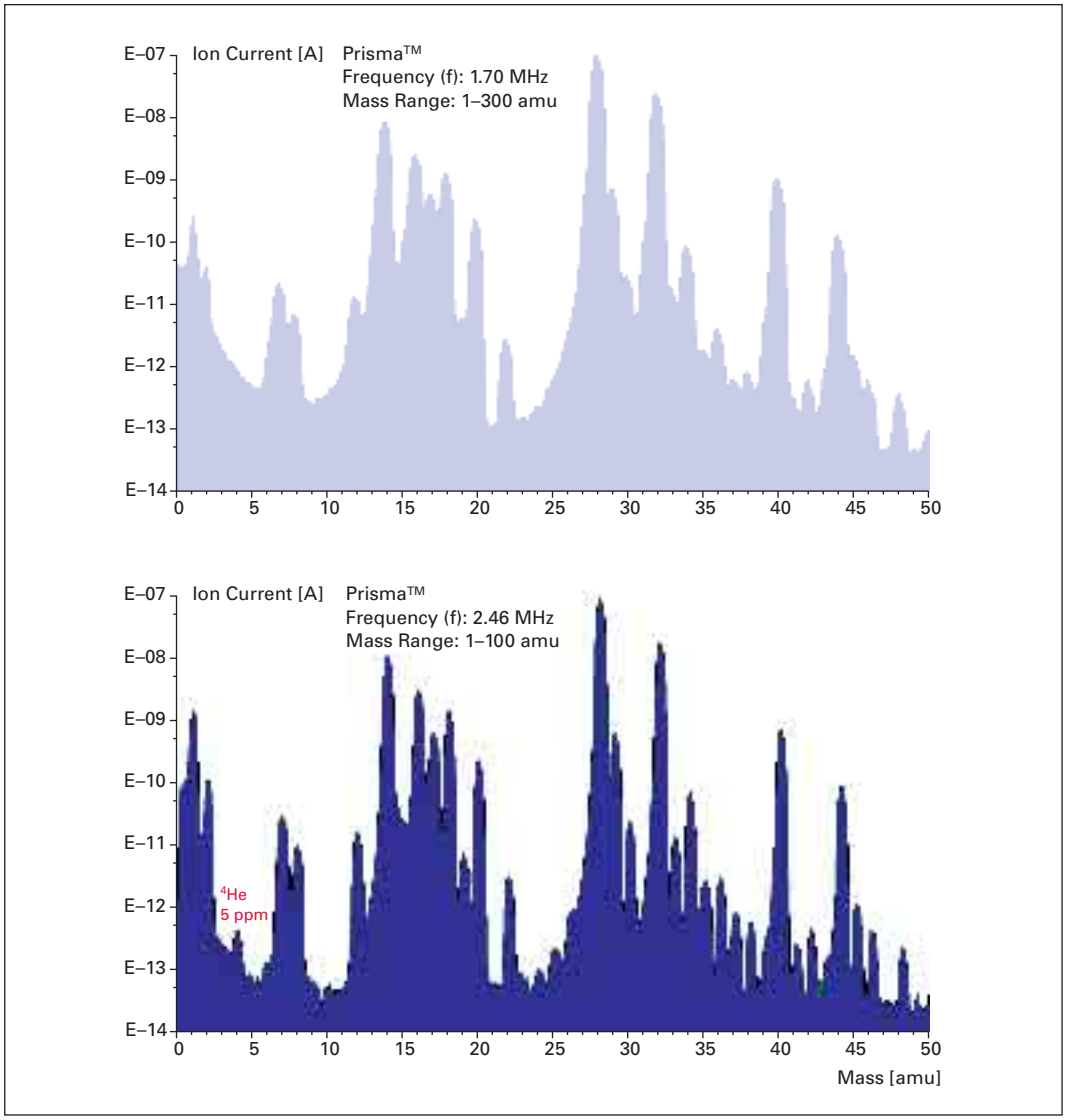


Fig. 22:
Air spectra, recorded with the QMA 200 with various HF generators.

An other important criteria for the size of the rod system is the mass discrimination. **The greater the diameter and the lenght of the rod system, the lower is the mass discrimination.** (Fig. 23)

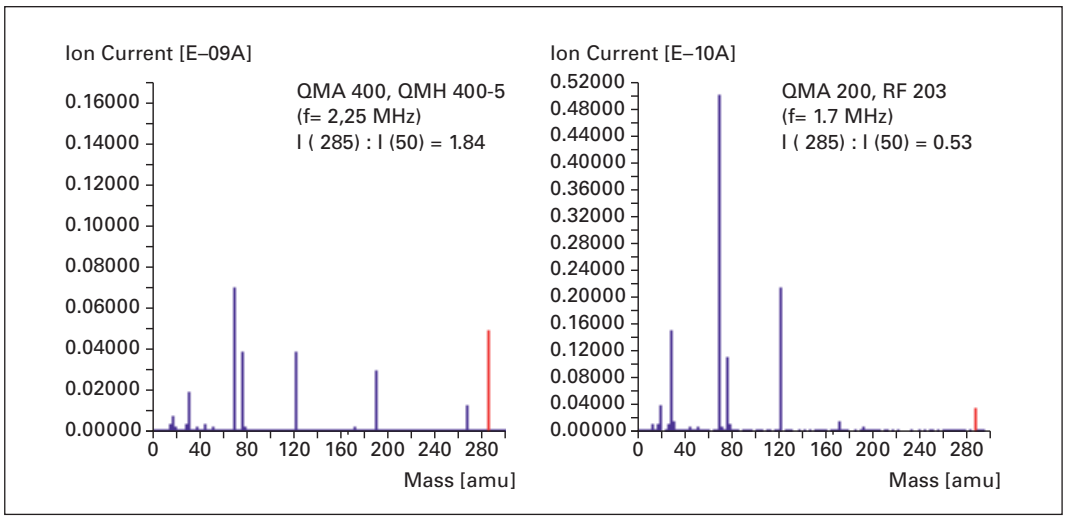


Fig. 23:
Spectrum of TFMT (2, 4, 6-Tris(trifluormethyl)-s-triazine) taken with QMA 400, (left) respectively QMA 200 (right) with 70 eV ionization energy. The inlet pressure was $1 \cdot 10^{-6}$ mbar.

Overview of the possible combinations of rod systems and HF generators

	Prisma™			QMG 422					
Rod diameter	6 mm	6 mm	6 mm	8 mm	8 mm	8 mm	16 mm	16 mm	16 mm
Rod length	100 mm	100 mm	100 mm	200 mm	200 mm	200 mm	300 mm	300 mm	300 mm
Material	stainless-steel	stainless-steel	stainless steel	Mo	Mo	Mo	Mo	Mo	Mo
Analyzer	QMA 200	QMA 200	QMA 200	QMA 400	QMA 400	QMA 400	QMA 410	QMA 410	QMA 410
Mass number range	1-100	1-200	1-300	1-512	1-1024	1-2048	1-128	1-340	1-16
HF generator	RF 201	RF 202	RF 203	QMH 400-5	QMH 410-1	QMH 410-2	QMH 400-1	QMH 410-3	QMH 402
Frequency	2.46 MHz	2.0 MHz	1.7 MHz	2.25 MHz	1.7 MHz	1.3 MHz	2.05 MHz	1.4 MHz	2.05 MHz
Power	0.08 kVA	0.1 kVA	0.1 kVA	9 kVA	8 kVA	8 kVA	7 kVA	8 kVA	7 kVA
Contribution to adjacent mass number ^{4}He/ 5 ^{40}Ar/ 41	10 ppm 10	20 ppm 20	100 ppm 50	10 ppb 10			< 1 ppb < 1	10 ppb 10	He/D_2 resol. possible
Transmission for Xe	–	10 %		35 %			–	50 %	–
Sensitivity for Ar with Faraday detector in A/mbar	$> 5 \cdot 10^{-4}$	$> 3 \cdot 10^{-4}$	$> 1 \cdot 10^{-4}$	$> 5 \cdot 10^{-4}$	$> 2 \cdot 10^{-4}$	$> 1 \cdot 10^{-4}$	$> 1 \cdot 10^{-3}$	$> 5 \cdot 10^{-4}$	–

The combination QMH 410 with QMH 402 (a modification of the QMH 400-1 for working in the so-called second stability region) is an exception. This combination has been specially developed for analysing gas mixtures such as $^4He/D_2$, $^3He/HD$, $H_3/^3He$, $CH_3/^{15}N$ and $CH_4/^{16}O$.

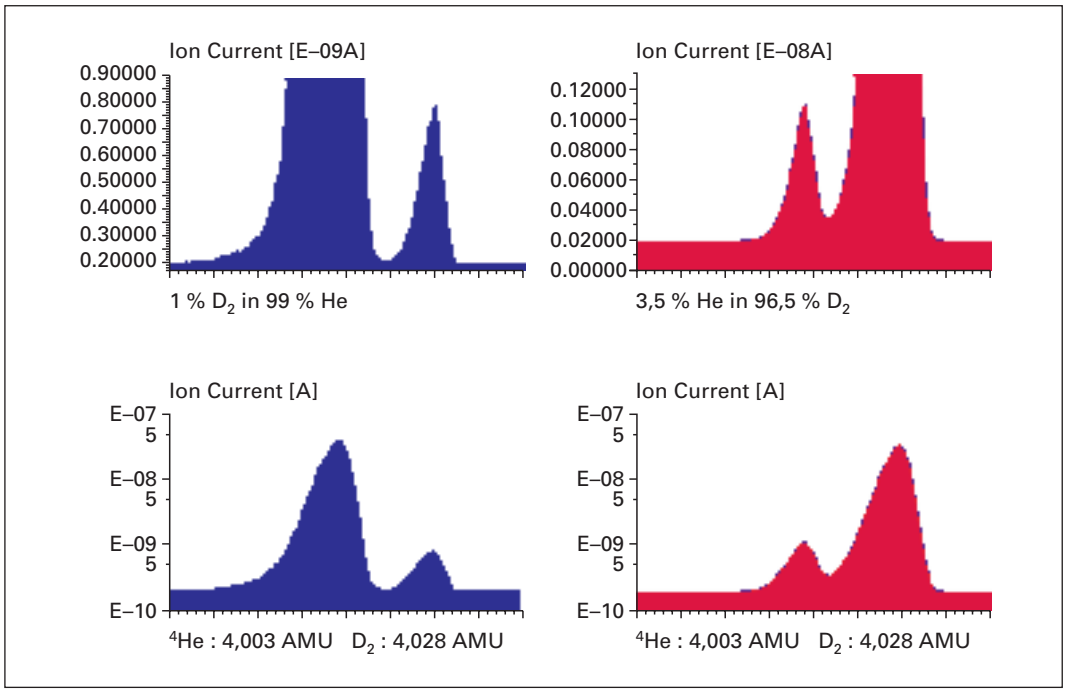


Fig. 24:
Spectra of $^4He/D_2$ gas mixtures in linear (top) and logarithmic (bottom) plot.

1.2.3 Ion detection

The ions, which have been separated according to their mass/charge ratio in the rod system, can be electrically detected by various types of detectors:
– Faraday cup
– continuous dynode secondary electron multiplier (C-SEM) and
– discrete dynode secondary electron multiplier (SEM).

The choice of detector is primarily based on the required detection sensitivity and the detection speed. It is also determined by other application-specific requirements, such as the required stability, the thermal and chemical stability and the amount of space available.

In the simplest case, but also that with the least systematic errors, the ions hit a Faraday collector (Faraday cup) where they give up their charge. A sensitive current/voltage converter (electrometer pre-amplifier EP 422, EP 200) converts the resulting current into a voltage signal that is proportional to the ion current. The detection limit lies between $1 \cdot 10^{-16}$ – $1 \cdot 10^{-14}$ A, depending on the time constant (from a couple of seconds to 100 ms). The Faraday signal is not affected by degradation or mass-discrimination effects at the detector. In addition to the simple and robust design, a Faraday detector also has long-term stability and high thermal resistance. The Faraday cup is therefore integrated into all analyzers described in this catalog. In combination with an electrometer preamplifier, the Faraday cup can only be used to detect positive ions.

Figure 25 shows a detector set-up with a Faraday cup and a C-SEM detector as used, e.g. in QMA 200. This C-SEM is a continuous dynode secondary electron multiplier in which the active layer has the task of multiplying the electrons as well as applied gain voltage distribution. This twin function limits the maximum current flow and the thermal stability of the continuous dynode detector. The utilizable amplification ratio of approx. 10^6 (at 2.5 kV) is essentially limited by the dark current in the active layer.

The C-SEM is positioned somewhat off the central axis of the rod system. The positive ions are deflected by applying a negative high voltage to the mouth of the C-SEM. The advantage of this arrangement is that it is very simple and quick to change between the two detectors. This change-over can also be carried out automatically depending on the ion current. In combination with the common electrometer pre-amplifier, the C-SEM is used to detect positive ions (from the originally neutral species) of small ion currents and rapid processes.

If there are very low ion currents and a very high measuring speed is required, the influence from photons must be reduced.

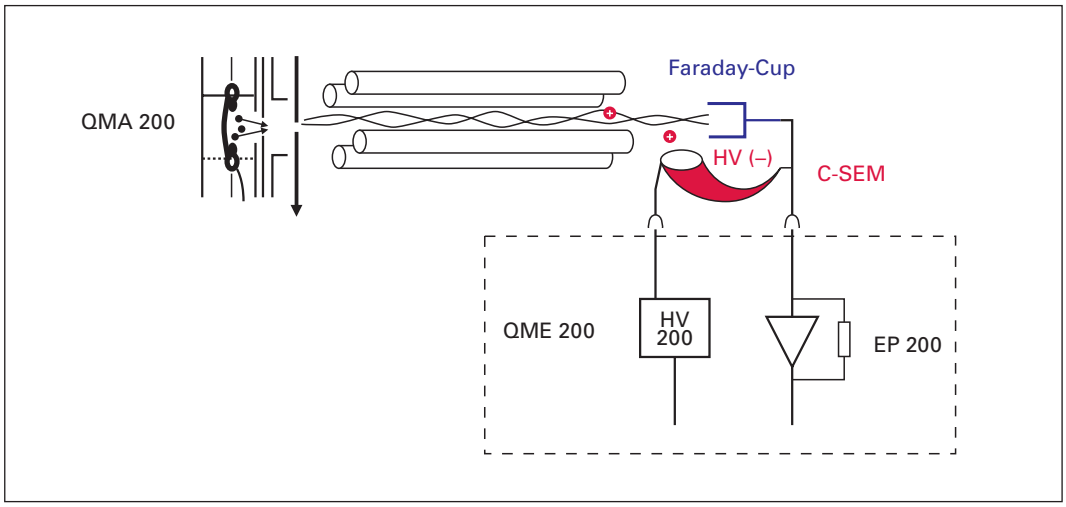
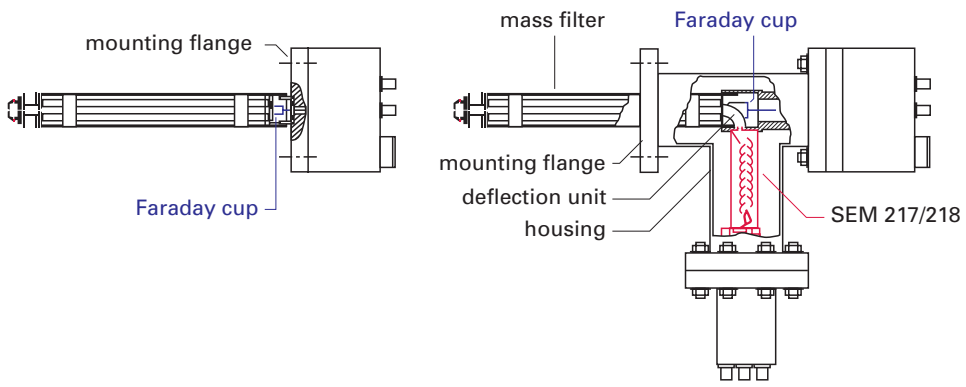


Fig. 25:
Arrangement of the Faraday cup and C-SEM in QMA 200.



QMA 400 with a Faraday cup

QMA 400 with a Faraday cup and SEM

Fig. 26:
Arrangement of the Faraday cup and SEM 217 in QMA 400.

In this case, a discrete dynode secondary electron multiplier (SEM) is used as the detector in a 90° off-axis arrangement, as shown in Figure 26.
The ions leaving the rod system are reaccelerated to several KeV. They are then deflected so that they hit the first dynode (conversion dynode) of the SEM. Here they eject a number of electrons which are then multiplied in a series of further dynodes (16 in SEM 217, 17 in SEM 218). The voltage for the individual dynodes is distributed via a separate resistance network. In order to minimize the contribution of impacting photons, soft x-rays or fast neutral particles (which are also coming from the direction of the rod system), the SEM is offset by 90° from the axis of the rod system. The ions are deflected by an electrostatic field which does not have any effect on uncharged particles. This produces the highest possible signal-to-noise

	C-SEM (continuous)	SEV 217 (discrete dynode)
		
voltage divider	continuous	1 MΩ/Dynode
amplification	10^6 at 2.5 kV	10^8 at 3.5 kV
arrangement	off-axis	90° off-axis
max. permissible current	10^{-6} A	10^{-5} A
max. nominal temperature range	120 °C	150 °C (at 1kV)
max. bakeout temperature	300 °C	400 °C

ratio. In this manner, current amplifications of up to 10^8 can be reached. Thanks to the high intensity, the subsequent electrometer preamplifier can operate in a higher measurement range and is thus very fast. The SEM 217 can be operated both in the electrometer mode (for positive ions) as well as in a "single ion counter" mode (in this case for positive and negative ions). Figure 27 shows the various operating modes and the corresponding electrical circuitry.

However, the use of a secondary electron multiplier as a detector in a mass spectrometer, whether it is a continuous or a discrete dynode SEM, does have some disadvantages. In quantitative analyses, it also brings uncertainties and sources of error. The number of electrons ejected per ion impacting the conversion dynode is dependent on both the mass of the ion, the type of ion, as well as on the energy of the ion. In a C-SEM and in the SEM 217, the energy of the impacting ion approximately corresponds to the operating voltage of the SEM, i.e. max. 3.5 kV. For this ion energy, the conversion rate of ions in the mass range between 100 AMU and 500 AMU may be reduced by a factor of 3, for example. In order to avoid this effect, the SEM 218 is equipped with an additional galvanically separated conversion dynode. The voltage applied to the conversion dynode is a constant – 6.3 kV and the ion energy is correspondingly higher (Figure 27, b). A further advantage of this variant is related to the dual high-voltage supply HV 421: the amplification of the SEM can be selected independently of the conversion rate.

Furthermore, the state of the surfaces and thus the yield of secondary electrons can change during operation. If more accurate quantitative measurements are to be carried out, the amplification must be checked at regular intervals and the unit must be recalibrated if necessary. Comparative measurements with the Faraday cup as the detector are suitable for this purpose. The SEM can be essentially freed from these sources of error if it is not operated as a "current amplifier" (which always averages over a certain period of time) but as an "ion counter" (Figure 27, c and d). The ions produce short pulses which can easily be detected individually. In this case, the detection limit is improved : less than 1 ion per 10 seconds can

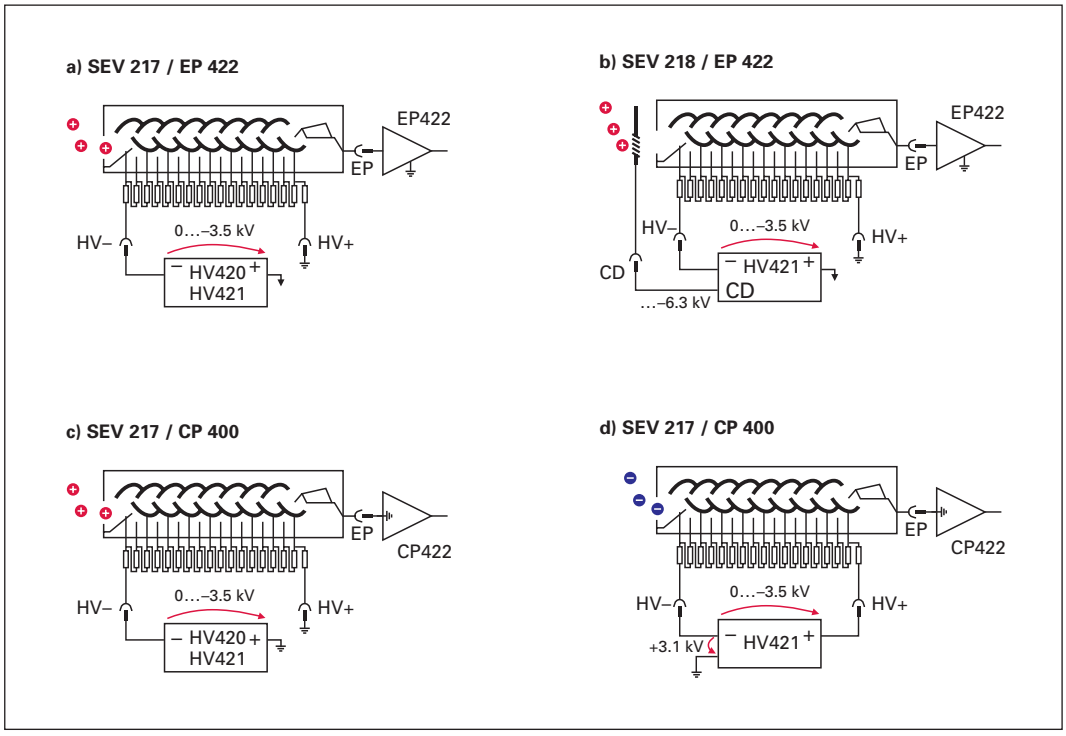


Fig. 27:
a) Detection of positive ions in the electrometer mode (current amplifier)
b) Detection of positive ions in the electrometer mode with a separate conversion dynode
c) Detection of positive ions in the counting mode
d) Detection of negative ions in the counting mode

be measured. The pulses triggered by the individual ions are counted directly or are summed after a corresponding standardization. In order to keep the counting loss as low as possible, both the ion energy as well as the amplification (> 10^6) should be sufficiently high. The accuracy of single-ion counting is not influenced so much by differences in the ion/electron conversion and the SEM amplification than in the case of current measurement. However, for large counting rates (> 10^6 counts/s), account must be taken of deviations in non-linearity caused by the time-overlapping of pulses [14]. The double pulse resolution of the SEM 217, the ion counter preamplifier CP 400 or the counter unit IC 421 amount to a total of approx. 20 ns.

The determination of the sensitivity and the amplification of a secondary electron multiplier is explained using a simple example. Air is admitted into a vacuum chamber flanged onto a mass spectrometer (Prisma™ M2). The total pressure before the air was admitted was $8.2 \cdot 10^{-8}$ mbar.

A mass spectrum recorded before the admittance of air showed water to be the major component. The intensity of the ion current for the mass number 28 was $3.5 \cdot 10^{-8}$ A or $2.1 \cdot 10^{-12}$ A, as measured by the C-SEM and Faraday detector respectively; it is neglected in the following considerations. After the introduction of air, the total pressure p_{tot} increased to $3.0 \cdot 10^{-6}$ mbar and the spectrum shown in Figure 28 was recorded.

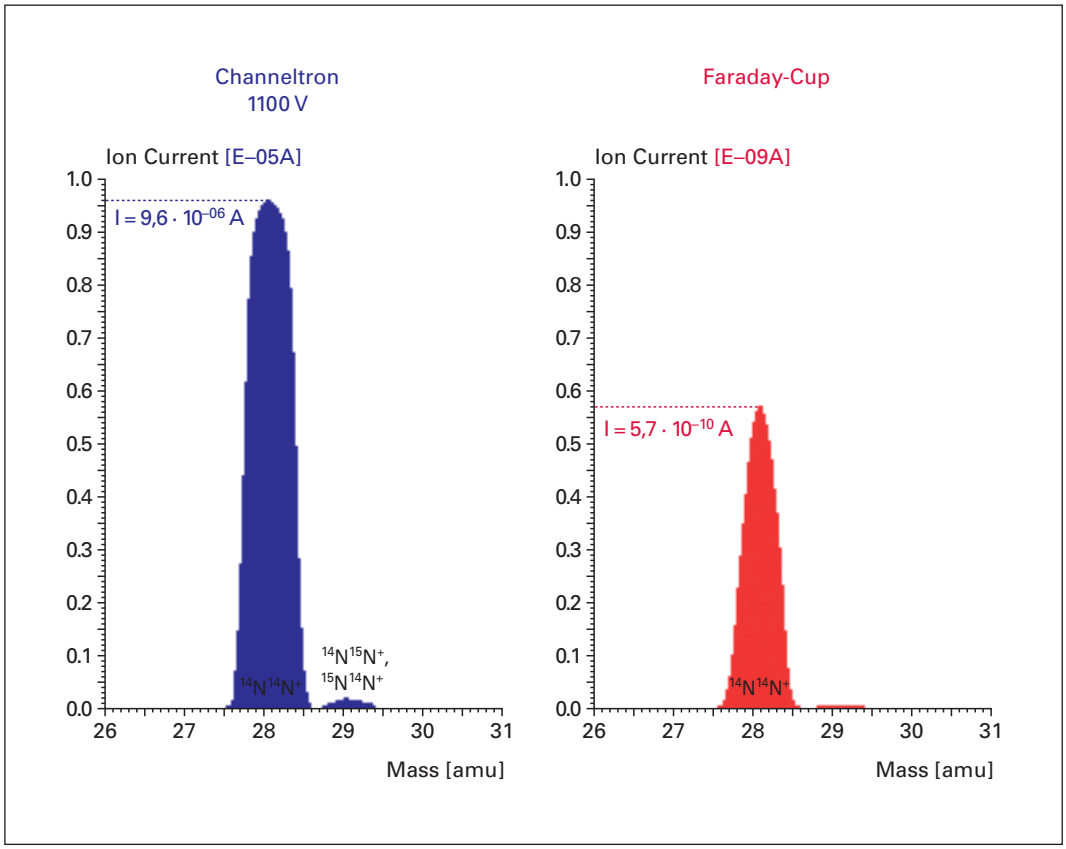


Fig. 28:
Spectrum measured with a C-SEM and with a Faraday detector with otherwise the same measuring conditions.

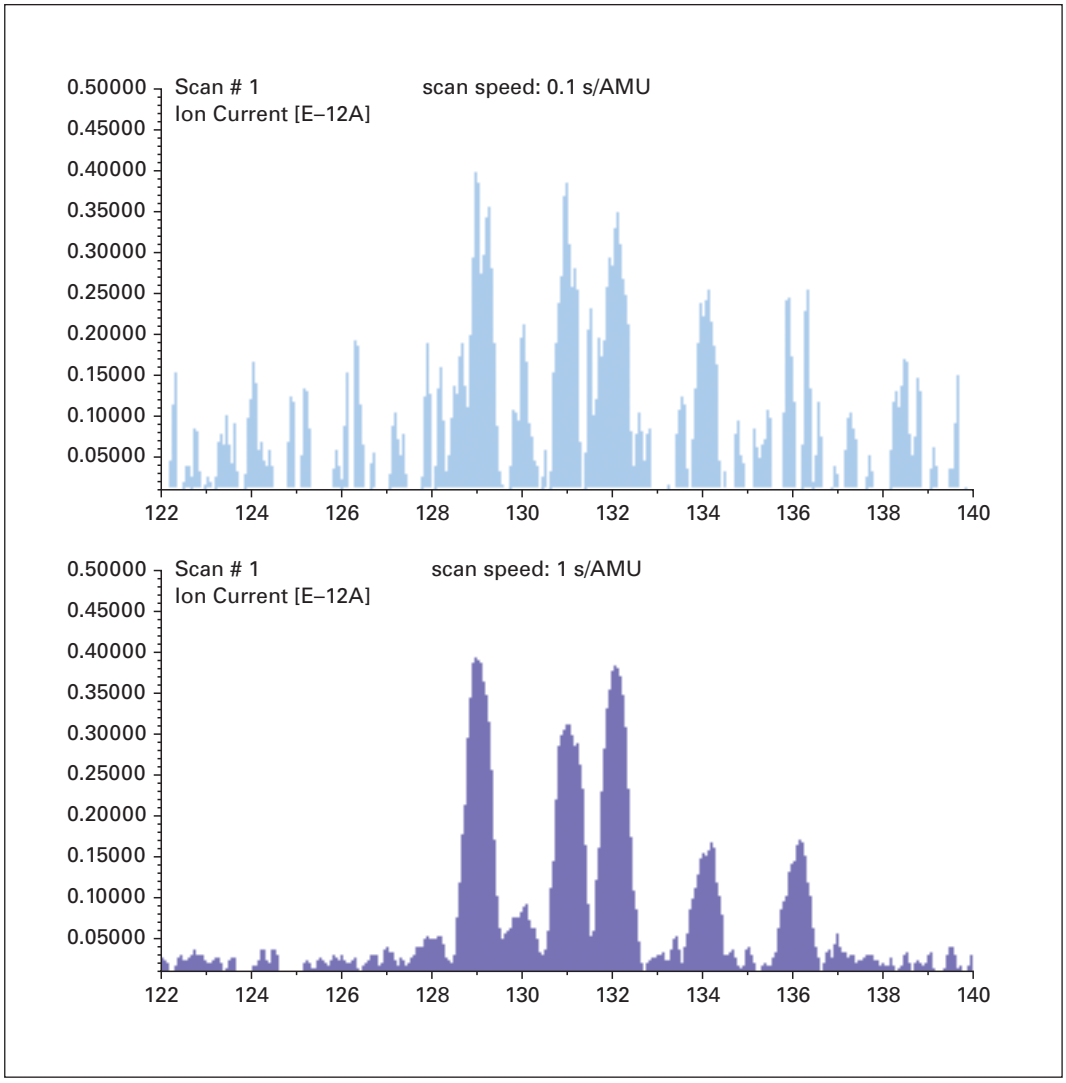


Figure 29: Measurement of Xe isotopes in air at various scan speeds (QMA 400 with cross-beam ion source and collimation magnet, inlet pressure $5 \cdot 10^{-6}$ mbar).

The proportion of nitrogen c_{N2} in air is 78.1 vol.-% (see Appendix), so that the partial pressure p_{N2} of nitrogen in the vacuum chamber is

$$p_{N2} = p_{tot} \cdot c_{N2}$$
$$p_{N2} = 3.0 \cdot 10^{-6}\ \text{mbar} \cdot 0.781 \approx 2.3 \cdot 10^{-6}\ \text{mbar}.$$

Because of the dominance of the nitrogen isotope ^{14}N in the natural distribution with 99.6 % compared to the nitrogen isotope ^{15}N with 0.36 % (see Appendix), only the mass number 28 is evaluated.
The sensitivity of the mass spectrometers under the measuring conditions and settings of the ion source amounts to:

$$E_{N2} = I(28) / p_{N2}$$
$$E_{N2} = 9.6 \cdot 10^{-6}\ \text{A} / 2.3 \cdot 10^{-6}\ \text{mbar} \approx 4.2\ \text{A/mbar}$$

with the C-SEM detector (1100 V)

or

$$E_{N2} = 5.7 \cdot 10^{-10}\ \text{A} / 2.3 \cdot 10^{-6}\ \text{mbar} \approx 2.5 \cdot 10^{-4}\ \text{A/mbar}$$

with the Faraday detector.

The amplification of the C-SEM at a voltage of 1100 V can be determined quite simply from the intensity ratios.

$$V = 9.6 \cdot 10^{-6}\ \text{A} / 5.7 \cdot 10^{-10}\ \text{A} \approx 1.7 \cdot 10^{4}$$

The detection of ions is a statistical process: ions hit the detector at random intervals. If a particular accuracy is required, then a certain number of events must be

measured. For N events (i.e. registered ions), the statistical error is ~ 1/√ N. If, for example, 100 counts/s are measured (this corresponds to a partial pressure of 10^{-13} – 10^{-14} mbar), then for a measurement time of 1 s, the relative statistical error is 10 %. For a given sensitivity of the mass spectrometer, this error can only be reduced by an increase in the measurement time (Fig. 29).
A scanning rate of 64 data points per AMU was used in the analog scan show in Fig. 29.
It should be mentioned that a further increase in the measurement time and suitable averaging over many scan cycles (1000 scans with each 1 s/AMU), the Xe isotopes 124 and 126 (with a concentration of approx. 90 ppt in air) can also be detected [13].
For rapid measurements of the gas composition, and in order to obtain a high measurement speed, an operating mode is generally used which is limited to the intensity maximum of the mass numbers of interest and which averages over a defined time interval (**M**ulti **I**on **D**etection).

1.2.4 Control and signal evaluation

The control of the components of the quadrupole analyzer described in the previous sections necessitates various electronic modules that are installed in the control units (QMS 422, QMI 422 or QME 200). The most important functional modules are:

- the quadrupole controller (QC) to control the mass scan and to process the measured signal
- internal data and parameter storage and a computer-interface for the transfer of data and parameters
- the voltage supply for the ion source (IS)
- the voltage supply for a secondary electron multiplier
- optional modules for the digital and analog output of the measured signals (DO, AO)
- optional modules for the digital and analog input of external signals (DI, AI)
- optional local operating console (CS 422)

These modules are individual units that are interconnected via an internal data and control bus. This modular construction allows a technically optimized, cost-effective design of the control unit for each task. Communication with a computer (PC) and the QuadStar™ software installed on it is carried out either via a RS-232-C or an optical LAN-ArcNet interface. The requirements of the computer are relatively low, they are almost exclusively determined by the operating system Microsoft Windows (WIN 95,98 or NT 4.0) that is required for the QuadStar™ operating software. At the start of a measurement, the control parameters are first sent from the computer to the control unit. This set of parameters is stored internally in the control unit and the current measurement is carried out. The data of the measurement signal are intermediately stored in the internal storage unit of the control unit and continuously sent back to the computer. The computer is then used to visualise and store the results for their subsequent processing. In case of an interruption in the communication between the computer and the control unit, the measuring job sent last is continued and the equipment status remains unchanged.

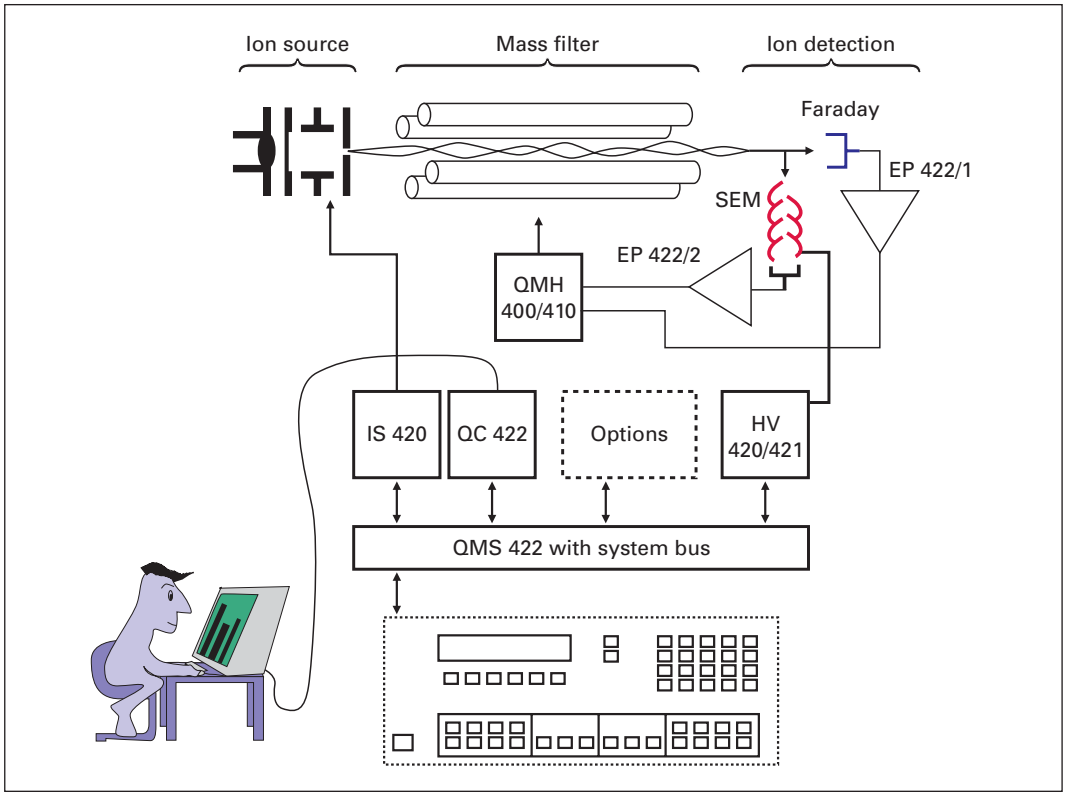


Fig. 30:
Diagram of the electronic modules of a QMG 422.

All of the optional input and output channels remain activated and the data, including any limits and threshold values, remain available. If the optional operating console CS 422 is used, there is no need for a computer. This operating unit then also serves as the front panel of the QMS 422. The control units QMS 422 or QMI 422 are designed as rack modules.
The QuadStar™ software is the common operating interface for all mass spectrometers (with the exception of the Prisma™ 80). This allows the exchange of measured data and control parameters between different units. At the same time, this also facilitates ease of operation between different systems for the user. A dynamic data exchange with other programs is possible via DDE. Measured data that is already stored can be transferred to other evaluation programs after conversion into ASCII format.

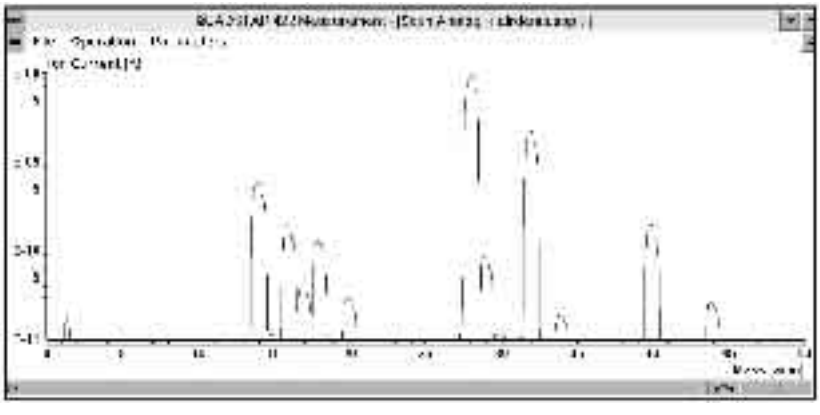


Fig. 31:
Scan analog measurement of air. The mass range is freely selectable, the y axis can be switched from linear to logarithmic.

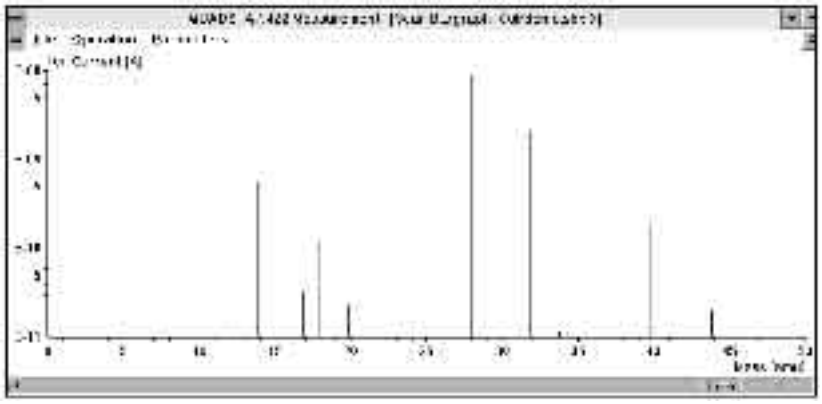


Fig. 32:
Scan bargraph measurement of air. Intelligent peak recognition routines allow major data reduction without significant loss of information.

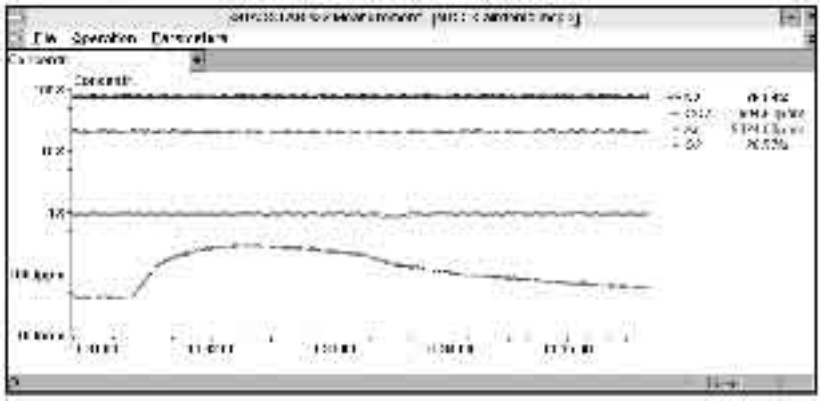


Fig. 33:
Concentration of nitrogen, oxygen, argon and carbon dioxide displayed as a function of the current time. The time and concentration axes are freely selectable.

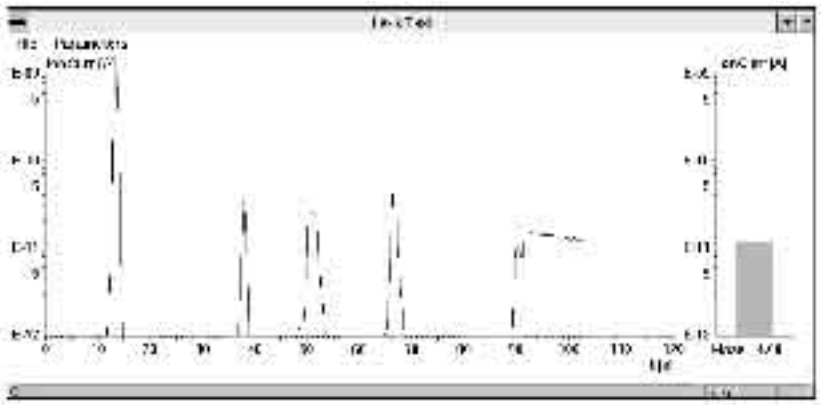


Fig. 34:
The leaktest is used for simple detection of leaks in vacuum apparatus. Display of time lapse of the helium signal and the actual intensity as a chart. Additional acoustic signal if desired.

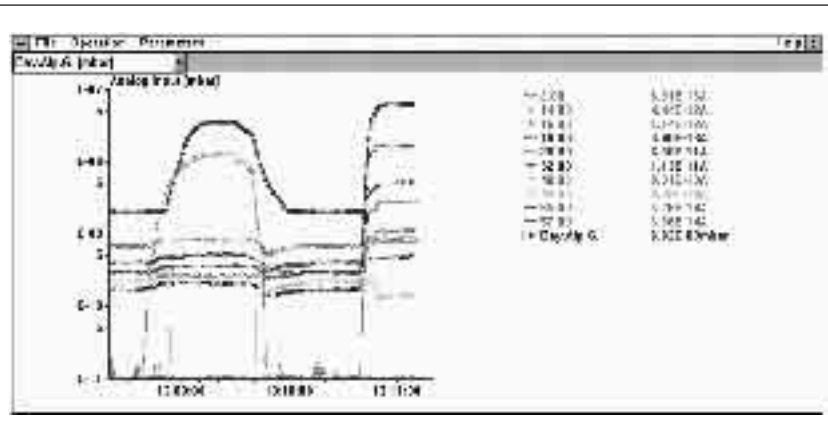


Fig. 35:
Simultaneous display of mass spectrometer data and analog data, e.g. of a vacuum gauge.

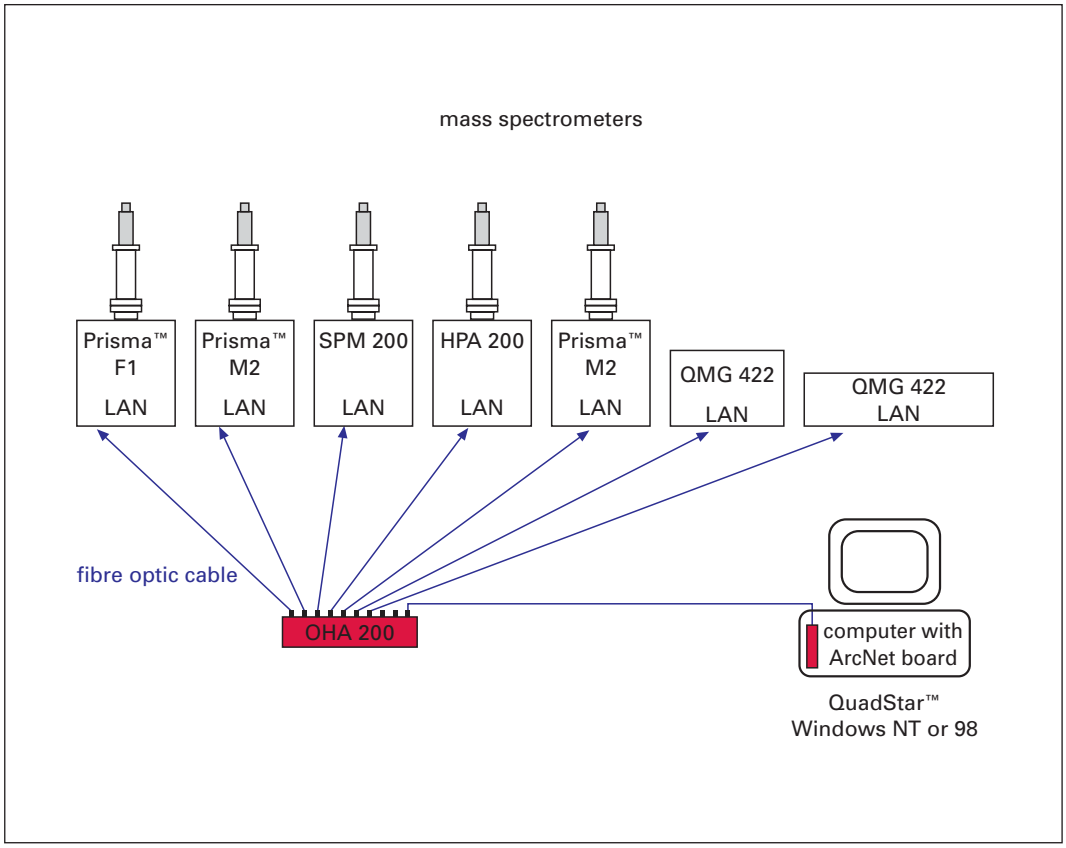


Fig. 36: Linkage of different mass spectrometers to a common network.

It is possible to connect several mass spectrometers via a common ArcNet network. (Fig. 36) Each of the mass spectrometers within this network can carry out its own independent measurement tasks. The individual mass spectrometers are connected via an optical LAN interface and fiber optic cables to the host computer in a network. The use of the fiber optic cables and optical hubs allows a fast and trouble-free data transfer, even over long distances (up to several hundred meters) as well as a clear voltage isolation between the mass spectrometers and PC. The mass spectrometers integrated into the network are not affected when a system is switched off or a new system is added.

1.3 Mass spectrometer in connection with gas inlet and pump systems

Quadrupole mass spectrometers require a working pressure or total pressure less than $1 \cdot 10^{-5}$ mbar (high vacuum). Since many processes operate at higher pressures, the mass spectrometer cannot be solely selected based on analyzer, ion source and detector.
A coordinated system consisting of a mass spectrometer, gas inlet with pressure reduction, vacuum pumps/pumping stations and total pressure measurement is required. In addition to knowledge of the properties of the mass spectrometer, knowledge of the characteristics of the pumps and gas inlet systems is necessary for a targeted design of an optimal system for the particular application.
The advantage here is supply from a single source. Pfeiffer Vacuum offers individually tailored mass spectrometer systems for your application using in-house components. The following chapters describe some typical systems.

Fig. 37:
Monitoring of gas composition on production system.

1.3.1 Mass spectrometers – set ups for inlet pressures < 10 mbar

For a classical residual gas analysis in the high vacuum range, the analyzer of the mass spectrometer should be connected directly to the vacuum chamber with the greatest possible conductance tubing. The direct insertion of the analyzer into the interior of the vacuum chamber is the best scenario. However, the analyzer should be protected from intense bombardment by any particle beams that may coat or erode the analyzer. Only so-called "open" ion sources (axial, screen, cross-beam ion sources) are used for this task. The upper pressure limit for such an arrangement is a few 10^{-04} mbar.

However, many processes, such as sputtering, CVD, MOCVD, plasma etching and ion plating, operate at higher total pressures of up to a few mbar. In this pressure range, differentially pumped mass spectrometers with open, gas-tight or special ion sources are used. The attachment of the process chamber to the analyzer unit should be implemented with a direct, short connection with a small internal surface area and a low dead volume to ensure a fast response time of the mass spectrometer to changes in the partial pressure conditions in the process chamber.

Fig. 37 shows three variants of a differentially pumped mass spectrometer with an open ion source and an axial gas inlet. In all three variants, the reduction of the pressure in the process chamber to the operating pressure of the mass spectrometer is carried out via a fixed or variable conductance value (aperture or gas metering valve) in front of the open ion source. Therefore, the pressure in the ion source equals the pressure in the analysis vacuum chamber.

A UHV gas metering valve (Fig. 38 a) to vary the conductance is preferable when a large process pressure range is to be covered and continuous heating of the gas inlet up to 200 °C is recommended. With the valve combinations b) and c), both a process gas measurement as well as a residual gas analysis at low total pressures is possible. For residual gas analysis both valves (b) and the gate valve (c) are opened resulting in the mass spectrometer (open ion source) being directly connected to the process chamber with a high conductance path (DN 40). The design with the valve combination HPI 010 allows the

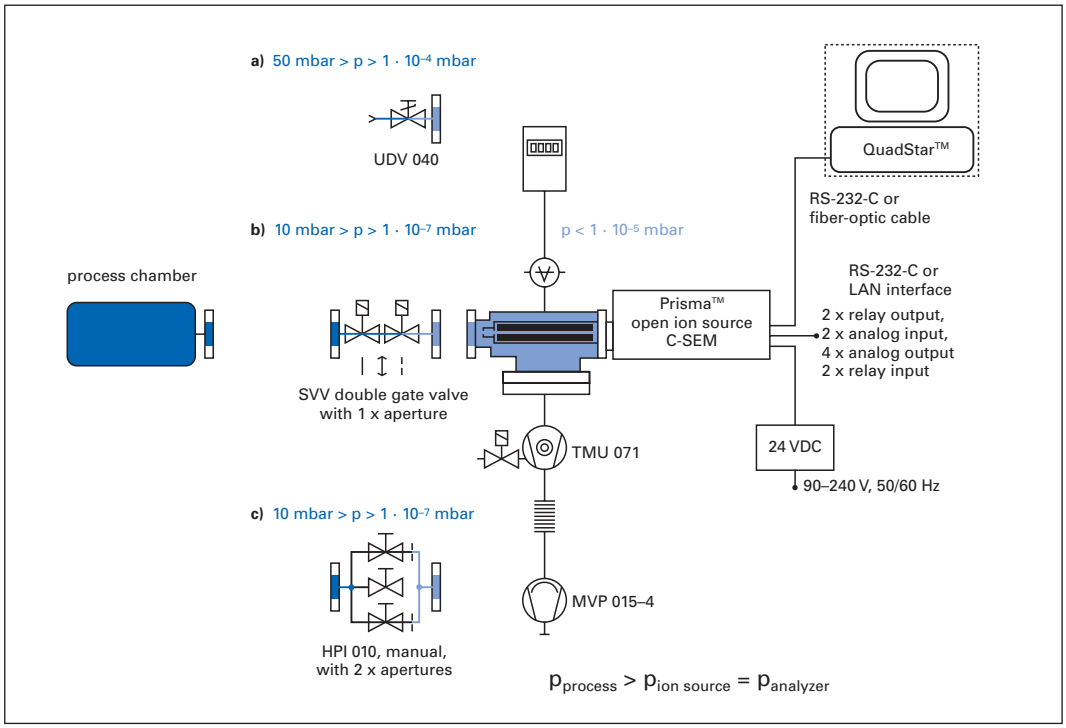


Fig. 38:
Differentially pumped mass spectrometer with an open ion source

a) with a UHV gas metering valve to adjust the conductance

b) with a SVV double valve (an aperture valve and a gate valve)

c) with HPI 010 valve combination (one gate valve, 2 x aperture valve)

optimization of the inlet conditions for 2 process steps operating in different pressure ranges as well as residual gas analysis.
In order to attain the lowest possible detection limit and a large dynamic measuring range, memory-free pumping systems with a high compression ratio are necessary for this arrangement. A suitable combination consists of e.g. a turbo-drag-pump TMU 071 with an oil-free 4-stage membrane pump as the backing pump. The gas load at the process pressure lies in the range of $1–5 \cdot 10^{-4}$ mbar · l/s, so that a pumping speed of approx. 50–200 l/s is sufficient for the turbopump. This gives a pumping speed for the backing pump of approx. 1 l/min, or approx. 10 l/min when the turbo-drag-pump is operated with a purge gas. Because of the simple single-stage pressure reduction and the relatively low total pressure in the whole analyzer unit, the arrangements shown in Fig. 38 are also suitable for the analysis of corrosive gas mixtures. For these applications, the turbopump is operated with an inert purge gas and the pressure in the analyzer unit is reduced further, if necessary, with smaller apertures. However, with this reduction of the working pressure, the influence of the background spectrum of the analysis unit on the measured results is greater, and thus determines the attainable limits of detection and the dynamic measuring range.
An example for a differentially pumped mass spectrometer with a gas-tight ion source is shown in Fig. 39.
In this case, the pressure in the process chamber is reduced in 2 steps, before and after the ion source. The pressure in the ion source is thus a factor of approx. 10–50 higher than the background pressure in the analyzer vacuum chamber.
In contrast to the systems with an open ion source, this set-up can reduce the influence of the background spectrum of the analyzer unit and thus lower limits of detection can be achieved. At the same time, however, the risk of contamination of the ion source increases so that this design should mainly be used for the analysis of non-condensable and non-corrosive gas mixtures. A classical residual gas analysis is only possible to a very limited degree with this type of design.
A new ion source was specially developed for the continual monitoring of the process and residual gas of sputtering processes (the SPM ion source), [16,17]. In this

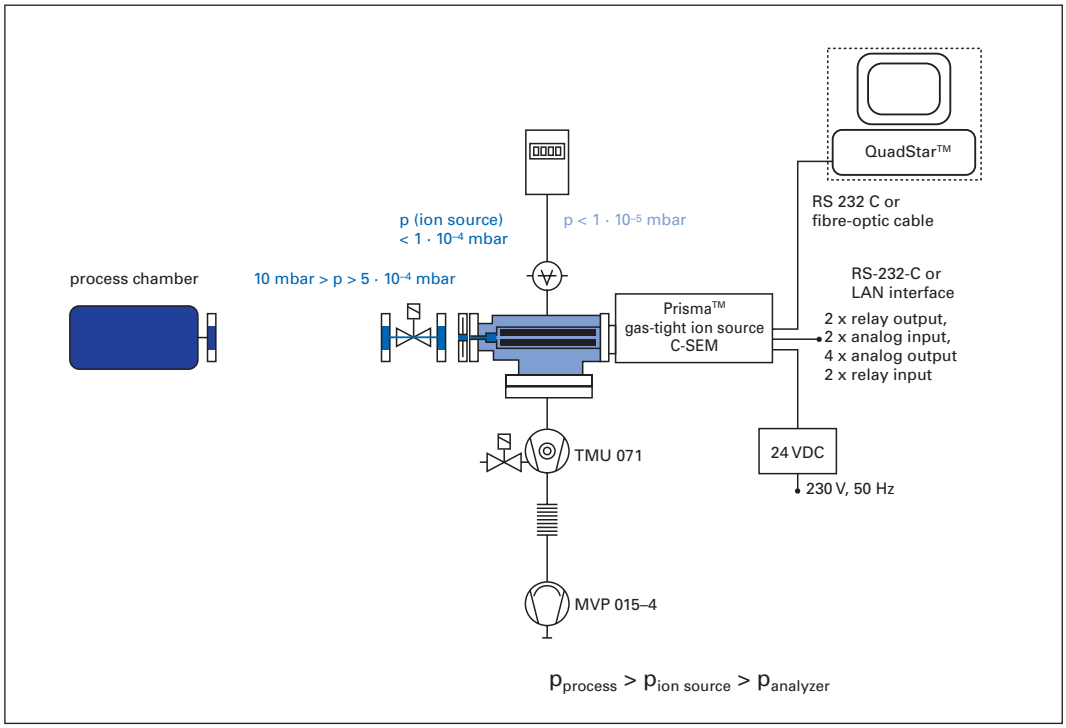


Fig. 39:
Differentially pumped mass spectrometer with a gas-tight ion source.

design, the ion source is not a separate component of the analyzer but is integrated into the analyzer vacuum chamber (Fig. 40a). Here the pressure is reduced only after ionization of the process gas, i.e. the pressure in the process chamber equals the pressure in the ion source, which essentially eliminates the contribution of the background spectrum of the analyzer unit to the measured results. This design provides limits of detection down to the ppb range, even for reactive gases

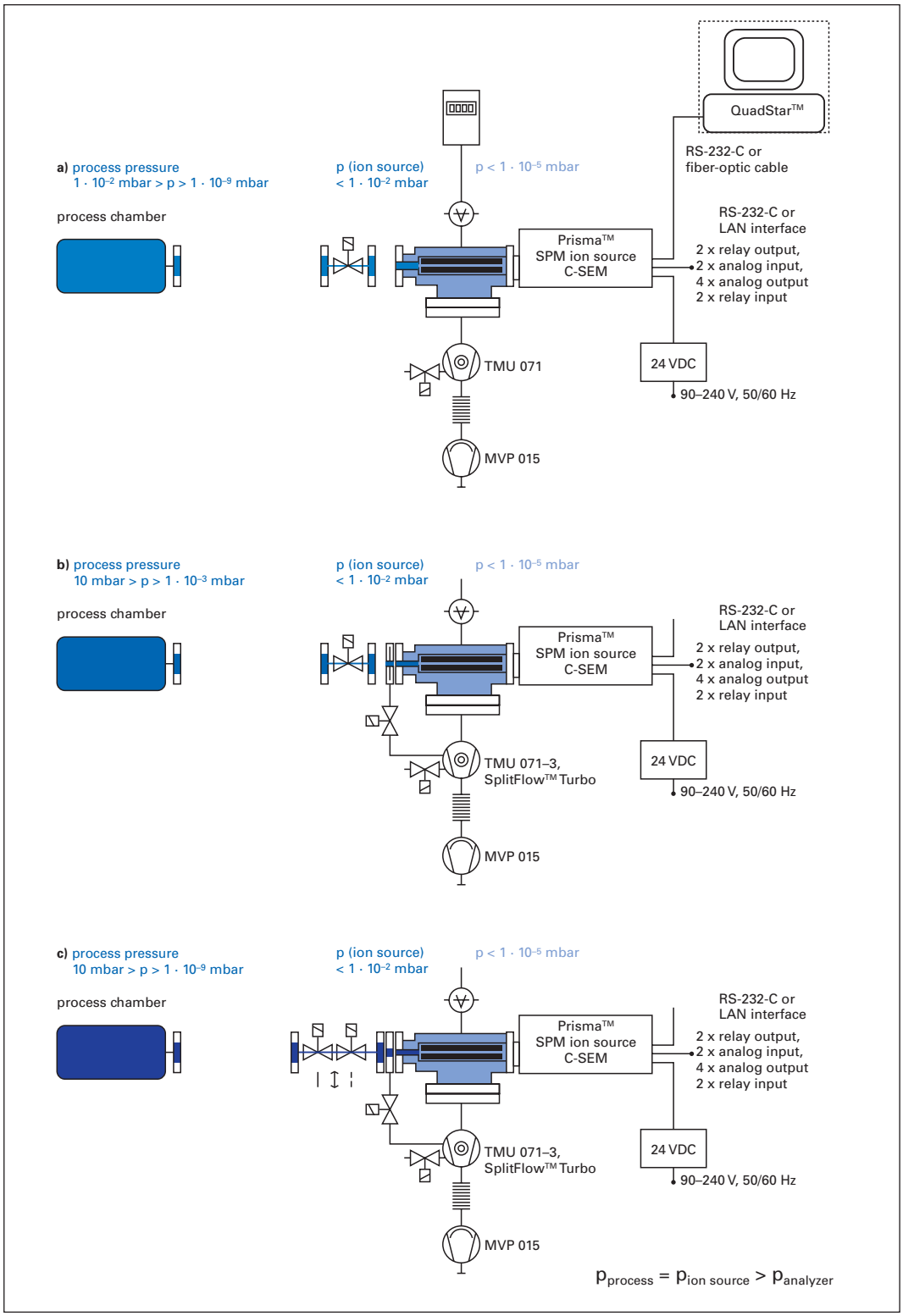


Fig. 40:
Differentially pumped mass spectrometer with a SPM ion source

a) SPM 200

b) SPM 200 with additional pressure stage with a fixed screen

c) SPM 200 with additional pressure stage with a removable screen

with a dynamic measuring range of > 8 decades. The working range of such an SPM ion source is from < 10^{-9} up to approx. 1–2 · 10^{-2} mbar. Starting from the conditioning phase of the sputtering chamber, ignition of the sources, the coating process itself and back to the initial state, the gas composition of the main components as well as any possible trace components can be monitored continuously without the need to switch any valves. Additional pressure stages are only necessary if the process pressure exceeds 10^{-2} mbar (Fig. 40 b and 40 c) .

To generate an intermediate vacuum for the additional pressure stage, the 2nd intake port of a SplitFlow™ turbo-drag-pump (TMU 071-3) can be used to advantage.

Such an interstage port in combination with the purge gas mode is also recommended for the analysis of corrosive gas mixtures. The following diagram shows further examples of pump combinations for the analyzer unit.

The pump combinations shown in Fig. 40 a are used for the analysis of gas mixtures with corrosive or explosive components. The injection of purge gas into the turbo-drag-pump dilutes the sample gas so that the corrosive loading of the backing pump (here an oil-free diaphragm pump) is reduced and an inert gas mixture is produced at the outlet of the system. The injection of purge gas also suppresses memory and enrichment effects of the sample gas in the backing pump.

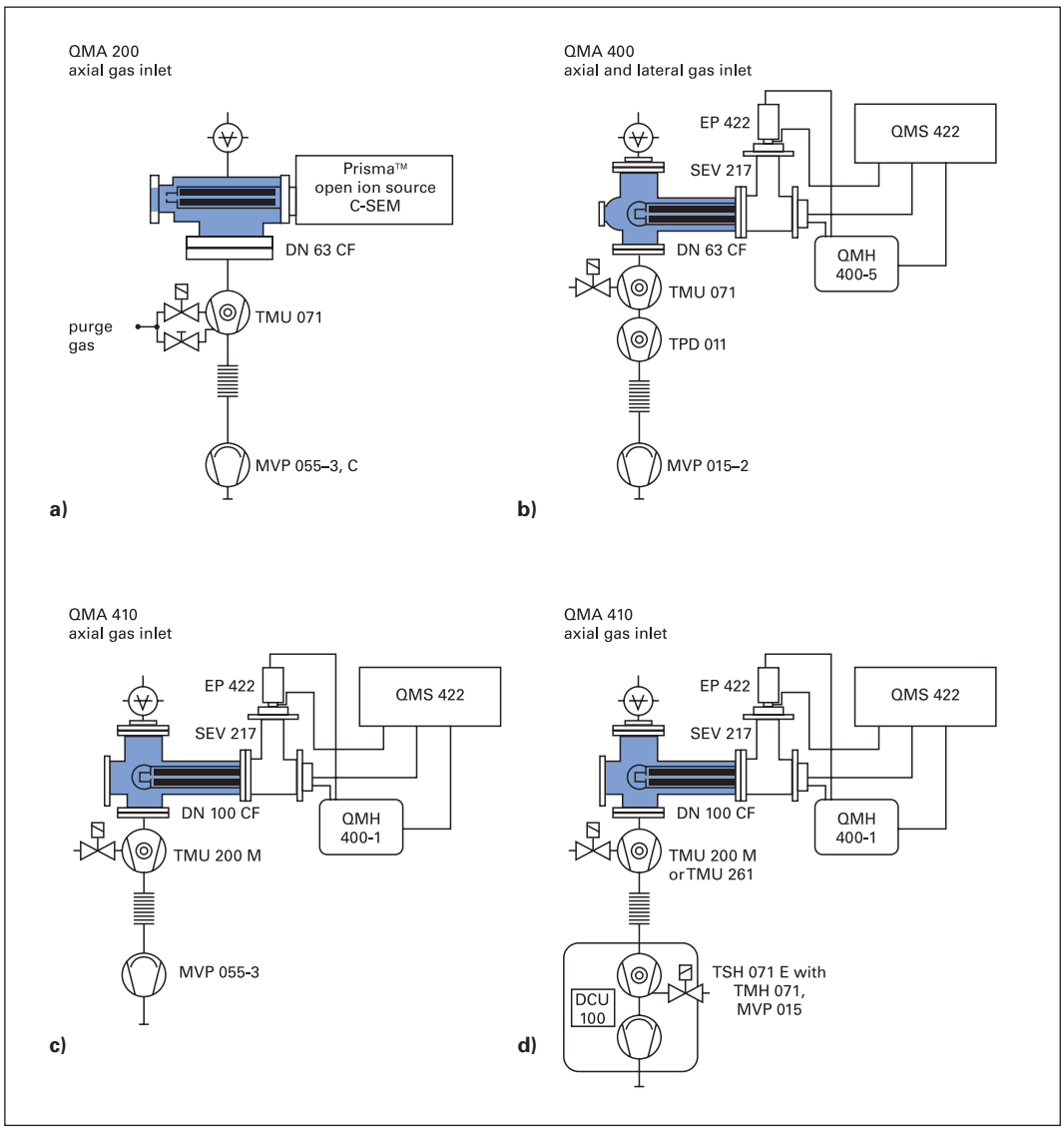


Fig. 41:
Examples of specially optimized pump systems for the analyzer unit.

The in-line connection of an additional turbopump (Fig. 41 b and d) is a means to increase the compression ratio of gases with a low molecular weight (H_2, He). This leads to a reduction in the partial pressure of these gases in the residual gas spectrum and thus to considerably better detection limits for these gases. The influence of the additional turbopump on the background of the residual gas is shown in Fig. 42. The experiment was carried out with the set up shown in Fig. 41 b. The effective pumping speed on the analysis vacuum chamber is not altered by the in-line connection of an additional turbopump, so that a reduction of the total pressure in the vacuum chamber is only then attained if it is dominated by the partial pressure of hydrogen or helium.

As can also be seen from Fig. 42, the attainable partial pressure of hydrogen in this case is determined by the backing vacuum pressure or the compression ratio of the TMU 071 ($K_{H_2} > 10^5$). The final partial pressure of components with a higher molecular weight is determined by the pumping speed of the TMU 071, since the compression ratio of $> 10^{11}$ for these components is already sufficient.

Fig. 41 c and 41 d show the pump combinations for the analysis vacuum chamber of the QMA 410 that have a greater effective pumping speed. Such combinations, particularly turbo-drag-pumps with magnetic bearings, are mainly used in the analysis of very pure gases and trace analysis. Their advantages include high compression and freedom from lubricants and routine maintenance.

In most cases, the total pressure in the analysis vacuum chamber is measured independently of the mass spectrometer. This serves as an independent monitoring of the maximum permissible inlet pressure, as the triggering sensor for the automatic closure of inlet valves as well as the pressure control of the baking and optimization cycles. In the selection of the gauge type and the positioning of the gauges to measure the total pressure, it must be ensured that there is no influence between the total-pressure gauge and the quadrupole analyzer via electrostatic or magnetic fields. In the case of very sensitive measurements of the gas composition with the mass spectrometer, the total-pressure gauge is frequently switched off or is positioned further away for this reason.

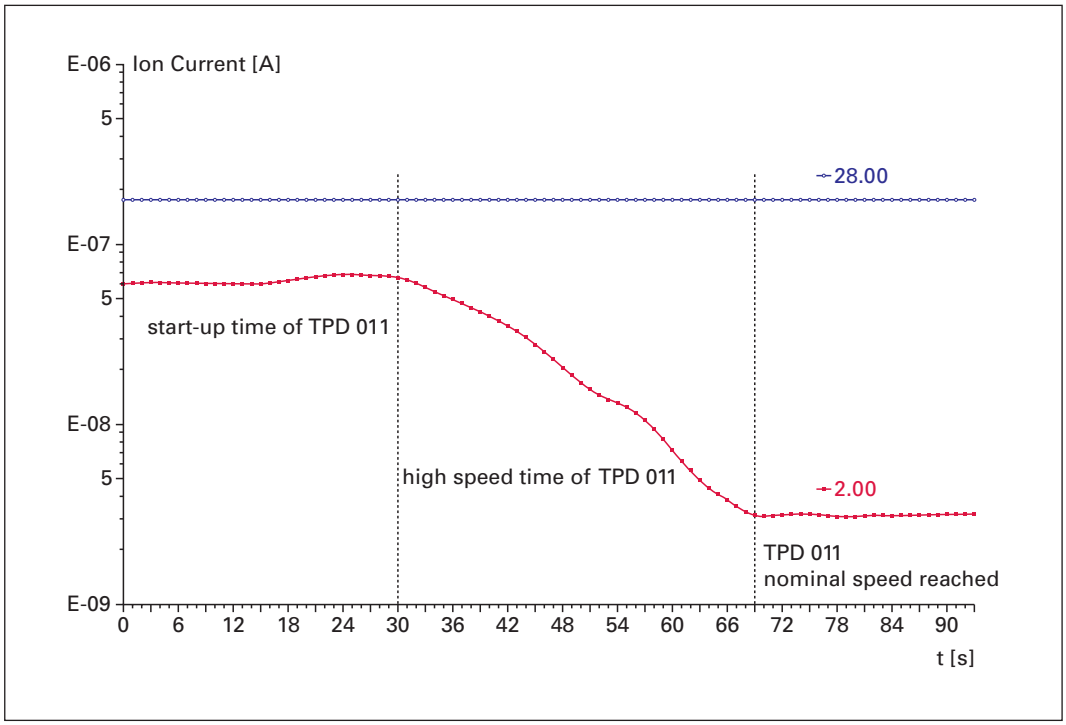


Fig. 42:
The effects of an additional turbopump on the partial pressures of hydrogen (m/e = 2) and nitrogen (m/e = 28).

1.3.2 Mass spectrometers – set ups for inlet pressures > 10 mbar

The utilization of mass spectrometers for process gas analysis is not confined to vacuum technologies. In numerous applications the gas mixture to be analyzed is at higher pressures. In most of these cases the parameter of interest is not the absolute partial pressure of the individual gas components, but instead their concentration. These concentrations are independent of the total pressure or inlet pressure of the gas mixture, so they can be compared universally with other measurements. This task is generally summarized under the term of "quantitative gas analysis". In quantitative gas analysis the mass spectrometer systems are operated either as stand alone analyzer unit, or in combination with other measuring methods such as gas chromatography, infra red spectroscopy, thermogravimetry and liquid phase chromatography. The particular advantages of the mass spectrometer systems lie in their universal connectivity, fast acquisition times, small sample gas consumption as well as their adaptability to various and variable inlet pressure ranges. Mass spectrometer systems are consequently especially suitable for online monitoring of the gas composition in rapidly fluctuating processes with large dynamic ranges. For the gas inlet systems described below, only small amounts of sample gas are needed and the requirements for conditioning the sample gas are relatively simple, so that in most applications they are either already fulfilled or can be achieved with little effort.

The connection to the gas sampling point must be direct and have limited volume and internal surface area in order to avoid affecting the gas composition before the measurement is taken and to achieve a fast response time for the mass spectrometer. Reduction of the inlet pressure of the sample gas to the operating pressure of the quadrupole analyzer is usually achieved in several pressure stages to avoid or minimize any mass discrimination effects that can otherwise change the gas composition. The gas is drawn from the high pressure side through a suitably sized capillary in laminar flow into a small volume from where it is withdrawn, again in laminar flow, by a throttled pumping system. The gas throughput of the capillary lies in the range of 1–10 sccm ($1.7 \cdot 10^{-2}$–$1.7 \cdot 10^{-1}$ mbar · l/s). A small fraction (0.01% – 1%) of the gas flows via a defined conductance value into the vacuum chamber in molecular flow. Here too, separation of the components does not take place in spite of the mass-dependent molecular flow, because the gas is pumped out of the vacuum chamber in molecular flow too. This two stage pressure reduction ensures that the composition of the gas mixture remains unchanged. Chemical reactions and condensation effects are largely suppressed by the following measures:

1) The capillaries and orifices or valves in the high pressure stage are heated.
2) Suitable selection of all construction materials in contact with the gas mixture.
3) Suitable dimensioning of the conductance values for producing optimum pressure gradient and gas throughput.
4) Suitable selection and dimensioning of the pumping system.

Requirements for the sample gas:

Temperature range	Room temperature to 200 °C
Pressure range	1–1200 mbar (absolute), depending on the inlet system
Moisture	non-condensing under the inlet conditions
Particle size	< 1 µm
Consumption (in continuous measurement)	1–10 sccm at 1000 mbar inlet pressure

The response time to changes of the gas composition at the input of the capillary until the ion currents and the concentration changes are displayed by the mass spectrometer depends on the type of gas, on the temperature of the capillary and on the gas flow rate through the capillary. For most gases, typical response times are in the range of 0.3 s to 1 s at 100°C and with a flow rate of 2 sccm. The greater the flow rate, the shorter will be the response time, but this is accompanied by a corresponding increase in sample gas consumption.

To avoid contamination of the capillary and the inlet apertures with hydrocarbons oil-free backing pumps should be used for pumping of the gas inlet system. In present day practice, combinations of turbopumps and diaphragm pumps, scroll pumps and dry piston pumps are utilized for this task. The use of diaphragm pumps as the only pumping stage is limited because in most cases the compression ratio is poor for light gases (H_2 and He) and this leads to a higher final pressure. In certain applications it is also possible to use oil-sealed rotary pumps equipped with appropriate devices for reducing oil backflow (vacuum side) and oil mist (output side).

A very cost-effective solution is to use a SplitFlow™ Turbo backed by a diaphragm pump (Fig. 47). This turbopump has a main pumping port for the high vacuum and an additional lower pumping speed port designed to pump the inlet. However, this requires a very good match between the dimensioning of the gas throughput in the capillary and the downstream pressure stages of the vacuum chamber. For analyzing gas mixtures containing a component with high temporal fluctuations (e.g. 10 ppm – 100%) of hydrogen or helium, such coupling is unsuitable because of the backflow entailed in the SplitFlow™ Turbo.

The choice of pumping system for the vacuum chamber depends on the required detection limits and on the selection of the analyzer. The selection criteria already pointed out in Section 1.2 apply here.

A stainless steel capillary (internal diameter 0.15 mm, length 1 m) and an interchangeable aperture for pressure reduction are utilized in the gas inlet system GES 010 (Fig. 43). The all-metal valve, GEV 010, serves for opening and closing the gas inlet in the analyzer unit. The sample gas flow of about 2–3 sccm is not interrupted even when the valve is closed. The gas inlet can be axial or at right angles to the rod system axis in conjunction with a cross-beam ion source. It is suitable for general gas analysis in the range from 100% to about 10 ppm.

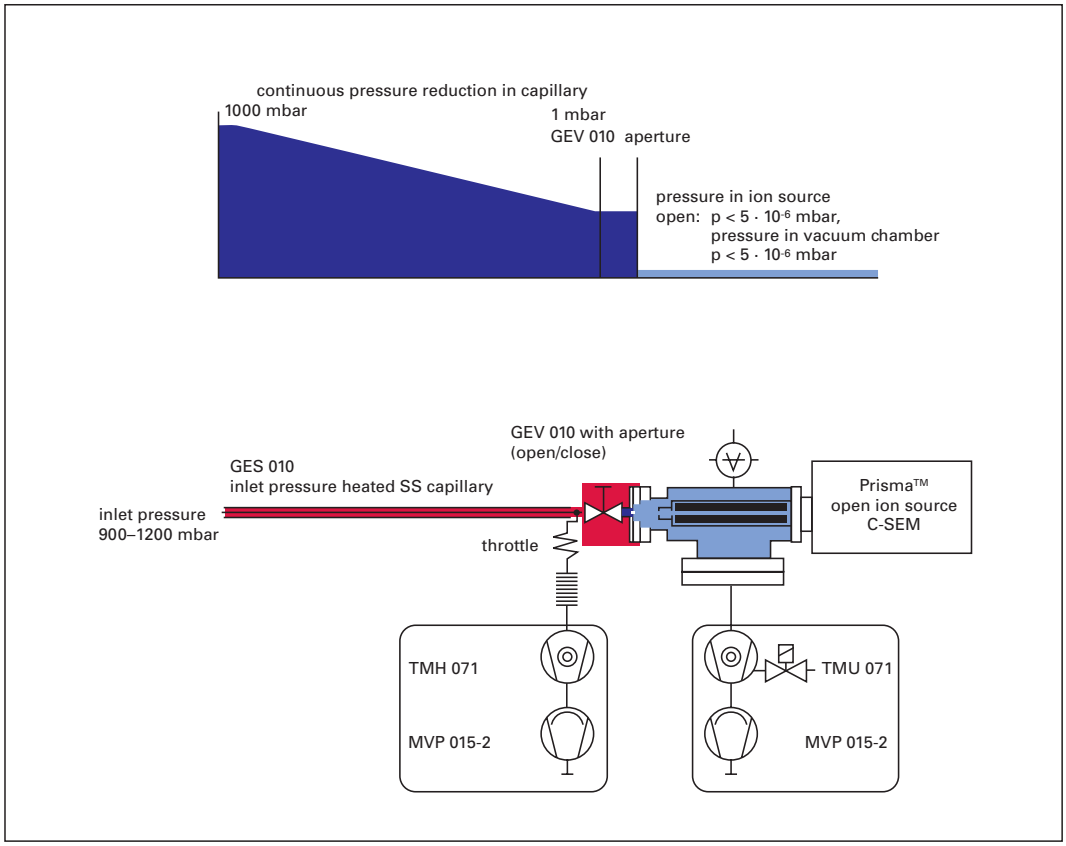


Fig. 43:
Design of an analysis system with the Prisma™ mass spectrometer.
The heated region of the gas inlet is marked red.

The inlet system shown in Fig. 44 employs a quartz capillary (internal diameter 0.15 mm, length 1 m) and an all-metal gas dosing valve for pressure reduction. With the valve combination UDV 040 and EVB 016 in the intake line, the gas throughputs and the pressure ratios can easily be varied, so that the setup can be optimized for various applications (different inlet pressures, sample gas consumption, analysis of corrosive gas mixtures). The flow into the vacuum chamber as well as the entire sample gas flow can be adjusted or turned off with these valves.
A molecular beam inlet into an open cross-beam ion source is preferred particularly for analyzing gas mixtures containing corrosive or other components that may condense on the analyzer. This results in better stability of the measurements and extends the length of time between analyzer maintenance.
With the help of separate heating circuits for the capillary and the valve, the respective temperatures can be matched optimally to the pressure conditions and to the gas to be analyzed. Fig. 44 shows the cold trap which reduces the water vapor residual partial pressure in the vacuum chamber. A cryo-baffle which is thermally connected to the cold trap surrounds the cross-beam ion source. The gas transfer pipe passes through the cryo-baffle (without thermal contact) directly into the formation chamber of the ion source. With this configuration it is also possible, for example, to achieve detection limits in the sub-ppm and ppb ranges for methane and other hydrocarbons.
An inlet system optimized for trace analysis of ultra pure gases is shown in Fig. 45. Pressure reduction is here effected with a quartz capillary and a fixed gold aperture directly upstream of the ion source. This system has been optimized with regard to minimizing the internal surface areas and the volume, so it is constructed without any valves in the gas flow. The gas inlet into the vacuum chamber is permanently open. Except for the gold aperture, the sample gas has no contact with metal surfaces before entering the ion source, therefore with this system it is also possible to reliably detect reactive gases such as oxygen in concentrations down to < 10 ppm.

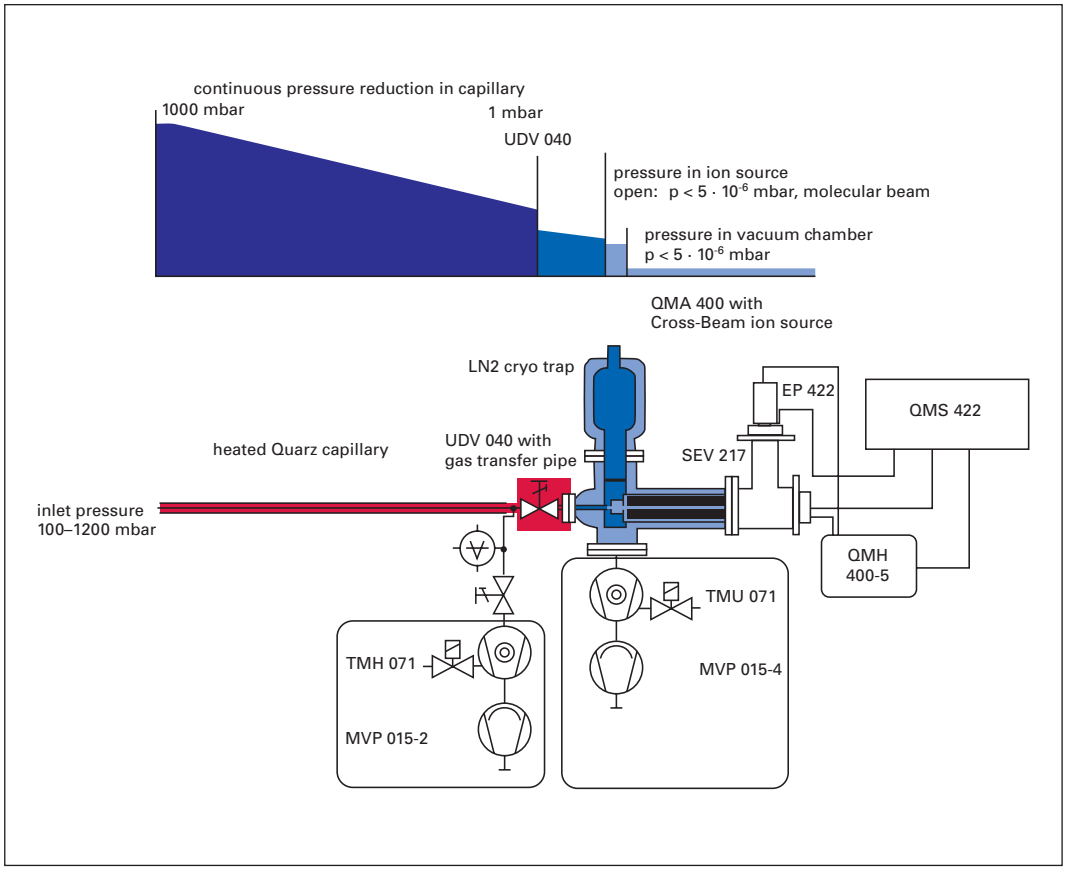


Fig 44:
Gas analysis system with a QMG 422 and LN2 cold trap. The gas inlet is here depicted in simplified form, turned through 90°. The heated region of the gas inlet is depicted red.

Very short reaction times can be achieved in conjunction with a gastight ion source. If valves are required upstream of the capillary for isolating the entire analyzer unit or for gas routing, special valves designed for ultra-pure gas technology must be used. The demand for increasing detection limits of course also entails stricter requirements for the vacuum system of the analyzer unit. With the pumping system shown in Fig. 45, base pressures in the lower 10^{-10} mbar range can be achieved without gas input to the vacuum chamber.

Apart from these dedicated solutions for particular measuring tasks, compact mass spectrometer systems are used for many different applications. Figs. 46 and 47 show the very compact internal construction and gas inlet of such benchtop instruments. The design of the gas inlet of the ThermoStar™ is similar to that of the GES 020. By virtue of its construction without valves and its small internal surface area, this device is also suitable for detecting reactive gases. The principal application field for these instruments is their coupling with thermal balance systems. For example, the temperature and weight loss of the sample can be read directly into the data record of the mass spectrometer via its two analog inputs, and processed along with the mass spec data. The sample gas inlet is permanently open, so high purity carrier gases, so-called “zero gases”, are used for exact determination of the mass spectrometric background.

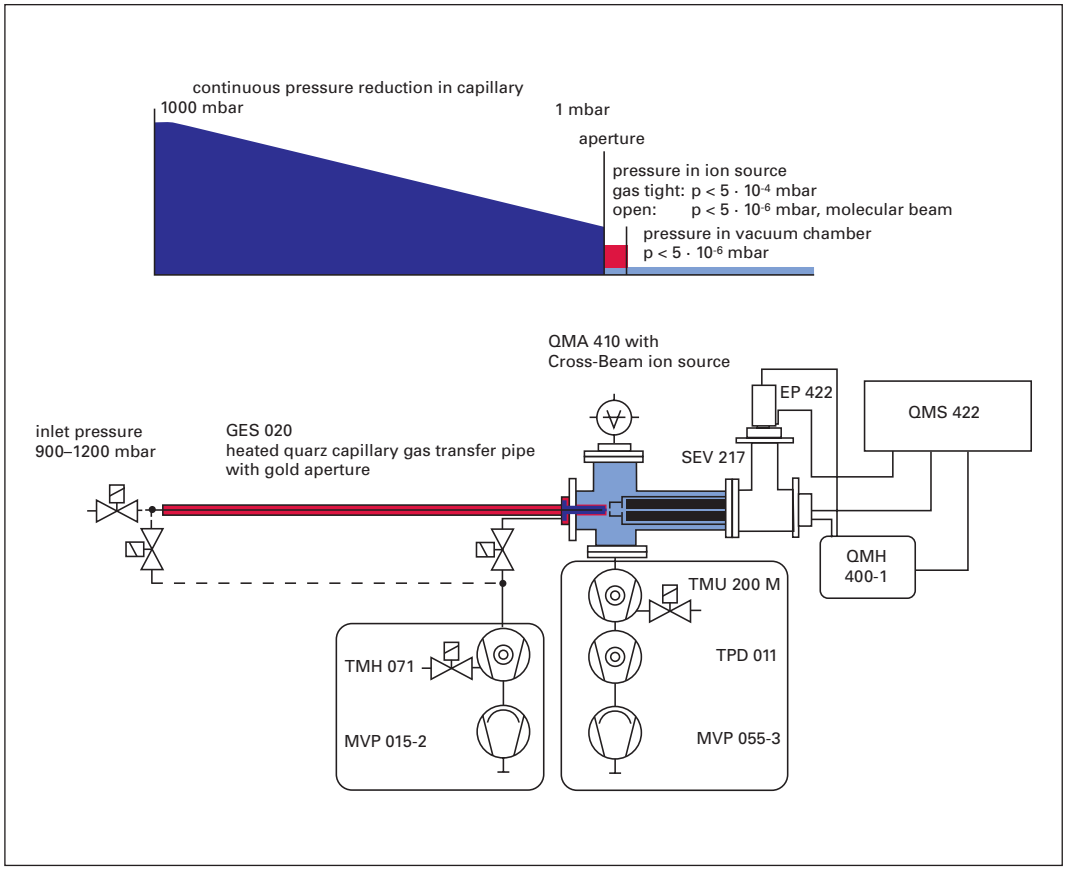


Fig. 45:
Gas analysis system using a QMG 422 with QMA 410 analyzer. The heated region of the gas inlet is marked red.

For the OmniStar™, the gas inlet in the vacuum chamber as well as the entire sample gas flow can be turned on or off with the valve combination in the inlet section. This is useful, for example, for connecting several sample gas lines to an analyzer system and to reduce the consumption of sample gas. This isolates the analyzer equipment from the actual process. For analyzing gases containing explosive or corrosive components, automatic shut off in the case of a problem is an important safety requirement. A special variant of the OmniStar™ (C version) has been developed especially for such applications. In this version the injection of purge gas (Ar, N_2) ensures that the gas mixture at the analyzer system output is never capable of combustion and the pump bearings are protected from corrosion. The dilution factor for the sample gas is about 500.

Optimum matching to inlet pressures in the range 1200–100 mbar is possible over larger capillary cross sections and greater aperture diameters. However, a pressure controlled gas inlet system is required if the input pressure for the analyzer unit changes by more than one decade during the measurement. Two variants of the OmniStar™ are available. Here the signal of the total pressure gauge in the vacuum chamber is used as control variable. In a mass spectrometer with a pressure controlled gas inlet, only the concentration values have real significance. The absolute

Fig. 46:
Picture of an OmniStar™ instrument with cover removed.

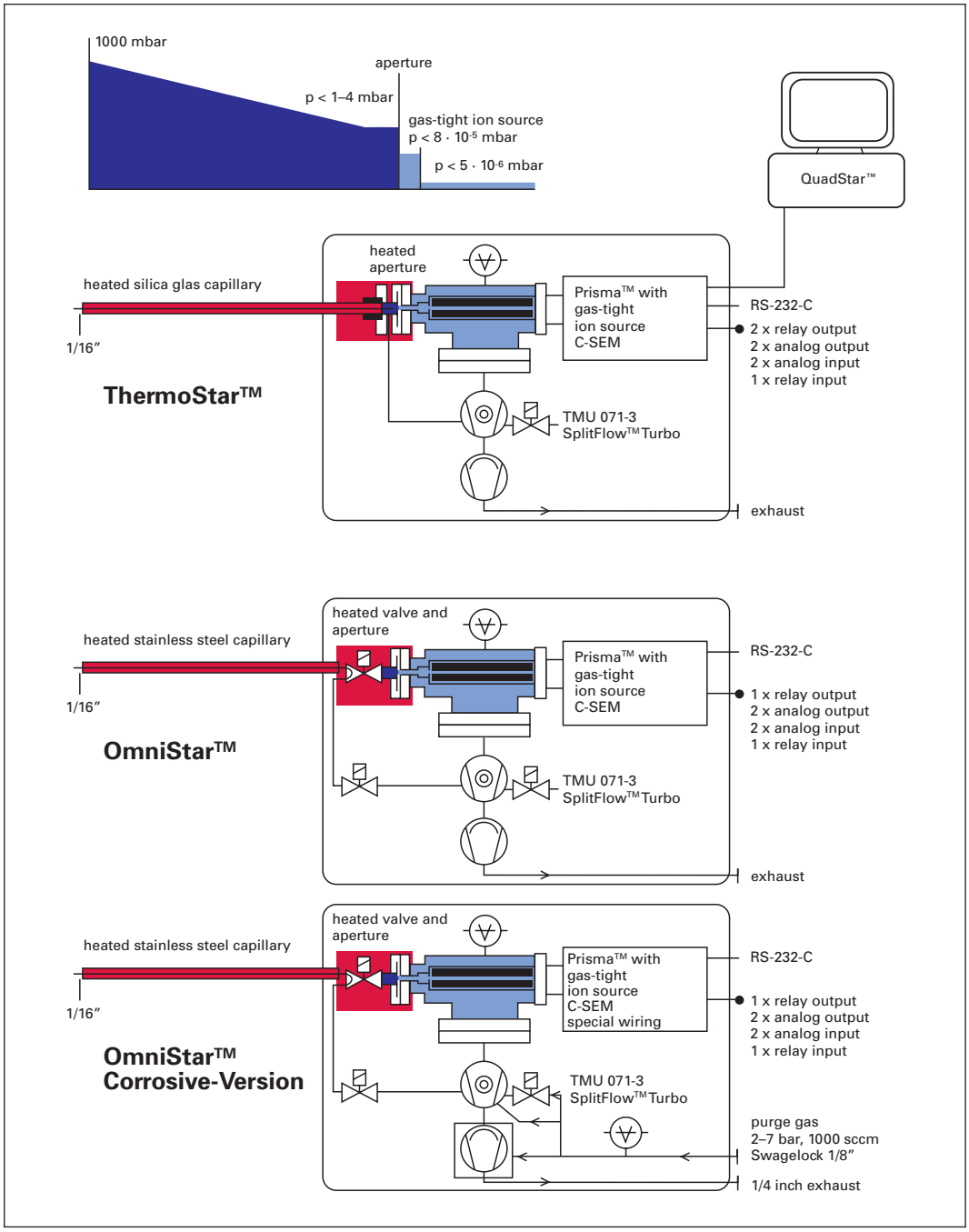


Fig. 47:
Schematic of the ThermoStar™ and OmniStar™ benchtop instruments.
The temperature controlled heated region of the gas inlet is marked red.

values of the ion currents and the partial pressures of the mass numbers of interest, do not relate directly the process gasses being analyzed. Only their mutual ratios, i.e. the concentrations, provide information reflecting the changes of the gas composition.

Extension of the inlet pressure range to pressures > 1.5 bar (absolute) is possible only with further pressure reduction. In the simplest case, the gas mixture under excess pressure is brought to atmospheric pressure via a reducing valve and then introduced into the inlet system described above. For selecting the pressure reducing valve, it is necessary to pay attention to the dosing range, the heating capability, the gas compatibility of the valve materials and the maximum pressure stress limit.

The gas switching unit GSS 300 serves for computer controlled sequential switching of up to 12 sample gas or calibration gas lines. It can be combined with all mass spectrometer configurations which have a capillary inlet. In order to obtain short response and switchover times, gas must flow continuously through the inlet valves. The volume between the inlet valves and the capillary connection is < 4 cm^3 and can be evacuated with the oil-free diaphragm pump of the GSS when the sample gas is changed. The valves are controlled with additional software under the control of QuadStar™, so that complete measurement, periodic calibrations and test measurements can be automated.

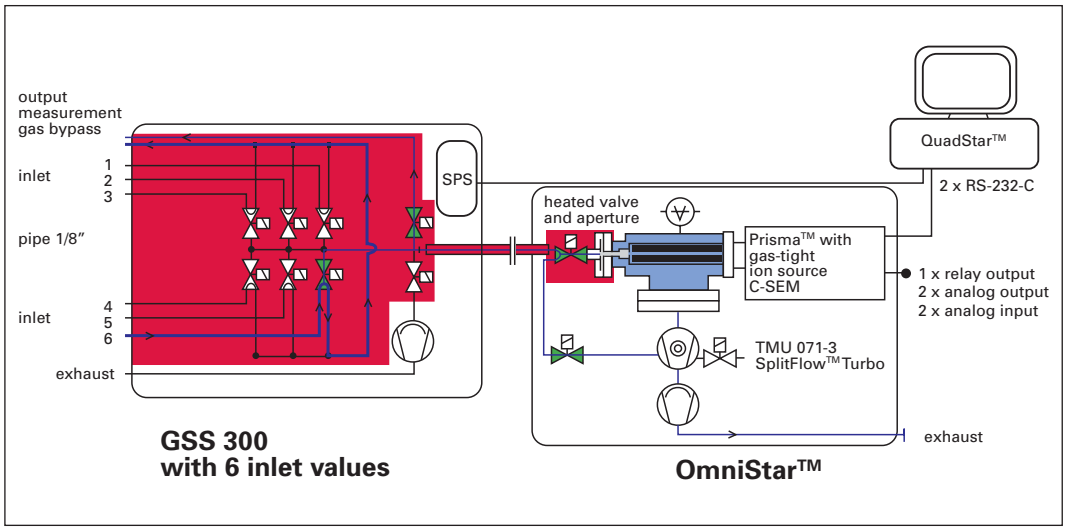
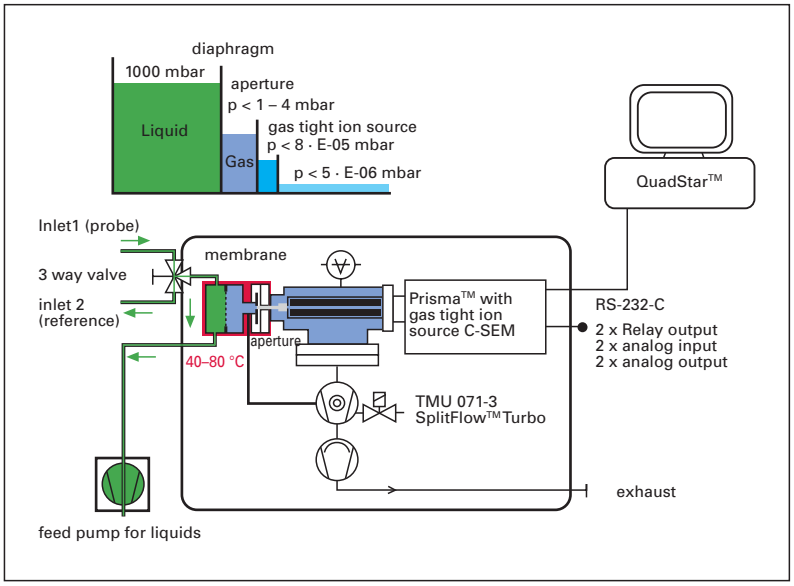


Fig. 48:
Diagram of the sample gas feed with a GSS 300 in combination with an OmniStar™. The gas flow of the currently selected sample gas (input 6) is depicted blue. The heated region is depicted red.

Besides the previously described capillary inlet systems there are a couple of differential pumped inlet systems are used for special measurement applications. Examples are skimmer set ups and membrane inlet systems. A set for analyzing in dissolved gases in liquids is shown in Fig. 49. The liquid to be analyzed is directed in front of a silicon membrane by a small feed pump. The in liquid solved gas is diffusing through the membrane into an evacuated space. Part of this gas reaches through an aperture the mass spectrometer in order to get analyzed.
Because the permeability depends highly an the temperature the thickness of the membrane and its condition it is recommended to do a comparison with a reference measurement. In order to achive the same measurement conditions a 3 way valve is used.

A similar set up can be used for in dissolved gases in liquids [20].

Fig. 49:
OmniStar™ with membrane inlet systems .



1.4 Mass spectrometer for detection of externally generated ions and plasma diagnostics

The previous chapters described mass spectrometers for analysis of neutral gas particles.
If generated ions are to be mass detected or energy selectively detected, a quadrupole mass spectrometer offers itself as a detector.
In such cases, the ion source integrated in the mass spectrometer often is superfluous. Instead, ion optics are needed to focus the available ions in the mass spectrometer.
Quadrupole mass spectrometers are used in differing measurement designs, such as SIMS (Secondary Ion Mass Spectroscopy), ICP-MS (Inductively Coupled Plasma Mass Spectrometry), proton transfer reactions and plasma diagnostics, etc., as a mass selective detector.
The requirements for sensitivity of the mass spectrometer, the performance of the ion optics and geometrical alignment conditions are sharply differentiated in these tasks.
A modular system is imperative in order to meet all requirements and to utilize tested functional units.

1.4.1 Detection of externally generated ions

Module: Detection of externally generated ions

Analyzer hardware:	Mass spectrometer control unit:	Mass spectrometer software:
Ion optics *Mass filter* *Detector* *Measuring amplifier* *Can be combined freely to optimize the measuring task*	*Signal amplifier* *Voltage supply* *Communication with computer* *Signal processing* *Communication with peripheral hardware signals*	*Operation of the mass spectrometer data storage and processing* *Design of the interface to other systems* *Allowing for complex specific measurement recipes*

The modular design encompasses the three areas of analyzer, control unit and software.
On the part of hardware, the functional units can be combined freely with each other. A selection on this level is set by the specific choice of mass spectrometer control unit. Independent of the selected variant of mass spectrometer, the control unit can be fitted with analog and digital inputs and outputs.
This allows quadrupole mass spectrometers to be arranged according to the requirements and to be integrated in complex measurement designs.
The analyzers, detectors and signal amplifiers are standardized.

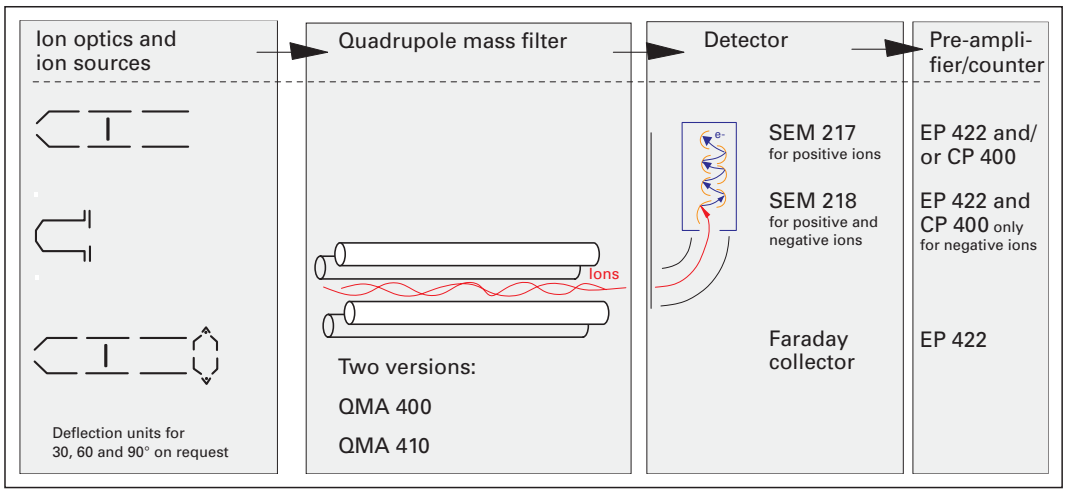


Fig. 50:
There are four variations of ion optics and combinations of optics and ion sources that can be used to interface with the specific measurement configuration:
The utilized functional units of the module are outlined below.

The **three-lens optic** is used as an ion transfer optic. Among other things, this optic allows for a large immersion depth. Due to the relatively high energy dispersion of this optic – approximately 1.5 eV half-value width – high-energetic ions and the primary beam are effectively suppressed in SIMS applications.
In other applications, the three-lens optic is used as a simple electrostatic energy filter.

Two-lens optic:
This optic is used if you only want to display ions in the mass spectrometer. This way ions with low kinetic energy are detected. This optic can be used with SIMS and SNMS (Secondary Neutral Mass Spectroscopy) in combination with the cross beam ion source.

Cross beam ion source:
This ion source allows electron energies to be set down to 4 eV.
It therefore is suitable for reception of excitation spectra. The energy of the electrons used for ionization is varied and the signal is measured dependent on the electron energy. This technique is known as “Appearance Potential Spectroscopy”.
The cross beam ion source can be combined with both 2- and 3-lens ion optics.

Deflection units:
An electrical sector field is used to map ions in the instrument that are formed vertically to the axis of the mass spectrometer. In the direction of the mass spectrometer axis, the design is rotatable by 360 degrees so that the largest possible detection range is covered.
Converging angles of 30, 45, 60 and 90 degrees are possible.
Of course, such a sector field also functions as an energy filter.

A highly precise quadrupole mass filter together with a discrete dynode designed SEM is the heart of all mass spectrometers for ion analysis.
Transmission through the quadrupole mass filter is relatively high and the measurement discrimination is low. Both characteristics are affected by the mechanical precision of the filter, the quality of the high-frequency generator and the use of Pfeiffer Vacuum field axis technology. Therefore, pre-filters are unnecessary.
Due to the 90° off axis arrangement of the SEM, photons, electrons and fast neutrals cannot reach the detector. This leads to a low noise background and is a necessary prerequisite for the high dynamic range of these mass spectrometers.

The additional conversion dynode with the SEM 218 further reduces an energy-dependent mass discrimination.

1.4.2 Application examples

SIMS and SNMS are decades-long established procedures for surface analysis and analysis of thin layers in the semiconductor industry and in related industry branches.
With SIMS, the sample is bombarded with ions or neutral particles from an ion source in a high or ultra-high vacuum. Secondary ions that occur when the layer is etched are measured by time and/or stationary resolution.
Pfeiffer Vacuum delivers mass spectrometers for these systems.

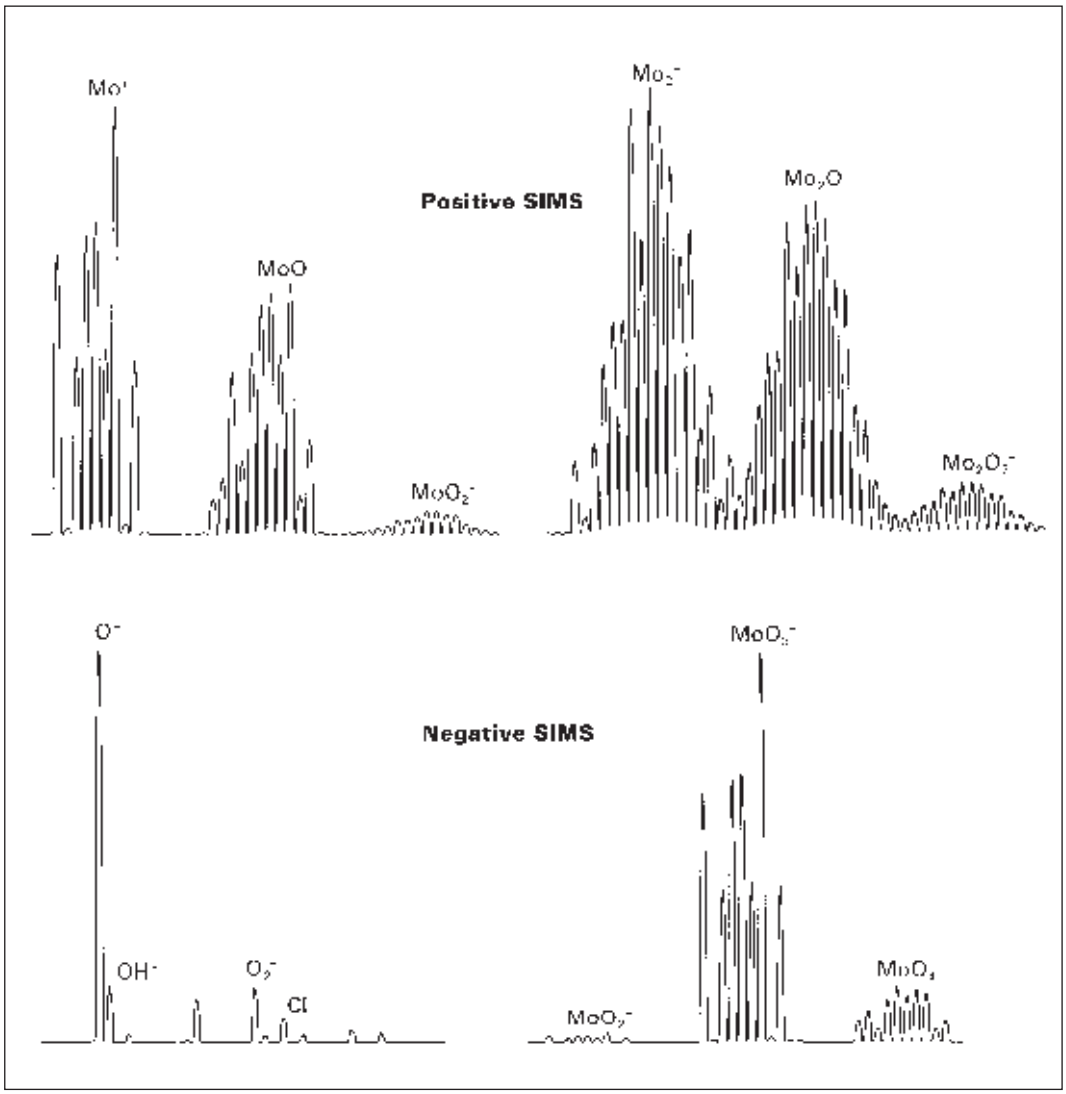


Fig. 51:
SIMS spectra of positive and negative ions. This example clearly shows the high dynamic range and the high sensitivity that can be achieved with such a mass spectrometer in SIMS systems. Partially oxidized molybdenum was used as a sample. This example also clearly shows the high measurement range that can be used for analysis.

End Point Detection:
Many manufacturing procedures in thin film technology require a film system to be built up before processing and, in some cases, to be selectively re-etched in the gas phase.
A technique that has been used for some time is “ion milling”. During ion milling, the substrate is bombarded with argon ions and thereby etched in the gas phase.
In recent times, the requirements for precision of the process have increased dramatically requiring use of a highly sensitive detector for monitoring and control during the process.
One option for monitoring such a process is to continuously measure the secondary ions occurring during the ion milling process. For this purpose, the EPD 400 was developed as a complete unit. The EPD 400 consists of a mass spectrometer, housing, pumping station for pressure reduction and control unit. It is delivered in two versions with a 90-degree acceptance angle as displayed below (Fig. 52) and as an in line version.

You can easily re-tool between both types at any time.

In addition to use as an endpoint detector in ion milling processes, the EPD is suitable for detection of ions in condensable materials, such as metal ions in industrial sputtering processes.
With conventional differentially pumped mass spectrometers, you achieve a comparably low sensitivity for condensable neutrals since they for the most part condense in the unit before reaching the ion source.
With the EPD 400, the ions arising from the process are mapped directly in the unit with comparably low losses by means of the ion optics.

Additional examples for detection of externally generated ions are proton transfer reactions and devices using chemical ionization or laser-induced ionization.

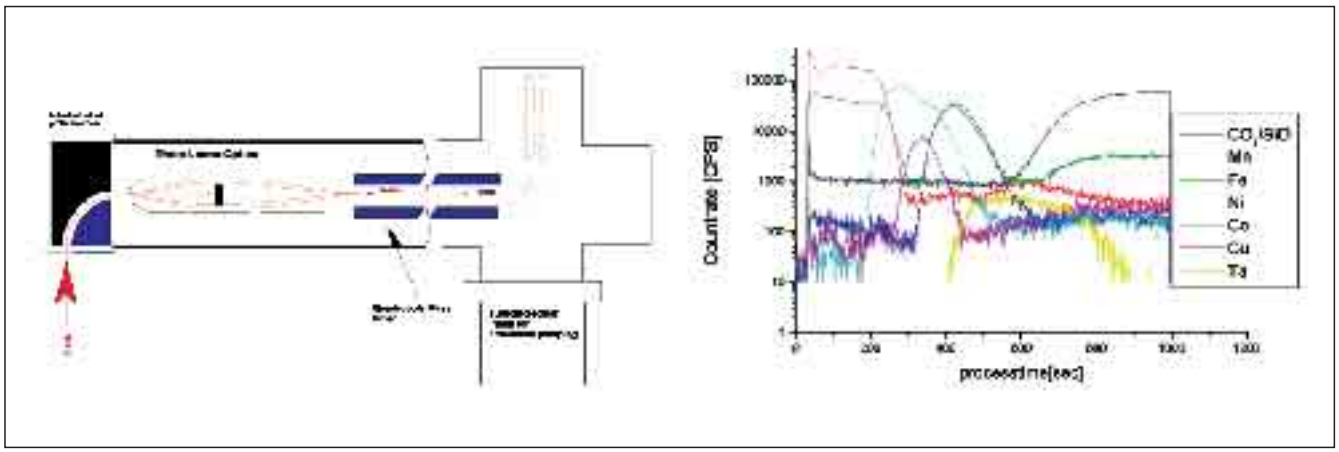


Fig. 52:
The example shows a signal sequence measured with an EPD 400 during an ion beam experiment in an ion milling system.
At any time – even with a process disruption – you can determine in which depth of the film system you are working.
The process can be set to be finished after a disruption or when reaching a pre-selected film depth (material).

1.4.3 Mass spectrometric plasma diagnostics

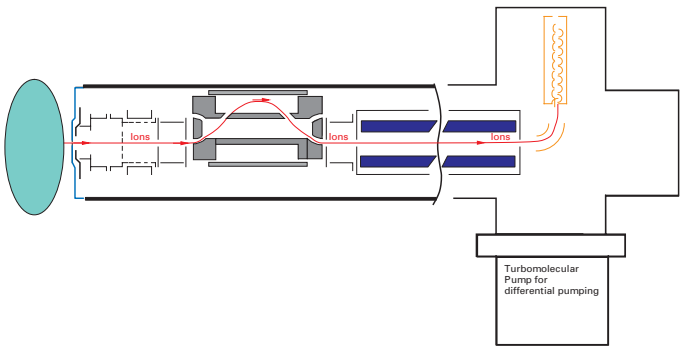
Plasma processes are a key component in almost all current procedures for vacuum coating, cleaning and modification of surfaces.
A plasma (in general a gas discharge) consists of positive and negative ions, electrons and neutral gas particles. Beside the type (mass), the power distribution and the density of the species are characteristic for the plasma.
To optimize and monitor such processes, simple or complex expensive plasma diagnostics must be executed depending on the process. Various techniques are in use; no method covers all plasma parameters completely.
Langmuir probes can be used to determine the plasma density, the electron energy distribution, the plasma potential and the floating potential in low-pressure gas discharges.
(Use of such probes is very easy, but interpretation of the results requires more scientific knowledge on behalf of the user.)
Some species can be detected very sensitively with optical analysis methods. With appropriate expenditure, the average energy of the particles can be determined in individual cases. Calibration is necessary so that particle densities can be measured. The difficulty of the procedure and its viability depends on the experimental design. Stationary resolution measurements by means of optical emission spectroscopy are difficult to impossible to generate.
A combination of a quadrupole mass filter and an electrostatic energy analyzer, in short, a **Plasma Process Monitor,** can be used to measure the following plasma parameters:

- **The energy distribution of positive and negative ions and their mass**
- **The energy distribution of the neutral particles**
  Neutral particles first must be ionized in order to be detected via a mass spectrometer. If the energy of the electrons is changed during the selected ionization procedure (Electron Impact Ionization), excitation spectra can be used to differentiate between neutral particles in a ground state and excited neutral particles (so-called **radicals,** see "Appearance Potential Spectroscopy").
- **The density and mass of the neutral particles** in the plasma (with this the unit can be calibrated easily.)
- You can obtain a measurement of the electron energy and its density; to do so, the **plasma monitor must be operated as a Langmuir probe**.

Consequently the mass spectrometric plasma diagnostic delivers the most comprehensive information about a plasma in the most demanding procedures.

1.4.4 Solution variations

Heavy-duty mass spectrometers operate with a pressure of $< 10^{-5}$ mbar. Most plasma processes operate at a pressure of 0.1 mbar or less.
Therefore, a single-stage differentially pumped mass spectrometer is offered as a standard version.
The **PPM 422** (Fig. 53) is a unit consisting of a differentially pumped mass spectrometer including a control unit and software for mass and energy resolved measurements of positive and negative ions, neutral particles and appearance potential.
A Cylindrical Mirror Analyzer (CMA) is used as an energy filter in the PPM 422. A linear beam path is achieved through spherical converging and diverging elements on the input and output of the filter. This allows for a high immersion depth in the process recipients.
The CMA is set to a fixed kinetic energy of the occurring ions for energy analysis. The entire analyzer including energy and mass filters is set to a variable electric bias. This allows a linear energy scale to be generated; since with this counter field method the kinetic energy of the ions in the analyzer is always the same, an energy dispersion cannot occur.
Likewise, to avoid an energy dispersion, we purposely dispensed with so-called



Maximum process pressure ≤ 10^{-2} mbar

Energy range ± 500 eV

Energy resolution : 0.3 eV FWHM

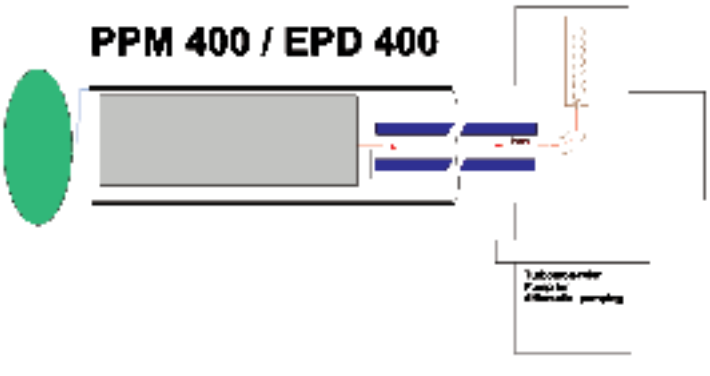
Mass range: 512, 1024 and 2012 amu

Fig. 53:
Schematic diagram of a PPM 422

drift lenses in the PPM 422. Drift lenses could be used to increase the immersion depth of a plasma monitor. However, you would introduce a complex energy dispersion.
In order to use this unit to measure neutral particles with an energy resolution corresponding to the CMA, the ion source itself must contribute as little as possible to energy dispersion. The PPM 422 uses a so-called field-free ion source that is expanded horizontally in the flow direction of the ions. The energy dispersion of the ion source is shown in the following examples.
The physical functionality of the PPM 422 is described in detail in the unit's operating manual and in additional documents [10].
Units from the PPM 400 family are best used when you have lesser requirements regarding the energy resolution or if you dispense with a high energy resolution in favor of increased sensitivity.

Units of the type **PPM 400/EPD 400** (Fig. 54) likewise are differentially pumped mass spectrometers with the most varying combinations of ion sources and energy analyzers.
Different types of energy filters or ion optics and an ion source can be combined in a PPM 422.
With all Pfeiffer Vacuum operated units of this type (PPM 422, PPM 400), the electrical potential of the first exposed aperture in the plasma can be selected freely.
This is especially important in order to minimize disruptions to the plasma by the detector.

Fig. 54:
Schematic diagram of the PPM 400/ EPD 400



Four configurations:

• Three-lens optics	pos. and neg. ions
• Three lenses and cross beam ion source	neutrals and pos. and neg. ions
• Two lenses and cross beam	ions and neutral particles no energy analysis
• Cross beam ion source	appearence spectroscopy

1.4.5 Measurements with the plasma monitor

Several application examples are shown below to illustrate various measurement options with a plasma process monitor.

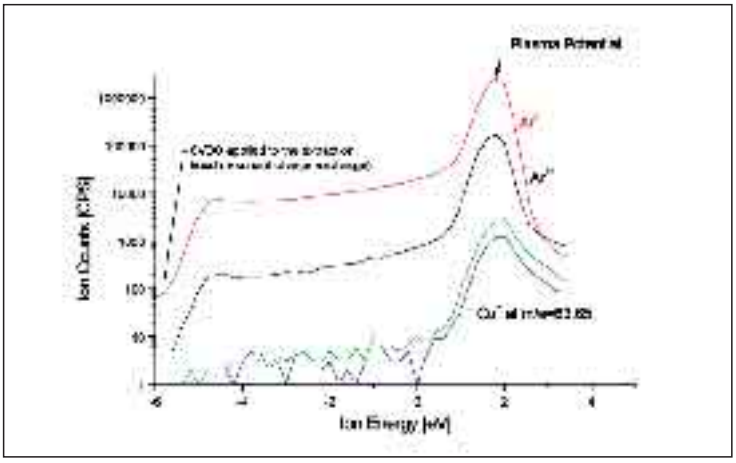


Fig. 55

The energy distribution of Ar and Cu ions from the plasma of a DC planar magnetron is displayed. The maximum of the distribution determines the plasma potential. – 6.0 VDC was applied to the extraction hood of the analyzer. Argon ions are formed to this potential through resonant charge exchange. Application of the spectrum at – 6 eV can be used to calibrate the energy scale.

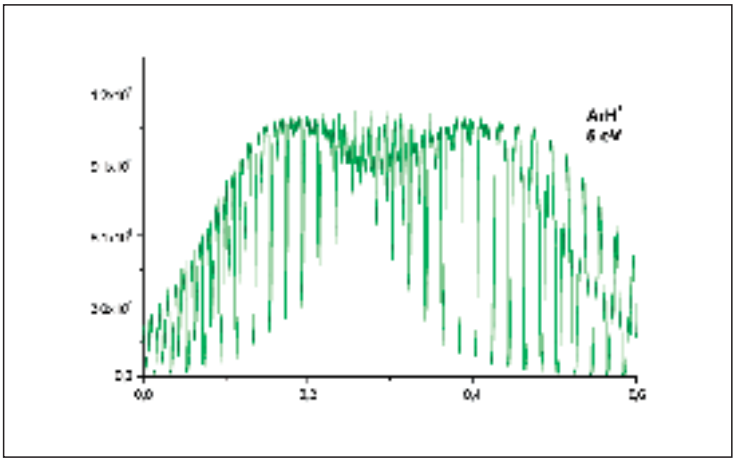


Fig. 56

The chronological sequence of the ion densities with a magnetically modulated Ar-H_2 plasma became calibrated energy. The ignition of a filament supplied with alternating current can be seen clearly next to the periodicity induced by the magnetic modulation.

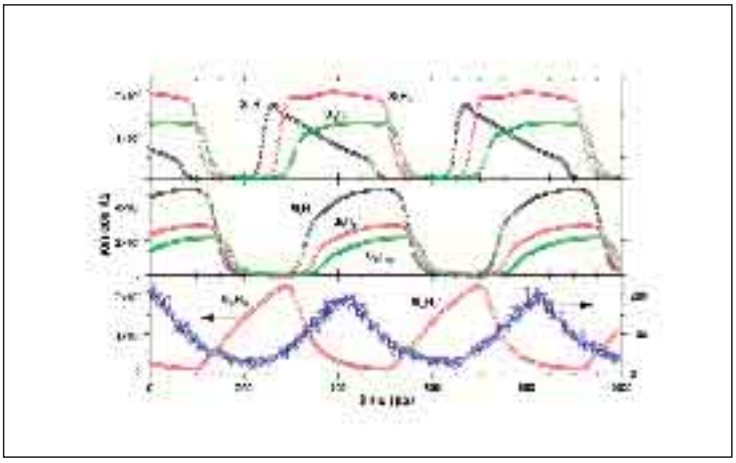


Fig. 57

The chronological sequence of the negative ions in a power-modulated silane plasma was measured with a PPM 422 and a multi channel scaler.

The resolution of the entire system is very important in regards to the energy measurement of neutrals. Not only the resolution of the energy filter (CMA) but also the energy distribution of the ions formed in the ion source determine the result.
In previous experiments on externally generated thermal ions, the energy resolution of the CMA was determined to 0.3 eV (FWHM). Measurement of the ions formed in the ion source of the PPM 422 show that their energy distribution lies in the same order of magnitude and leads to an additional epansion of the curve from 0.3 eV to 0.64 eV.
The PPM 422 therefore can be used to measure ions with an energy resolution of 0.3 eV and neutrals with an energy resolution of 0.64 eV.
(A closer look shows that the electrical field of an extraction aperture reaches into the formation chamber set at 100 VDC and thus leads to a shift of the energy scale by approximately 2 eV.)

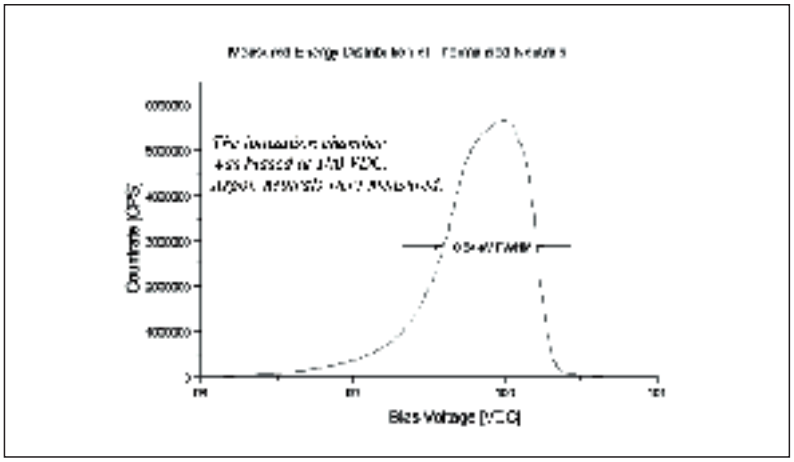


Fig. 58

The energy distribution of neutral Cu atoms was calibrated with a DC planar magnetron. The ion source of the unit was raised to + 100 VDC to discriminate against a high energetic ion. However, the standard unit required slight modification to reach this level of sensitivity. The aperture angle between the ion source and the extraction opening was increased.

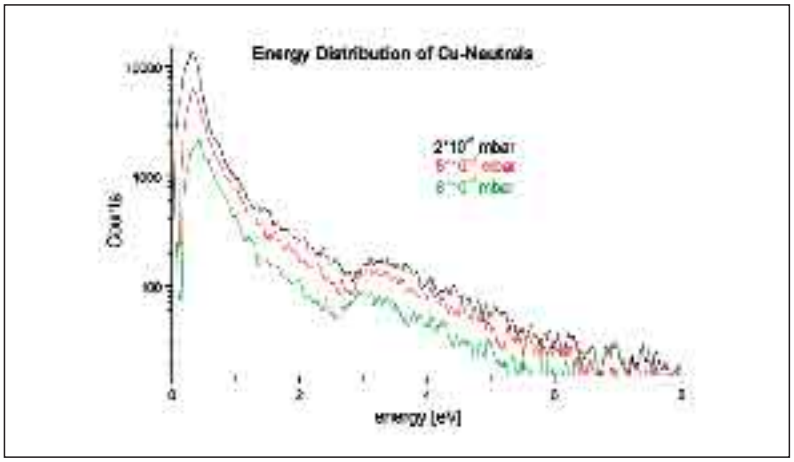


Fig. 59

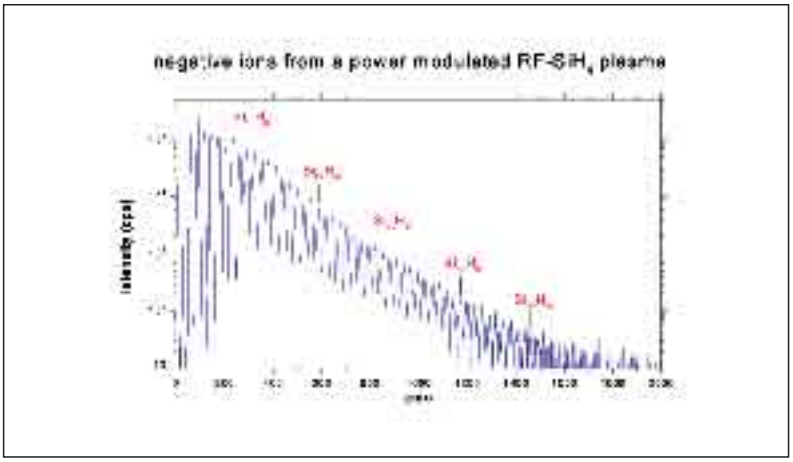


Fig. 60

Negative ions were extracted from a power-modulated silane plasma. The clusters within the plasma can be detected across a large mass range.

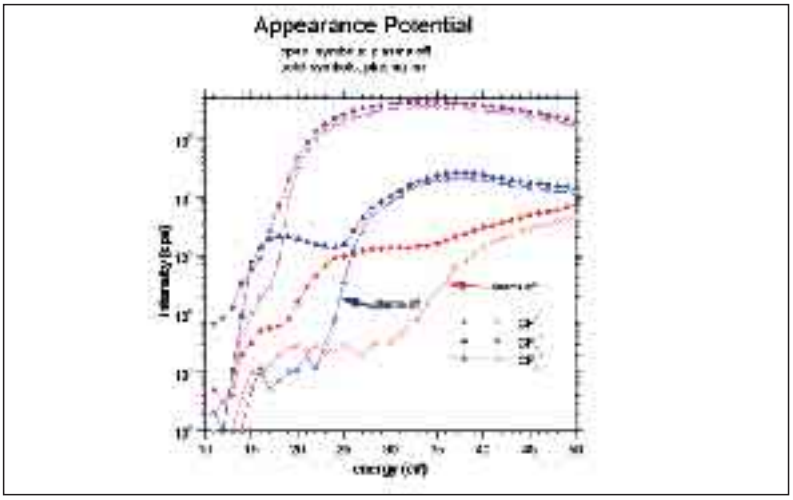


Fig. 61

You can differentiate between neutral particles in a ground state and excited neutral particles from a plasma, so-called radicals, by varying the electron energy in the PPM 422.

Additional application examples are described in the selected publications [12, 13, 14, 15,16, 17, 18, 19].

1.4.6 Measurement range extension:

While a broad palette of applications is covered in the above mentioned units, new trends in processing must be taken into account.
While in the past low pressure plasmas were applied for the most part, today more gas discharges, which are operated at atmospheric pressure, are used.
If possible, we try to fall back on available instruments and functional units to expand the pressure range of the analysis unit so that customers owning standard units only need to make the most necessary new investments.

For **time-resolved measurements** < 0.1 seconds and to increase the sensitivity, the signal of all mass spectrometers fitted with an ion counter can be processed further with a readily available signal processing unit.
For this purpose, a signal converter, which transfers the counting pulse of the counter to TTL signals, is used.

Screening against magnetic fields:
An additional option is screening against magnetic fields (up to 10 m Tesla flow density) that occur during some plasma processes and that can disrupt operation. The

apertures are integrated in the chamber of the plasma monitor.
Screenings against high magnetic fields within the process system can be obtained on request.

Measurements at the substrate level are described in publication [11].

Langmuir probes:
Langmuir probes can be used in addition to a plasma monitor to determine the electron energy and the density in the plasma. However, since the electrical potential of the first exposed aperture of the plasma can be selected freely with these units, it can be operated principally as a Langmuir probe. In this case, you are dealing only with a “single sample”.

The molecular beam inlet deals with a self-centering second differential pump stage that can be retrofitted on all PPM 422 and PPM 400 units in operation. In this design also, the electrical potential of the first exposed aperture can be selected freely.

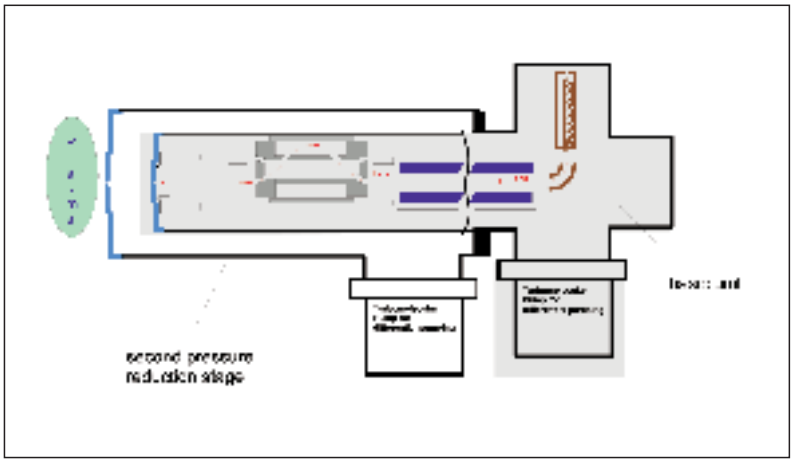


Fig. 62

2 Mass spectrometers for residual gas analysis

Contents


PFEIFFER VACUUM
Prisma

Prisma™ 80

Cheap residual gas analysis and leak detection
User-friendly software
Selectable partial pressures
Robust analyzer
High reliability of operation by two filaments.

Technical Data

Mass range	1–80 amu	Operating temperature/electronics	0–40 °C
Rod system, diameter/length	6 mm/100 mm	Operating temperature/analyzer	max. 150 °C
Detector	Faraday	Measurement speed, scan analog	200 ms–60 s/amu
Detection limit	$1 \cdot 10^{-12}$ mbar	Measurement speed, scan Bargraph	20 ms–60 s/amu
Sensitifity for Ar	$1 \cdot 10^{-3}$ A/mbar	Measurement speed, MID	10 ms–60 s/amu
Operating pressure, max.	$1 \cdot 10^{-4}$ mbar [1]	Measuring channels	64
Contribution to neighboring mass (40/41)	< 10 ppm	RS-232-C interface	1200–19200 bits/s
Peak ratio reproducibility[2]	± 0,5 %	Digital output	2 Relais, 24 VDC
Resolution, at 10% peak height	0,5–2,5 amu	Voltage	90 ... 260 VAC
		Weight	3 kg

[1] at reduced emission current of 0,2 mA: $1 \cdot 10^{-3}$ mbar
[2] at constant conditions while 8 hours, N_2 and Ar from Air

	Ordering number
Prisma™ 80	**PTM04100**

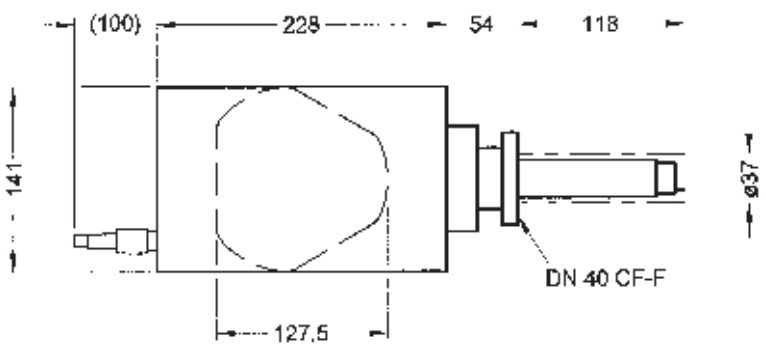
Scope of delivery

TalkStar™ software with RS-232-C-cable, SP 200 mains unit with cable and installation material

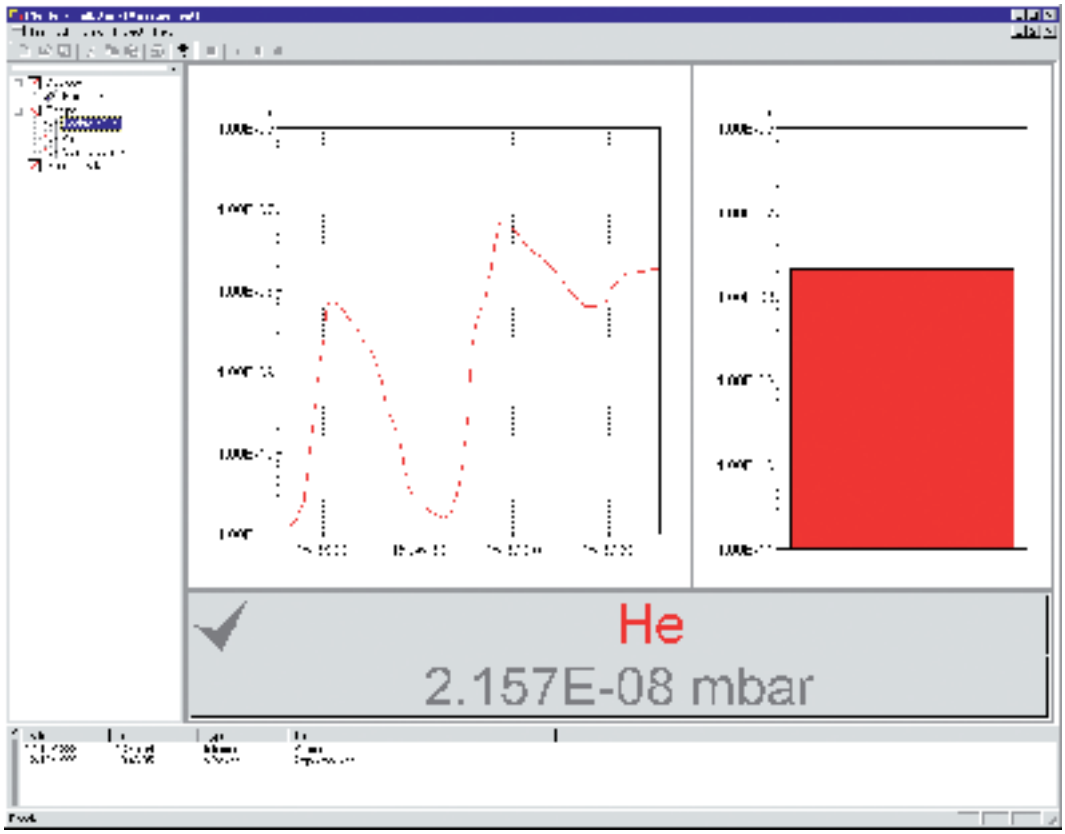
Stand-alone Components

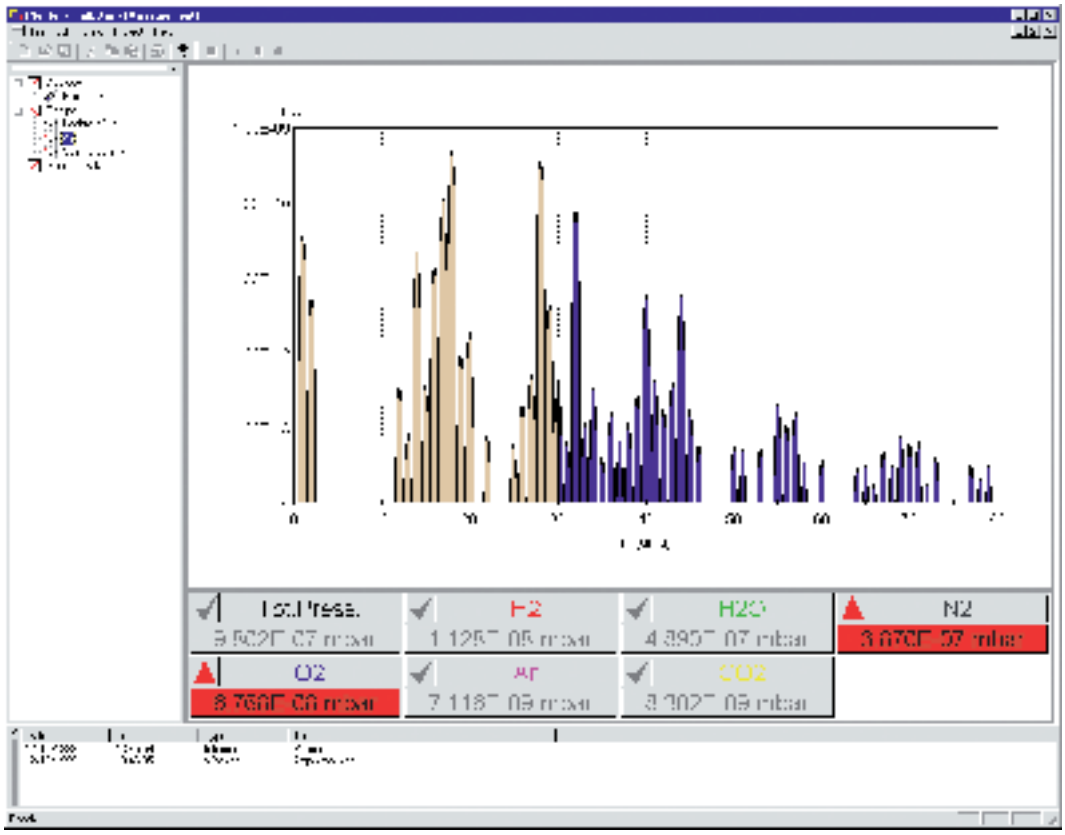
Prisma™ 80	Ordering number
Analyzer, QMA 200 F	**PTM25250**
Electronics, QME 80	**PTM28515**
Cathode unit, 2 filaments, yttr. Iridium	**BN846138-T**

Dimensions in mm



Prisma™ 80 – TalkStar™





Prisma™ QMS 200 F with Faraday detector

Economical residual gas analysis and process-monitoring at high vacuum range.

Easy system integration.

Fast and error-free data transfer via fiber optics.

Multiplex mode.

High reliability of operation by two filaments.

Mass ranges 1-100 amu, 1-200 amu, 1-300 amu

Summary Prisma™ QMS 200 F with Faraday Detector

		QMS 200 F1	QMS 200 F2	QMS 200 F3
Mass range	amu	1–100	1–200	1–300
Rod system, diameter/length	mm	6/100	6/100	6/100
Detection limit, min.	mbar	$1 \cdot 10^{-12}$	$2 \cdot 10^{-12}$	$4 \cdot 10^{-12}$
Sensitifity for Ar	A/mbar	$1 \cdot 10^{-3}$	$6 \cdot 10^{-4}$	$3 \cdot 10^{-4}$
Operating pressure, max. [1]	mbar	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
Contribution to neighboring mass (40/41)	ppm	< 10	< 20	< 50
Operating temperature/analyzer	°C	150	150	150
Connection flange		DN 40 CF-F	DN 40 CF-F	DN 40 CF-F
Weight	kg	3	3	3

[1] at reduced emission current of 0.2 mA: $1 \cdot 10^{-3}$ mbar

General Technical Data

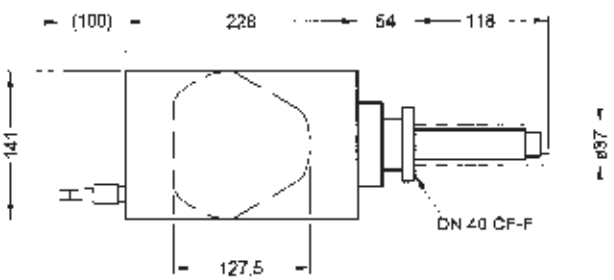
Resolution, at 10 % peak height	0.5–2.5 amu	Operating temperature/electronics	0–40 °C
Measurement speed, scan analog	200 ms–60 s/amu	Operating temperature/analyzer	200 °C/300 °C [3]
Measurement speed, scan Bargraph	20 ms–60 s/amu	Temperature, storage	–25 – +70 °C
Measurement speed, MID	10 ms–60 s/amu	LAN interface	2.5 Mbits/s, ArcNet
Measuring channels	64	RS-232-C interface	300–19200 bits/s
Peak ratio reproducibility[2]	± 0.5 %	Voltage	90 ... 260 VAC

[2] at constant conditions while 8 hours, N_2 and Ar from Air, 100 amu

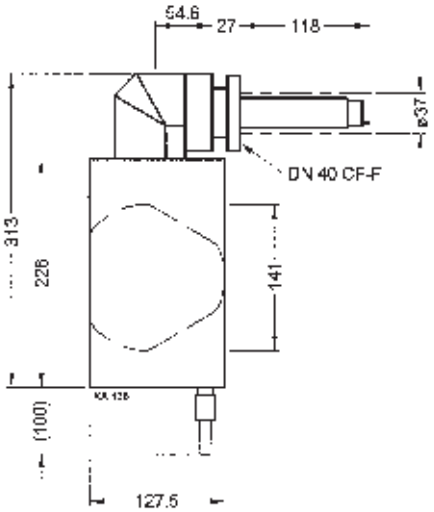
[3] defined by ordering number

Information to interfaces, inputs and outputs see page 64 und 65

Dimensions in mm



QMS 200 F



QMS 200 F 90° connection

Prisma™ QMS 200 F Versions

Prisma™ with 90° connection
– When there is not enough space for fitting the standard version
– Technical Data identical to standard version

Analyzer for bakeout temperature up to 300 °C
– Technical Data identical to standard version

Prisma™ QMS 200 F-Ordering numbers

PT M03 011 000

Open ion source | 1

Detector Faraday | 1

Bakeout temperature
1 | 200 °C
2 | 300 °C

Connection
1 | 0°
2 | 90°

Mass range
1–100 amu | 1
1–200 amu | 2
1–300 amu | 3

Cathode
1 | Tungsten
2 | Iridium yttriated

Example:
PT M03 111 211
1 – Mass range: 1–100 amu
1 – Detector: Faraday
1 – Ion source: open
2 – Cathode: Iridium yttriated
1 – Bakeout temperature: 200 °C
1 – Connection: 0°

For special applications
Prisma™-Analyzer with Mo-wiring 3

on request

Scope of delivery

QuadStar™ software with RS-232-C-cable and adapter, SP 200 mains unit with cable,"control" plug, installation material

Information to the software see chapter 1.2.4

Stand-alone components

QMS 200 F with Faraday detector	Ordering number
Analyzer, QMA 200 F with W-filament	PTM25251
Analyzer, QMA 200 F with yttr. Ir-filament	PTM25250
Electronics QME 200, 1–100 amu	PTM28504
Electronics QME 200, 1–200 amu	PTM28500
Electronics QME 200, 1–300 amu	PTM28502
Cathode unit, 2 filaments, Tungsten, for open ion source	BN846139-T
Cathode unit, 2 filaments, yttr. Iridium, for open ion source	BN846138-T

Accessories

QMS 200 F with Faraday detector	Ordering number
Optical HUB, OHA 200, 5 Ports	PT442510-T
Optical HUB, OHA 200, 10 Ports	PT442520-T
ArcNet-PCMCIA adapter set	PT442530-T
PCI-PCMCIA Bridge for PC	PT442540-T
Fiber optic cable, 10 m	P51596152H
Fiber optic cable, 20 m	P51596152K
Fiber optic cable, 50 m	P51596152Q
Total pressure gauge PKR 251, DN 40 CF, Viton sealed, $5 \cdot 10^{-9}$ till 1000 mbar	PTR26002
Total pressure gauge PKR 261, DN 40 CF, metal sealed, $5 \cdot 10^{-9}$ till 1000 mbar	PTR26252
Sensor cable, PKR-QMS 200, 3 m	PT448250-T

Prisma™ QMS 200 M with C-SEM

Economical residual gas analysis and process-monitoring at HV and UHV range.

Also usable for gas analysis application.

Easy system integration.

Fast and error-free data transfer via fiber optics.

Multiplex mode.

High reliability of operation by two filaments.

Mass ranges 1–100 amu, 1–200 amu, 1–300 amu

Summary Prisma™ QMS 200 M

with continuous Secondary electron multiplier			QMS 200 M1	QMS 200 M2	QMS 200 M3
Mass range	amu		1–100	1–200	1–300
Rod system, diameter/length	mm		6/100	6/100	6/100
Detection limit, min.	mbar	Faraday	$5 \cdot 10^{-12}$	$1 \cdot 10^{-11}$	$2 \cdot 10^{-11}$
		C-SEM	$1 \cdot 10^{-14}$	$< 2 \cdot 10^{-14}$	$< 4 \cdot 10^{-14}$
Sensitifity for Ar	A/mbar	Faraday	$5 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$
		C-SEM	200	200	100
Operating pressure, max.	mbar	Faraday	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
		C-SEM	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
Contribution to neighboring mass (40/41)	ppm		< 10	< 20	< 50
Operating temperature/analyzer	°C		120	120	120
Connection flange			DN 40 CF-F	DN 40 CF-F	DN 40 CF-F
Weight	kg		4.4	4.4	4.4

General Technical Data

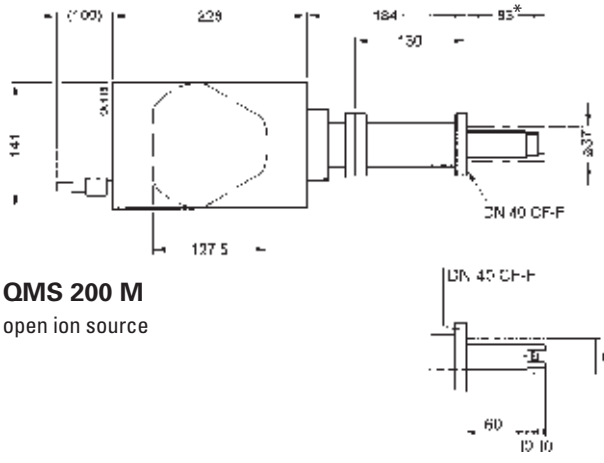
Resolution, at 10% peak height	0.5–2.5 amu	Operating temperature/electronics	0–40 °C
Measurement speed, scan analog	200 ms–60 s/amu	Operating temperature/analyzer	200 °C/300 °C [2]
Measurement speed, scan Bargraph	20 ms–60 s/amu	Temperature, storage	– 25 – +70 °C
Measurement speed, MID	10 ms–60 s/amu	LAN interface	2.5 Mbits/s, ArcNet
Measuring channels	64	RS-232-C interface	300–19200 bits/s
Peak ratio reproducibility[1]	± 0.5 %	Voltage	90 ... 260 VAC

[1] at constant conditions while 8 hours, N_2 and Ar from Air, from air, Faraday, 100 amu

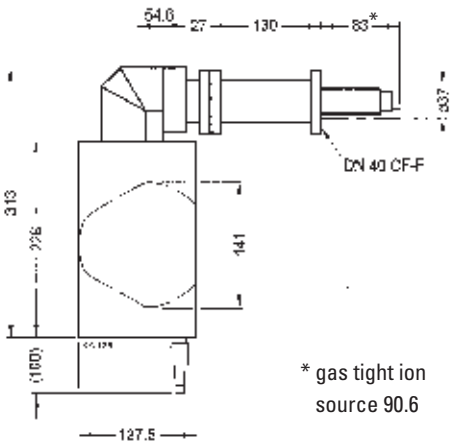
[2] defined by ordering number

Information to interfaces, inputs and outputs see page 64 and 65

Dimensions in mm



QMS 200 M
open ion source



* gas tight ion source 90.6

QMS 200 M
Cross-Beam ion source

QMS 200 M 90° connection
open ion source

Prisma™ QMS 200 M Versions

Prisma™ with 90° connection
- When there is not enough space for fitting the standard version
- Technical Data identical to standard version

Analyzer for bakeout temperature up to 300 °C
- Technical Data identical to standard version

Cross-Beam ion source
- For qualitative and quantitative analysis
- for corrosive gas applications

Gas tight ion source
- Particularly suitable for analyzing gases or gas mixtures which are under higher pressure and are conveyed directly to the ionization chamber of the ion source through pressure reduction inlets
- improved signal/background ratio
- Low gas comsumption
- Low vacuum time constant
- Conductance 0.8 l/s for N_2

Prisma™ QMS 200 M-Ordering number

Ion source		Bakeout temperature	
open (standard)	1		
gas tight (only with W-cathode)	2	1	200 °C
Cross-Beam (only with W-cathode	3	2	300 °C

PT M03 020 000

Mass range		Connection	
1–100 amu	1	1	0°
1–200 amu	2	2	90°
1–300 amu	3		

		Cathode
	1	Tungsten
C-SEM	2	2 yttr. Iridium

Example:
PT M03 121 212
1 – Mass range: 1–100 amu
2 – C-SEM
1 – Source: open ion
2 – Cathode: yttr. Iridium
1 – Bakeout temperature: 200 °C
2 – Connection: 90°

For special applications
Prisma-Analyzer with Mo-wiring
on request

Scope of delivery

QuadStar™ software with RS-232-C-cable and adapter, SP 200 mains unit with cable, "control" plug, installation material

Information to the software see chapter 1.2.4

Stand-alone components

QMS 200 M with C-SEM	Ordering number
Analyzer, QMA 200 M, open ion source with W-cathode	PTM25253
Analyzer, QMA 200 M, open ion source with yttr. Ir-cathode	PTM25252
Analyzer, QMA 200 M, open ion source with W-cathode, 300 °C	PTM25273
Electronics QME 200 with C-SEM-supply, 1–100 amu	PTM28505
Electronics QME 200 with C-SEM-supply, 1–200 amu	PTM28501
Electronics QME 200 with C-SEM-supply, 1–300 amu	PTM28503
Cathode unit, 2 filaments, Tungsten, for open ion source	BN846139-T
Cathode unit, 2 filaments, yttr. Iridium, for open ion source	BN846138-T
Cathode unit, 2 filaments, Tungsten, for gas tight ion source	BN846281-T
Cathode unit, 2 filaments, Tungsten, for Cross-Beam ion source	PT160000-T

Accessories

QMS 200 M with C-SEM	Ordering number
Optical HUB, OHA 200, 5 Ports	PT442510-T
Optical HUB, OHA 200, 10 Ports	PT442520-T
ArcNet-PCMCIA adapter set	PT442530-T
PCI-PCMCIA Bridge for PC	PT442540-T
Fiber optic cable, 10 m	P51596152H
Fiber optic cable, 20 m	P51596152K
Fiber optic cable, 50 m	P51596152Q
Vacuum chamber for differential pressure stage	PT442830-T
Total pressure gauge PKR 251, DN 40 CF, Viton sealed, $5 \cdot 10^{-9}$ till 1000 mbar	PTR26002
Total pressure gauge PKR 261, DN 40 CF, metal sealed, $5 \cdot 10^{-9}$ till 1000 mbar	PTR26252
Sensor cable, PKR-QMS 200, 3 m	PT448250-T

Prisma™ QMS 200 M Connectivity

Total pressure measurement and system locking as option

TPR Pirani CompactGauge

$5 \cdot 10^{-4}$ mbar — 1000 mbar

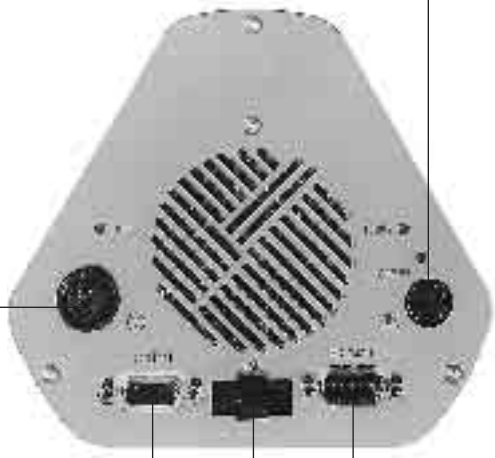
$5 \cdot 10^{-9}$ mbar — 1000 mbar

PKR FullRange™ CompactGauge

Other gauge types via analog input

or external locking

Contact
5 V DC



24 V DC

Voltage 90–260 V AC
Frequency 47–63 Hz

Mains unit SP 200

L x W x H
180 x 95 x 60 mm

Cable lenght 3 m

Weight 0.7 kg

ArcNet board
at PC

PC

	External start	Analog outputs	Analog inputs	Digital outputs
Specification	Contact 5 V DC	4 Channels – 5.12 – + 5.12 V 16 bit	2 Channels – 5.12 – + 5.12 V 11 bit	2 Relays N. O. 24 V DC
Characteristics		Measured values (i. e. ion current) Ratios (concentration)	Reading in of data e. g. pressure, temperature, gas flow	Free assignment of switching functions
Application examples	Starting of measurement cycle	Diagnosis by recorder, Oscilloscope Process control	Correlation of process data and spectrometer data	Forward breakover point on/off Valve open/close Alarm

Components for multiplex mode and Software-Update

Optical HUB OHA 200

Fast and error-free data transfer via fiber-optics, even over long distances, up to 1000 m.

Multiplexing – simultaneous operation of several instruments via the same optical interface.

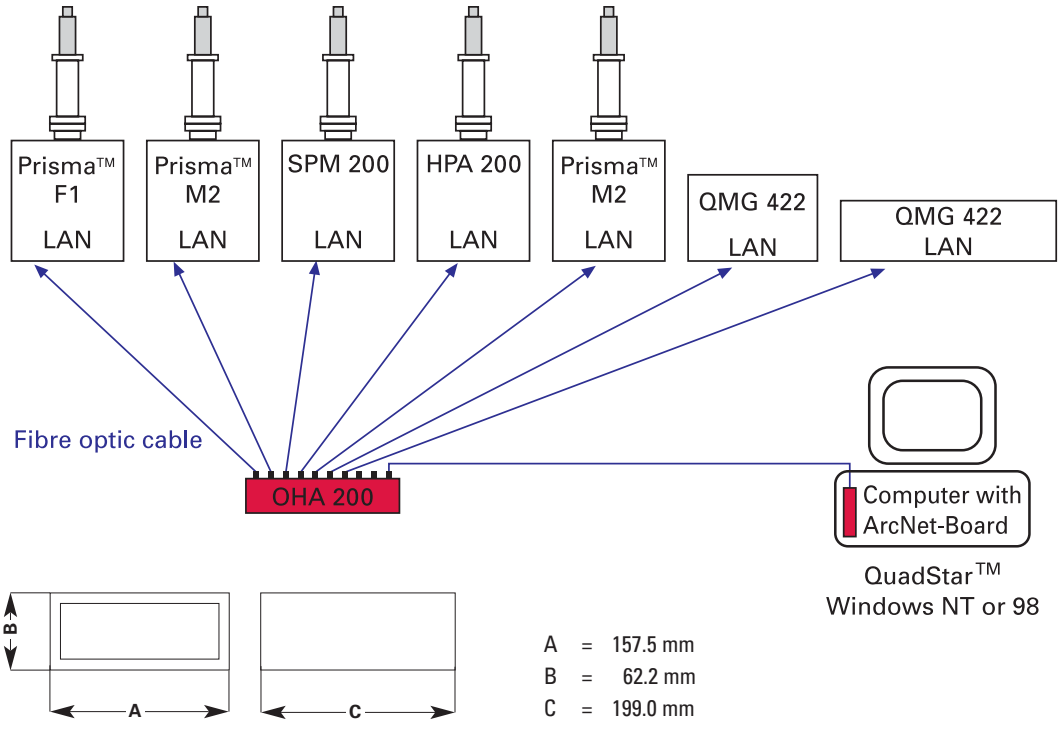
Stand-alone Components

Optical Hub	Ordering number
OHA 200, 5 Ports	PT442510-T
OHA 200, 10 Ports	PT442520-T

Accessories

Optical Hub	Ordering number
ArcNet-PCMCIA adapter set	PT442530-T
PCI-PCMCIA Bridge for PC	PT442540-T
Fiber optic cable, 10 m	P51596152H
Fiber optic cable, 20 m	P51596152K
Fiber optic cable, 50 m	P51596152Q

Software-Update	Ordering number
Update for QuadStar™ and TalkStar™	PT882093-T



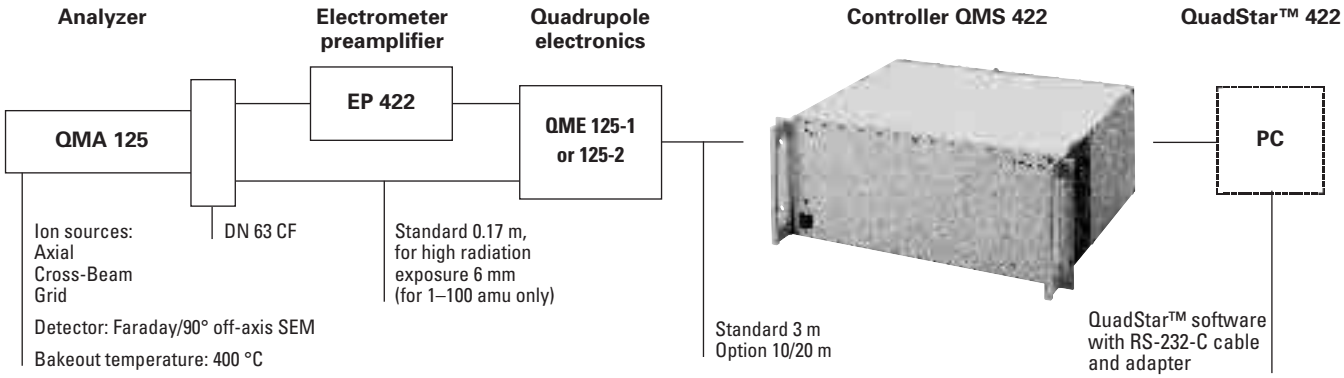
A = 157.5 mm
B = 62.2 mm
C = 199.0 mm

QMG 422 with QMA 125

Residual gas analysis – even in the extreme UHV range.
Ideal for residual gas analysis at accelerator.
Analysis of fast processes

Modular, versatile, expandable.
Mass ranges 1–100 amu, 1–200 amu

Scope of delivery



Summary QMG 422

Version			90°-SEM/Faraday	90°-SEM/Faraday	90°-SEM/Faraday
Mass range	amu		1–100	1–100	1–200
Rod system, diameter/length	mm		6/100	6/100	6/100
Quadruopl-Electronics			QME 125-1	QME 125-1	QME 125-2
Connecting cable QMA/QME	m		0.17	6	0.17
Detection limit, min.	mbar	Faraday 90°-SEM	$2 \cdot 10^{-11}$ $5 \cdot 10^{-15}$	$1 \cdot 10^{-10}$ $5 \cdot 10^{-14}$	$4 \cdot 10^{-11}$ $1 \cdot 10^{-14}$
Sensitifity for Ar	A/mbar	Faraday 90°-SEM	$1.5 \cdot 10^{-4}$ 1000	$5 \cdot 10^{-5}$ 1000	$1 \cdot 10^{-4}$ 1000
Operating pressure, max.	mbar	Faraday 90°-SEM	$1 \cdot 10^{-4}$ $1 \cdot 10^{-5}$	$1 \cdot 10^{-4}$ $1 \cdot 10^{-5}$	$1 \cdot 10^{-4}$ $1 \cdot 10^{-5}$
Partial pressure ratio with SEM	ppm		< 0.1	< 0.1	< 0.1
Operating temperature/analyzer	°C		150	150	150
Bakeout temperature	°C		400	400	400
Connection flange			DN 63 CF-F	DN 63 CF-F	DN 63 CF-F

Version with	Ordering number		
Axial ion source with Re filament	**PTM27103**		
Cross-Beam ion source with two W filaments	**PTM27104**		**PTM27154**
gas tight Cross-Beam ion source with two W filaments	**PTM27105**		**PTM27155**
Grid ion source with W filament	**PTM27106**		
vacuum annealed QMA with grid ion source, W filament	**PTM27107**	**PTM27110**	

Other combinations of devices on request

Technical data of controller QMS 422 see page 74

Stand-alone Components, QMG 422

Analyzer QMA 125	Ordering number
with 90°-SEM, axial ion source, Re filament	PTM10774
with 90°-SEM, Cross-Beam ion source, two W filaments	PTM10775
with 90°-SEM, gas tight Cross-Beam ion source, two W filaments	PTM10770
with 90°-SEM, grid ion source, W filament	PTM10776
vacuum annealed QMA with 90°-SEM, grid ion source, W filament	PTM10777

Filaments to QMA 125	Qty.	Rhenium	Tungsten	yttr. Iridium
for Axial ion source	1 piece	BN845061-T	BN845082-T	BN845166-T
	5 pieces	BN845018-T	BN845031-T	–
for Cross-Beam ion source (also gas tight)	2 pieces	BN845052-T	BN845088-T	BN845282-T
for Grid ion source	1 piece	–	BN845291-T	–

SEM 217	
secondary electron multiplier, 17 Cu-Be-dynodes, 400 °C, max.	BG521611-X

Quadrupole Control Unit QMS 422	
Quadrupole controller QC 422 (technical data and dimensions see page 74)	PTM26580

Quadrupole Electronics QME 125
contains RF-generator, ion source supply and high voltage supply for SEM

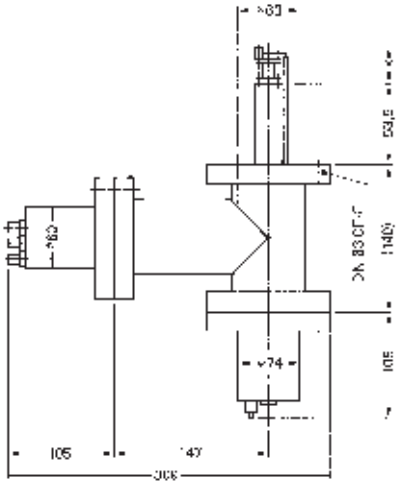
QME 125-1; 2.45 MHz (1-100 amu), cable length QME/QMA 0.17 m, weight 2.5 kg	PTM36376
QME 125-1; 2 MHz (1-100 amu), cable length QME/QMA 6 m, weight 4 kg	PTM36382-1
QME 125-2; 2 MHz (1-200 amu), cable length QME/QMA 0.17 m, weight 2.5 kg	PTM36378
cable QME/control unit, 10 m	BG448197-T
cable QME/control unit, 20 m	BG448170-T
QME holder, DN 63 CF	BG546510-T

Electrometer preamplifier EP 422	
fast, highly sensitive current-to-voltage converter with auto ranging in all ranges for direct connection to the analyzer, include cable to QME	PT444570-T

Accessories, QMG 422

Input/Output modules and components for multiplex mode and for completion with ion counter
see accessories for QMG 422, page 73

Dimensions in mm



QMA 125 with 90° off-axis SEM

*
- Axial beam ion source = 30.5 mm
- Grid ion source = 29 mm
- Cross-Beam ion source = 18.6 mm (10 mm to the middle of the sensitive volumen)
- Gas tight Cross-Beam ion source = 18.6 mm (10 mm up to the gas connection)

3 Mass spectrometer for gas analysis

Contents


OmniStar

QMG 422 with QMA 400/410/430

Unit resolution in all mass ranges, even up to 2048.

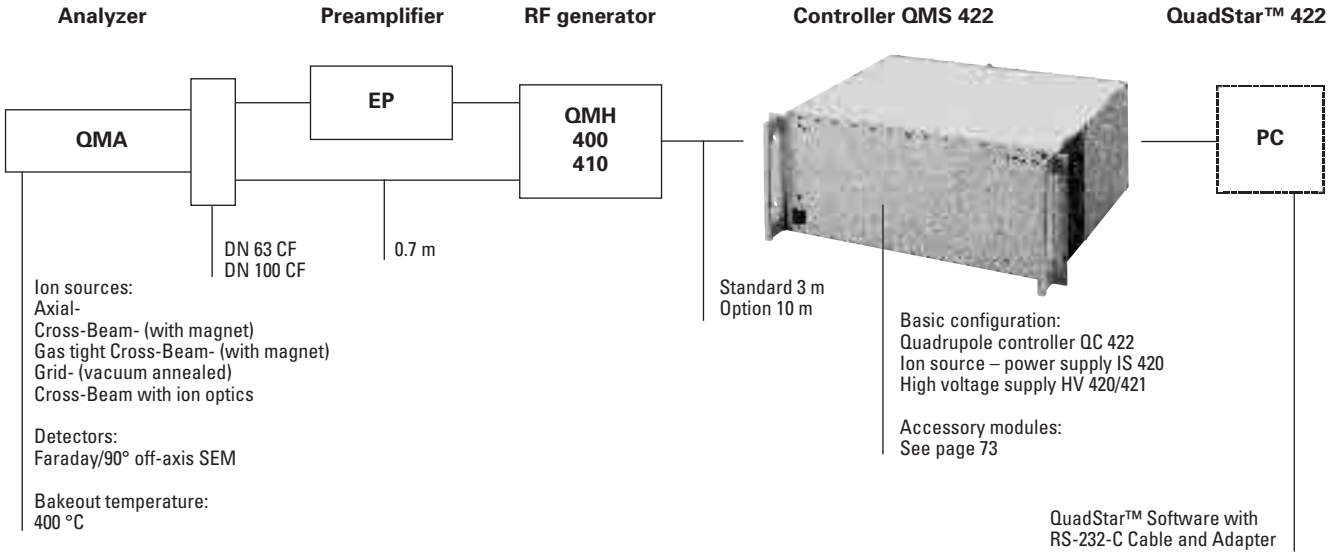
Higher resolution selectable, also at low mass numbers e. g. for the separation of He and D_2.

Fulfills analytical requirements ppb range detection limit, high reproducibility and long term stability, small contribution to neighboring masses, large dynamic.

Detection of neutrals, positive and negative ions

Multiplex mode

Scope of delivery



Technical Data of controller QMS 422 see page 74

Summary QMG 422

Mass range in amu			1-128	1-128	1-340	1-340	1-300
Detection limit, min.		mbar	$5 \cdot 10^{-16}$	–	$1 \cdot 10^{-15}$	–	$2 \cdot 10^{-15}$
Sensitivity for Ar, min.[1]		A/mbar	$1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$2 \cdot 10^{-4}$
Operating pressure, max.	Faraday	mbar	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
	SEM	mbar	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
Partial pressure ratio with SEM		ppb	< 0.3	< 0.3	< 0.5	< 0.5	< 1
Analyzer			QMA 410	QMA 410	QMA 410	QMA 410	QMA 430
Rod system, material/diameter/length		mm	Mo/16/300	Mo/16/300	Mo/16/300	Mo/16/300	st. steel/8/200
90° off-axis SEM			SEM 217	SEM 218	SEM 217	SEM 218	SEM 217
High voltage supply			HV 420	HV 421	HV 420	HV 421	HV 420
RF-generator			QMH 400-1	QMH 400-1	QMH 410-3	QMH 410-3	QMH 400-5
Electrometer preamplifier			EP 422	EP 422	EP 422	EP 422	EP 422
Operating temperature/Analyzer		°C	150	150	150	150	150
Bakeout temperature/Analyzer		°C	400[3]	400[3]	400[3]	400[3]	400
Connection flange			DN 100 CF-F	DN 100 CF-F	DN 100 CF-F	DN 100 CF-F	DN 63 CF-F

with ion source	Ordering number				
Axial-, with Re filament	-	-	-	-	**PTM27320**
Cross-Beam-, with two W filaments	**PTM27316**	**PTM27318**	**PTM27317**	**PTM27319**	**PTM27321**
Cross-Beam-, with magnet and two W filaments	**PTM27300**	**PTM27305**	**PTM27310**	**PTM27315**	-
Gas tight Cross-Beam-, with two W filamente	**PTM27301**	-	-	-	**PTM27322**
Gas tight Cross-Beam-, with magnet and two W filaments		**PTM27302**	-	**PTM27311**	-
Grid-, with W filament	-	-	-	-	**PTM27323**

Mass range in amu			1-512	1-512	1-1024	1-2048
Detection limit, min.		mbar	$1 \cdot 10^{-15}$	-	-	-
Sensitivity for Ar, min.[1]		A/mbar	$5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
Operating pressure, max.	Faraday	mbar	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
	SEM	mbar	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
Partial pressure ratio with SEM		ppb	<0.5	<0.5	-	-
Analyzer			QMA 400	QMA 400	QMA 400	QMA 400
Rod system, material/diameter/length		mm	Mo/8/200	Mo/8/200	Mo/8/200	Mo/8/200
90° off-axis SEM			SEM 217	SEM 218	SEM 217	SEM 218
High voltage supply			HV 420	HV 421	HV 420	HV 421
RF-generator			QMH 400-5	QMH 400-5	QMH 410-1	QMH 410-2
Electrometer preamplifier			EP 422	EP 422	EP 422	EP 422
Operating temperature/Analyzer		°C	150	150	150	150
Bakeout temperature/Analyzer		°C	400[3]	400[3]	400[3]	400[3]
Connection flange			DN 63 CF-F	DN 63 CF-F	DN 63 CF-F	DN 63 CF-F

with ion source	Ordering number			
Axial-, with Re filament	**PTM27330**	-	-	-
Cross-Beam-, with two W filaments	**PTM27331**	-	-	-
Cross-Beam with magnet and two W filaments	**PTM27332**	-	**PTM27340**	**PTM27350**
gas tight Cross-Beam-, with two W filaments	**PTM27333**	-	-	-
gas tight Cross-Beam with magnet and two W filaments	**PTM27406**	**PTM27334**	-	-
Cross-Beam-, with two W filaments and ion optics, 3 lenses[2]	**PTM27336**	-	-	-
Grid-, with W filament	**PTM27335**	-	**PTM27341**	-

Other combinations of devices on request.
Stand-alone components and accessories see next page.
For gas analysis please also see Prisma™ QMS 200 M page 62 and 63.

[1] Faraday in deflection unit, unit resolution, crossbeam ion source with magnet, emission 1 mA

[2] Isolated

[3] with magnet max. 300 °C

Stand-alone Components QMG 422

Analyzers		QMA 400	QMA 410	QMA 430
Rod system/material		QMF 150/Mo	QMF 160/Mo	QMF 130/st. steel
Rod diameter/length	mm	8/200	16/300	8/200
Operating temperature/Analyzer	°C	150	150	150
Bakeout temperature/Analyzer	°C	400[1)]	400[1)]	400[1)]
Connection flange		DN 63 CF-F	DN 100 CF-F	DN 63 CF-F
Weight with 90°-SEM	kg	10.7	17.2	10.7

	Ordering number		
with SEM 217, Axial ion source, Re filament	**PTM07710**	-	**PTM09710**
with SEM 217, Cross-Beam ion source, two W filaments	**PTM07711**	-	**PTM09711**
with SEM 217, Cross-Beam ion source, with magnet and tow W filaments	**PTM07718**	**PTM08711**	-
with SEM 217, gas tight Cross-Beam ion source, two W filaments	**PTM07713**	**PTM08712**	**PTM09712**
with SEM 217, Cross-Beam ion source, two W filaments, ion optics, 3 lenses	**PTM07717**	-	-
with SEM 217, Grid ion source, W filament	**PTM07715**	-	**PTM09713**

Filaments of QMA 400/410/430	Qty.	Rhenium	Tungsten	yttr. Iridium
for axial ion source	1 piece	-	-	**BN845057-T**
	5 pieces	**BN845022-T**	**BN845024-T**	-
for Cross-Beam ion source (gas tight)	2 pieces	**BN845052-T**	**BN845088-T**	**BN845282-T**
for grid ion source	1 piece	-	**BN845095-T**	-

Secondary electron multiplier	Ordering number
SEM 217 with 17 Cu-Be-dynodes, 400 °C, max.	**BG521611-X**
SEM 218 with conversion dynode, 18 Cu-Be-dynodes, 400 °C, max.	**BG444220-T**
HC-SEM 218 mounted at flange, for conversion SEM 217 to SEM 218	**BG444248-T**

Quadrupole Control Unit QMS 422	Ordering number
Quadrupole Controller QC 422 (technical data and dimensions see page 74)	**PTM26580**

Ion source supply IS 420	Ordering number
For installation at controller QMS 422. 5 slots of QMS are needed. The IS 420 supplies ion source and ion optics.	**BG512900-T**
cable IS 420/QMA, 3 m	**BG548082-T**
cable IS 420/QMA, 10 m	**BG548083-T**

High voltage supply HV 420/421 for installation at controller QMS 422	Ordering number
HV 420, two slots of QMS 422 and one cable HV/SEM are needed supplies voltage, 0 till –3.5 kV in steps of 1 V, for SEM 217	**BG546040-T**
HV 421, three slots of QMS 422 and two cables HV/SEM are needed supplies voltage, 0 till –3.5 kV in steps of 1 V, for SEM 217/218, supplies voltage for detection of positive and negative ions with SEM 217, and supplies voltage for additional acceleration (–6 kV) for SEM 218	**BG442250-T**
cable HV/SEM, 3 m	**BG541978-T**
cable HV/SEM, 10 m	**BG541979-T**

[1)] with magnet max. 300 °C

RF-generator QMH 400/410

include cable QMH/QMA 0.7 m; technical data see page 75	Ordering number
QMH 400-1; 2.05 MHz	PTM23067
QMH 400-5; 2.25 MHz	PTM23066
QMH 410-1; 1.7 MHz	PTM40566
QMH 410-2; 1.3 MHz	PTM40567
QMH 410-3; 1.4 MHz	PTM40568
Extension cable QMH/QMS 422, 7 m	BG448175-T

Electrometer Preamplifier EP 422

	Ordering number
fast, highly sensitive current-to-voltage converter with auto ranging in all ranges for direct connection to the analyzer, include cable to QME/QMH	PT444570-T

Accessories QMG 422

Input/output board for QMS 422

	Ordering number
AI 421 analog input, 16 channels, ±10.24 V, 12 bit	BG442240-T
IC/AO 421 analog output include ion counter, 12 channels, ±10.24 V, 12 bit	BG442320-T
DI 420 Digital input, 32 inputs	BG574700-T
DO 420 Digital output, 32 outputs	BG546004-T

For completion with ion counter

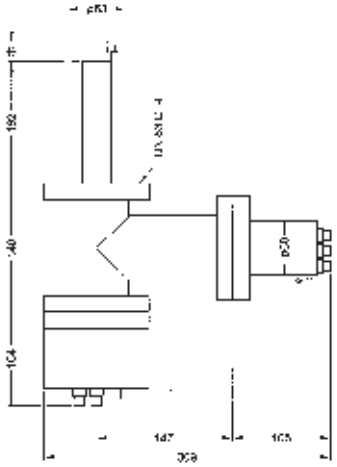
	Ordering number
IC/AO 421 ion counter include analog output, counting frequency, max. 50 MHz; pulse width min. 10 ns	BG442320-T
CP 400 ion counter preamplifier, pulse width 10 ns typ, pulse pair resolution <20 ns, dimensions page 75	PT442210-T
cable CP/IC, 3 m	BG448134-T
cable CP/IC, 10 m	BG448199-T

For LAN- and multiplex mode

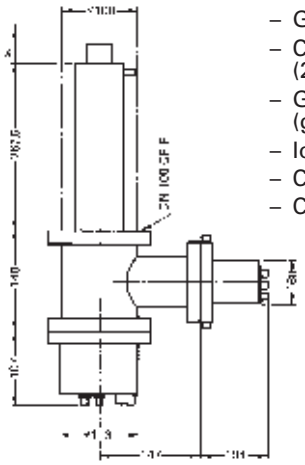
Technical data see page 65	Ordering number
OHA 200, Optical HUB, 5 Ports	PT442510-T
OHA 200, Optical HUB, 10 Ports	PT442520-T
ArcNet-PCMCIA adapter set	PT442530-T
PCI-PCMCIA Bridge for PC	PT442540-T
Fiber optic cable, 10 m	P51596152H
Fiber optic cable, 20 m	P51596152K
Fiber optic cable, 50 m	P51596152Q

Chambers and gas inlet for combination of complete systems for higher pressure ranges see page 82/83 and page 88.

Dimensions in mm

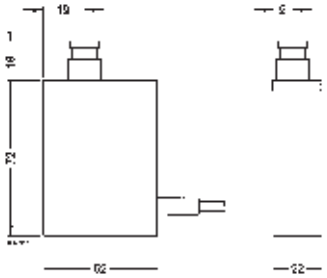


QMA 400, QMA 430
with 90° off-axis SEM



QMA 410
with 90° off-axis SEM

*
- Axial beam ion source = 26 mm
- Grid ion source = 27 mm
- Cross-Beam ion source = 35.5 mm (23.5 mm to the middle of the sensitive volume)
- Gas tight Cross-Beam ion source = 48 mm (gas connection in axis)
- Ion optics, 3-lense = 129 mm
- Cross-Beam ion source with axial ion optics = 43.5 mm
- Cross-Beam ion source with 3-lense ion optics = 171 mm



EP 422 Electrometer preamplifier

Quadrupole Controller QMS 422

The QMS 422 contains the quadrupole controller QC 422, a power supply and a data bus with 14 free slots. Configuration adapted to the application.

The main features are:

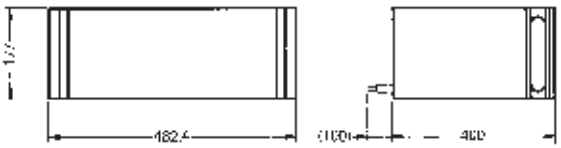
- extremely high measurement speeds are achieved thanks to the multiprocessor technology, which facilitates parallel data acquisition and sequence control.
- Electrometer amplifier with autoranging results in a wide dynamic range within one mass scan. Measurement speeds of up to 10 ms/amu.
- Optimized raw data acquisition through different operating modes.
- Service aids through internal spectrum simulation. The QMS 422 supports diagnosis via modem.
- Measurement algorithms such as moving averages, automatic measurement range search and peak jumping in steps to 1 amu simplify and improve the measurement data processing.

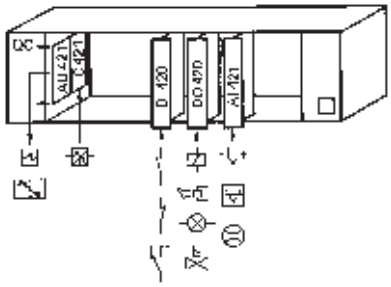
Technical Data

Measurement speed, MID	0.5 ms–60s
Measurement speed, scan analog	0.5 ms/u–60s/u
Measurement speed, scan Bargraph	0.5 ms/u–60 s/u
Measuring channels	64
Operating temperature/electronics	+5 bis +40 °C
Temperature, storage	–40 bis +65 °C
LAN interface	2.5 Mbits/s, ArcNet
RS-232-C interface	300–19200 bits/s
Analog connections	ELM OUT/EXT IN ± 10.24 V
Digital connections, EXT PROT	TTL
Digital connections, START/RUN IN	TTL
SYNC	TTL
ELM/MON	± 10.24 V
Scan	0 ... +10.24 V
Voltage	90–265 V/47–63 Hz
Weight	9.8 kg

Modules and completion boards:	
free slots	14
Modules, space requirem./max. config.	
IS 420	5/1
HV 420	2/1
HV 421	3/1
AI 421	1/1
DI 420	1/2
DO 420	1/3
Board mounted on QC: IC/AO 421	max. 1

Dimensions in mm





QMS 422

RF-generator QMH 400/410

The quart stabilized radiofrequency generator supplies the required voltages to the mass filter. The connection to the analyzer is established via two RF cables, length 0.7 m. The lenght of the connection cable to the controller is 3 m. The output of the radiofrequency generator is floating. It's reference voltage can be regulated between 0 and –60 V relative to the ion formation chamber.

The design results in advantages such as:

– ion source at positive potential. Prevents emision of electrons into the environment
– high ion injection energy; provides short transit time of the ions through fringe fields

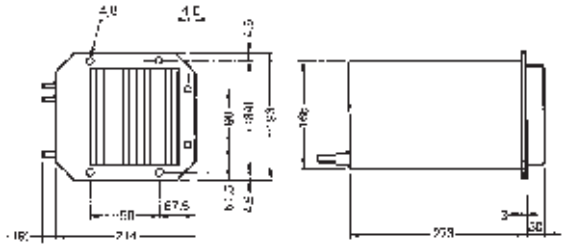
Technical Data

Mass range	QMH 400-1	QMH 400-5	QMH 410-1	QMH 410-2	QMH 410-3
with QMA 430	–	1–300 amu	–	–	–
with QMA 400	–	1–512 amu	1–1024 amu	1–2048 amu	–
with QMA 410	1–128 amu	–	–	–	1–340 amu
RF-frequency	2.05 MHz	2.26 MHz	1.7 MHz	1.3 MHz	1.4 MHz
Weight	4.5 kg	4.5 kg	6 kg	6 kg	6 kg

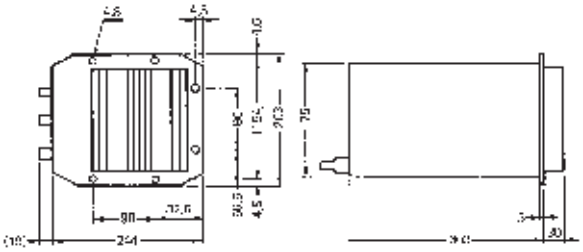
Ordering number

	PTM23067	PTM23066	PTM40566	PTM40567	PTM40568
Extension cable QMH/QMS, 7 m	–	–	–	–	BG448175-T

Dimensions in mm



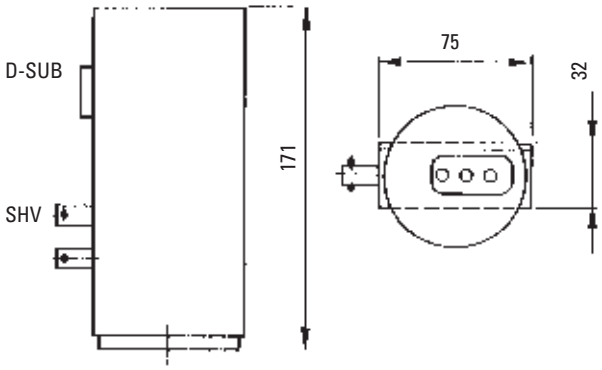
QMH 400



QMH 410

Ion counter preamplifier CP 400

Dimensions in mm



SPM Sputter Process Monitor

Online monitoring of sputter coating and reactive processes.

For maximum process yield and optimal product quality.

Quality assurance through in situ monitoring of the vacuum conditions and process gases.

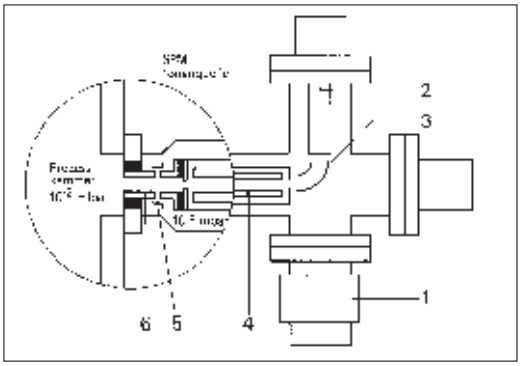
Quantitative results – data output in ppb, ppm, % or mbar.

Large dynamic range – simultaneous measurement from 100 % to ppb range.

SPM 200

SPM 400

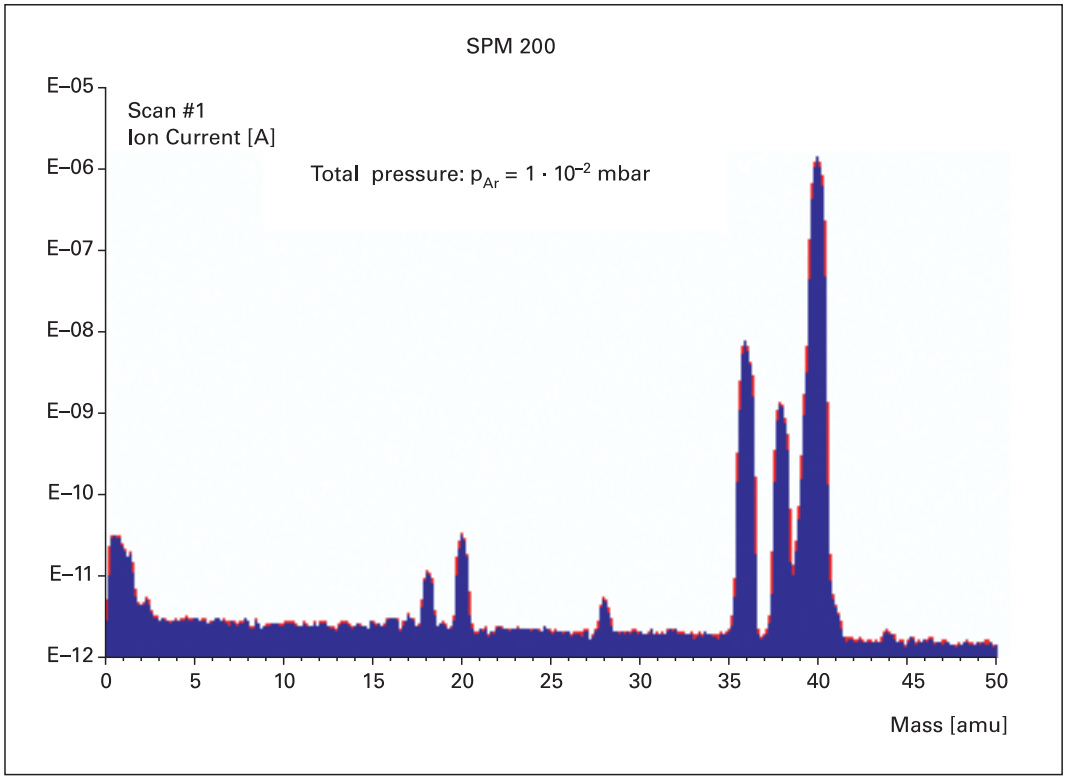
The picture schematically illustrates the complete analyzer flanged to a process chamber. The ion source does not penetrate into the process chamber. A short, wide piece of tubing establishes the connection to the process region. Due to the high conductance, the pressure in the ionization area is virtually the same as in the process chamber. The results demonstrate that under normal operating conditions, there is no significant partial pressure difference between the process and ionization area, even for water vapor in the 10^{-8} mbar range. "Normal operating conditions" means that the ion source is continually open toward the process chamber, also during the evacuation and conditioning phase. Another advantage of this solution is that the filaments are arranged on the high vacuum side of the analyzer. The openings for the electron injection and the ion extraction are the main conductances between the process area nd the high vacuum of the analyzer.



Any back diffusion from the analyzer chamber into the ionization region will be negligible due to the high conductance to the process chamber. The SPM is operated with the software package QuadStar™ with a special SPM user interface. This package contains routines for the process gases Ar, $Ar+N_2$, $Ar+N_2+0_2$ and for residual gas analysis.

Principle construction SPM (here SPM 400)

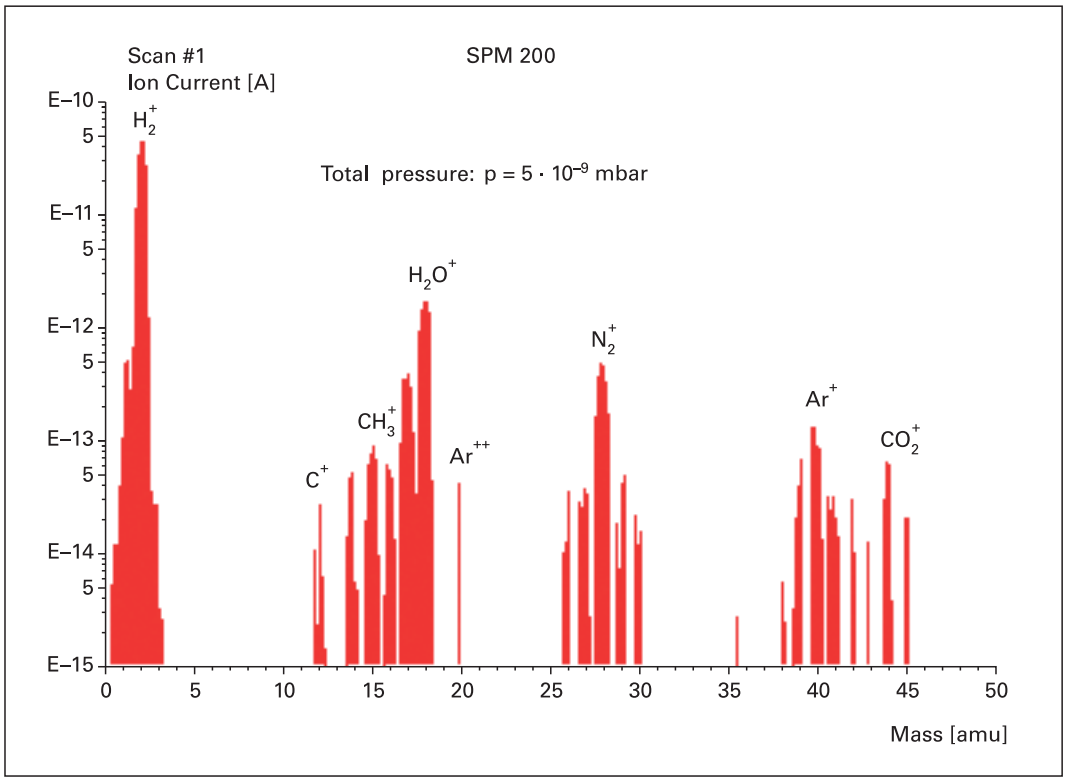
1 Turbo pump for differential pumping
2 Secondary electron multiplier SEM
3 Deflection unit
4 Quadrupole mass filter
5 Filaments
6 Conductance tube to process



Spectrum 1:
Total pressure
$1 \cdot 10^{-2}$ mbar (Argon),
recorded with 40 eV
ionization energy

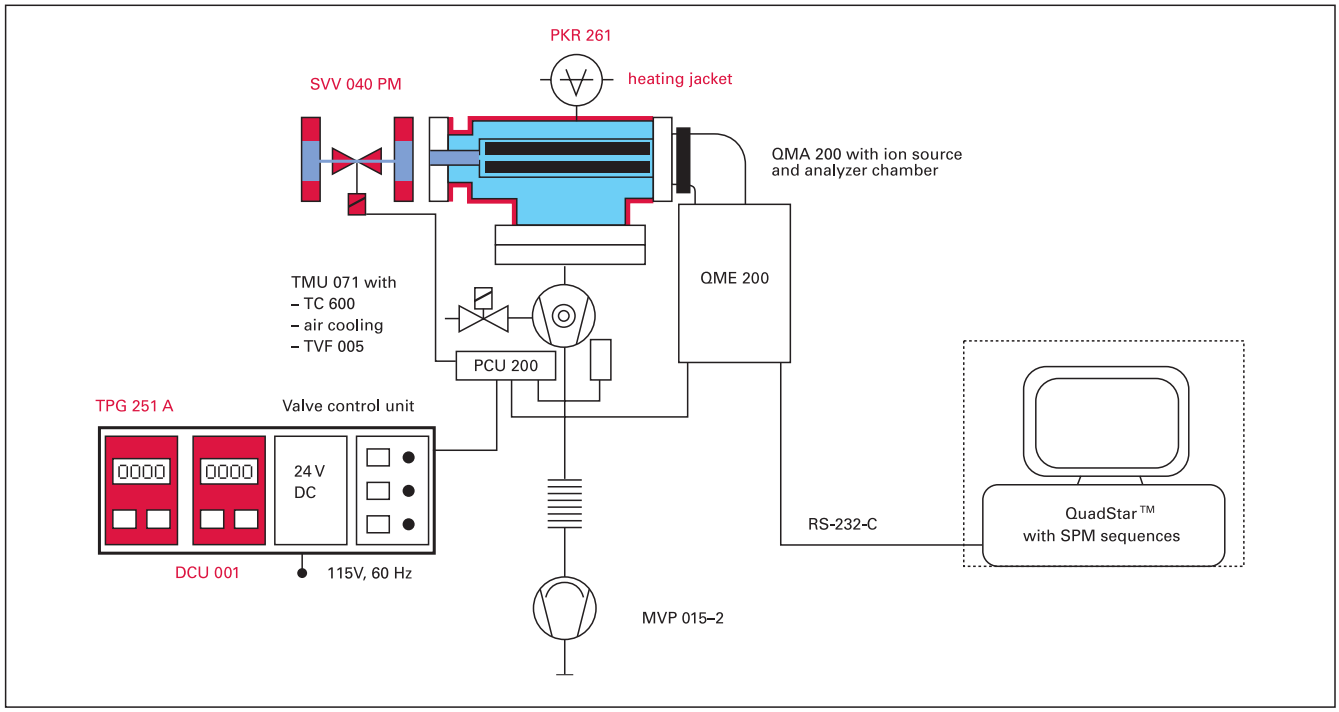
Both spectra clearly show that with the SPM as well process monitoring at pressure of $1 \cdot 10^{-2}$ mbar as residual gas analysis at pressure of $5 \cdot 10^{-9}$ mbar is possible.

The comparison of the ratios of mases 40 (Ar^{+}) and 20 (Ar^{++}) show the possibility to reduce formation of double loaded ions by variation of the ionization energy.



Spectrum 2:
Total pressure
$5 \cdot 10^{-9}$ mbar (Argon),
recorded with 70 eV
ionization energy

3.2 Gas Analysis at Pressure Range up to 10 mbar



SPM 200 with options

Scope of delivery SPM 200

- Quadrupole electronics QME 200
- Analyzer QMA 200 with SPM ion source and analyzer chamber
- Turbomolecular-Drag pumping unit, air cooled, with TMU 071-03, TC 600, venting valve TVF 005 and diaphragm pump MVP 015-2
- Pump control unit PCU 200
- 19" rack unit with valve control unit and power supply 24 VDC for QME and pumping unit
- QuadStar™ 422 with SPM-sequences and RS-232-C-cable

Options:

- heating jacket for analyzer chamber
- safety valve SVV 040 PM
- Total pressure measurement equipment with SingleGauge™ TPG 261, FullRange™ gauge PKR 261 and cable.
- Turbocontroller DCU 001 with cable DCU/TC

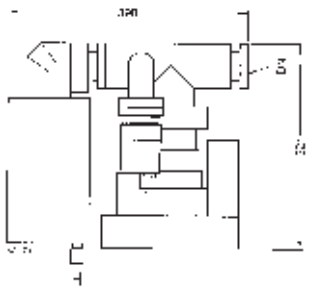
Scope of delivery SPM 400

- Quadrupole mass spectrometer system with control unit QMS 422, RF-generator and electrometer preamplifier
- Analyzer QMA 430 with SPM ion source and analyzer chamber
- Turbomolecular-Drag pumping unit, air cooled, with TMU 071-03, TC 600, venting valve TVF 005 and diaphragm pump MVP 015-2
- Pump control unit PCU 200
- 19" rack unit with valve control unit and power supply 24 VDC for QME and pumping unit
- QuadStar™ 422 with SPM-sequences and RS-232-C-cable

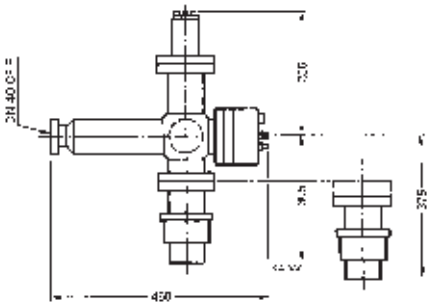
Options:

- safety valve SVV 040 PM
- Turbocontroller DCU 001 with cable DCU/TC

Dimensions in mm



SPM 200



SPM 400

Summary SPM Sputter Process Monitor

SPM 200: Economical, compact solution.

SPM 400: Highest sensitivity, lowest detection limit, high measurement speed.

Sputter process monitor		SPM 200	SPM 200	SPM 400
Mass range	amu	1–100	1–200	1–512
Detection limit (in Argon)				
Hydrogen	ppb	<3000	<6000	<100
Water vapor	ppb	<500	<500	<500
Nitrogen	ppb	<100	<100	<10
Oxygen	ppb	<100	<100	<10
Carbon dioxide	ppb	<100	<100	<20
Analyzer with SPM ion source		QMA 200 M	QMA 200 M	QMA 430
Rod system, material/diameter/length	mm	st. steel/6/100	st. steel/6/100	st. steel/8/200
Detector		C-SEM/Faraday	C-SEM/Faraday	SEM 217/Faraday
Weight, Analyzer incl. Turbo	kg	13	13	22
Quadrupole control unit		QME 200 M	QME 200 M	QMS 422
Software		QuadStar™	QuadStar™	QuadStar™
Connection flange		DN 40 CF	DN 40 CF	DN 40 CF

SPM for process pressure, max. 0.01 mbar		Ordering number		
With turbomolecular pumping station, consist of turbopump TMU 071-03, diaphragm pump MVP 015 and pumping control unit PCU 200	230 V	**PTM26122**	**PTM26124**	**PTM26222**
	115 V	**PTM26123**	**PTM26125**	**PTM26223**
Without turbomolecular pumping station, without pumping control unit PCU 200		**PTM26102**	**PTM26104**	

SPM for process pressure, max. 10 mbar		Ordering number		
With turbomolecular pumping station with purge gas system for corrosive gas applications, consist of turbopump TMU 071-03, diaphragm pump MVP 015-2 pumping control unit PCU 200 and CF-flange with orifice for pressure till 10 mbar	230 V	**PTM26112**	**PTM26114**	**PTM26212**
	115 V	**PTM26113**	**PTM26115**	**PTM26213**

Stand-alone Components

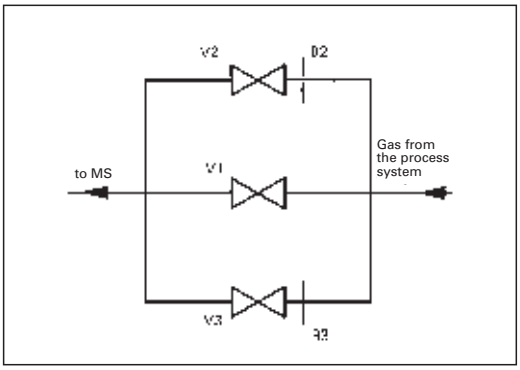
SPM	Ordering number		
Cathode unit for SPM ion source, yttr. Iridium	**BN846384-T**	**BN846384-T**	**BN845837-T**
Pumping control unit PCU 200	**PTM47440**	**PTM47440**	**PTM47440**

Accessories

SPM	Ordering number		
Heating for SPM chamber	**PT442711**	**PT442711**	
SVV 040 PM, safety valve, electropneum. 24 VDC (between chamber of customer and SPM)	**PFF58231**	**PFF58231**	**PFF58231**
TPG 261, SingleGauge™	**PTG28030**	**PTG28030**	
PKR 261, FullRange™ Gauge	**PTR26252**	**PTR26252**	
Cable, PKR-TPG, 3 m	**PT448250-T**	**PT448250-T**	
DCU 001, Display Control Unit	**PM041816-T**	**PM041816-T**	
Cable, DCU-TC, 3 m	**PM051431-T**	**PM051431-T**	

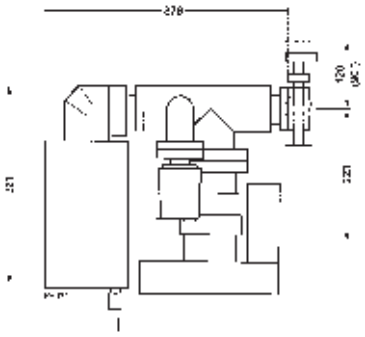
HPA 200 High Pressure Analyzer

Differentially pumped mass spectrometer unit.
For processes between 10^{-6} and 5 mbar.

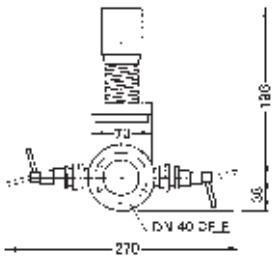


The valve interface consists of three valves. V1 is a bellows valve with high conductance and nominal fitting diameter of 40 mm. This valve is opened for residual gas analysis or for leak testing under high vacuum conditions in the process plant. In V2 and V3, orifices are built-in. The conductance values are designed to cover the pressure range of 1–10^{-3} mbar. An orifice with a diameter of 0.03 mm is used in V2 for pressures between 1 and 5 mbar. The modules run on QuadStar™ software.

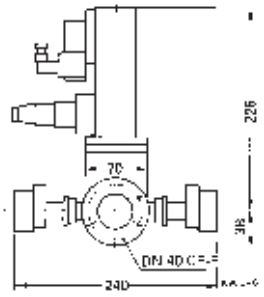
Dimensions in mm



HPA 200



HPI 010 manual



HPI 010 electropneumatic

Summary HPA High Pressure Analyzer

Mass range in amu			1–200
Operating pressure, max.	mbar		5
Detection limit, min.	mbar	Faraday	$1 \cdot 10^{-11}$
		C-SEM	$1 \cdot 10^{-14}$
Sensitivity for Ar	A/mbar	Faraday	$3 \cdot 10^{-4}$
		C-SEM	200
Analyzer			QMA 200 M
Rod system, material/diameter/length	mm		6/100
Detector			C-SEM/Faraday
Mass spectrometer electronics			QME 200 M
Software			QuadStar™
Turbo pump			TMU 071-03
Diaphragm pump			MVP 015-2
Pumping control unit			PCU 200
Valve interface, electropneumatic			HPI 010
with orifice	mm		0.1/0.3 [1]
Compressed air	bar		4.5–7
Weight, without diaphragm pump	kg		15
Connection flange			DN 40 CF

[1] orifice 0.03 mm also part of delivery

	Ordering number
HPA 200, 230 V, with HPI 010, elektropn.	**PTM26710**
HPA 200, 115 V, with HPI 010, elektropn.	**PTM26711**
HPA 200, 230 V, with HPI 010, manual	**PTM26712**
HPA 200, 115 V, with HPI 010, manual	**PTM26713**

Stand-alone Components

HPA 200	Ordering number
Cathode unit, yttr. Iridium	**BN846138-T**
Valve interface HPI 010 (with orifice) electropneumatic, 24 VDC, without control unit	**B8071104EH**
manual	**B8070201GG**

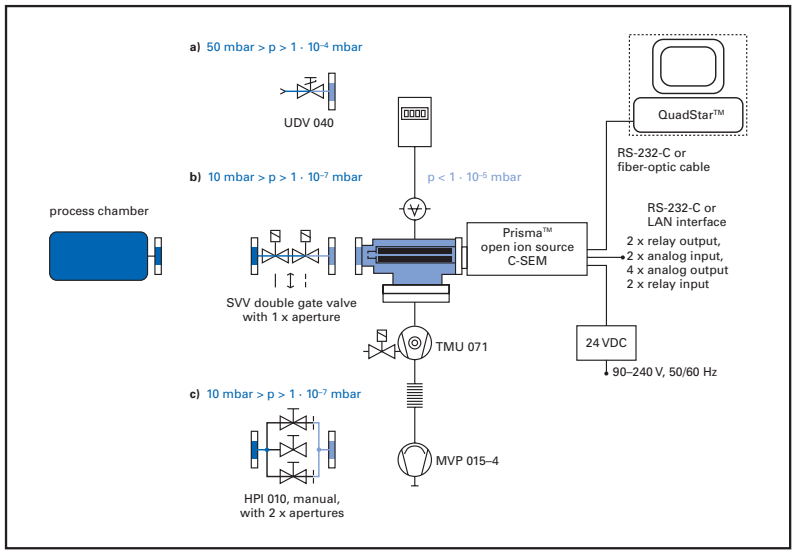
Accessories

HPA 200	Ordering number
Heater jacket for HPA chamber	**BG442668**
PKR 261, FullRange™ Gauge	**PTR26252**
Cable, PKR-QME 200; 0.6 m	**PT448249-T**

Examples for Combination of Stand-alone Components

Mass spectrometer arrangements for gas analysis at pressure range 10^{-5} to 10 mbar.

See also chapter **1.3.1 Mass spectrometer arrangements for pressure < 10 mbar.**



Differentially pumped mass spectrometer with open ion source and pressure reduction by:

a) UHV gas dosing valve UDV 040 as an adjustable conductance.

b) Double gate valve, one slide with orifice for pressure reduction, one closed slide. For residual gas analysis (both slides open) at pressure <10-5 mbar and gas analysis at pressure up to 10 mbar (only slide with orifice closed).

c) Valve interface HPI 010 for residual gas analysis at pressure <10^{-5} mbar and gas analysis at two different pressures up to max. 10 mbar (adjustable by two orifice)

Stand-alone Components

Quadrupole Mass Spectrometer	Ordering number
Prisma™ QMS 200 M with C-SEM, Technical Data see page 62 and 63	
QMS 200 M1, Mass range 1–100 amu	**PTM03121111**
QMS 200 M2, Mass range 1–200 amu	**PTM03221111**
QMS 200 M3, Mass range 1–300 amu	**PTM03321111**
Chamber for QMS 200 M, dimensions see page 89	**PT442830-T**
Heater jacket for chamber	**BG442668**
QMG 422 Quadrupole Mass Spectrometer QMG 422 with analyzer QMA 400/430, 90°-off-axis-SEM 217, axial-, Cross-Beam- or grid-ion source. Selection, ordering number and technical data see page 70/71	
Chamber for QMA 400/430, dimensions see page 89	**BG442540-X**

Turbomolecular pumping station	Ordering number
TSU 071, water cooled, connection flange DN 63 CF, consist of: Turbo-Drag-pump TMU 071 with heating, venting valve, air drier and diaphragm pump MVP 015-2, TSU 071, 190-260 V, 50/60 Hz	**PMS0602212**
TSU 071, 90-125 V, 50/60 Hz	**PMS0601212**

Other turbo pumping stations and combinations of stand-alone components on request

Total pressure measurement outfits	Ordering number
Measurement range 1000 till 5 · 10^{-9} mbar, consist of: TPG 261 SingleGauge™, 90–260 VDC	**PTG28280**
PKR 261, FullRange™ Gauge, DN 40 CF	**PTR26252**
Cabel, PKR-TPG 261, 3 m	**PT448250-T**

Gas Inlet Valve

	Ordering number
UHV gas dosing valve UDV 040, DN 40 CF, inlet VCR 1/4", manual operated All metal valve, valve seat – Cu-alloy, valve plate – Sapphire, housing – st. Steel	**PFI52031**
Heater jacket, 200 °C, for UDV	**PT420376-T**
Quartz capillary, inlet side, 2 m	**PT420537-T**
Quartz capillary, vacuum side, 1 m	**PT418976-T**

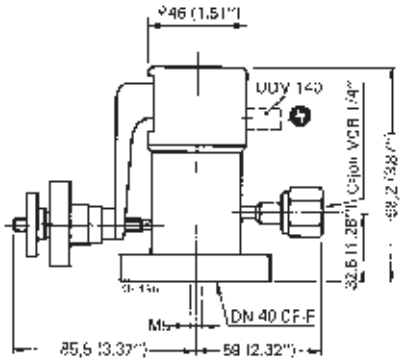
Double gate valve

	Ordering number
One slide with standard valve plate, one slide with tapped hole for taking up a orifice. Housing and valve plate - st. steel, valve seal - Viton, bakeout temperature max. 200 °C. Fastening screw and orifice must be ordered separately.	
Double gate valve, DN 40 CF, manual	**PT160100-T**
Double gate valve, DN 40 CF, electropneumatic, 24 VDC	**PT160101-T**
Fastening screw for orifice	**BK356429**
Orifice 0.01 mm	**BK212573**
Orifice 0.02 mm	**BK212574**
Orifice 0.03 mm	**BK212575**
Orifice 0.05 mm	**BK212576**
Orifice 0.1 mm	**BK212577**

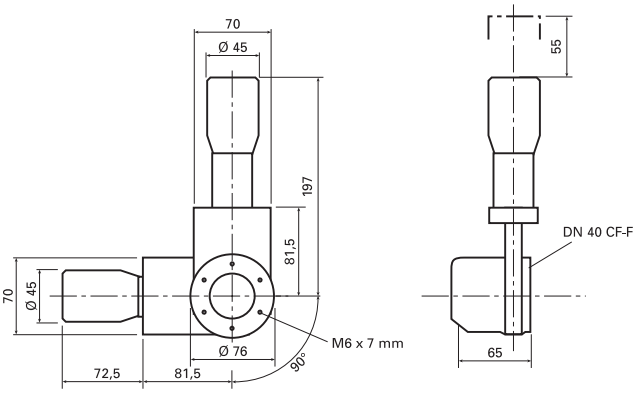
Valve interface HPI 010

	Ordering number
Valve combination with shutter and two by-pass lines with orifices 0.1/0.3 mm, see page 80	
HPI 010, DN 40 CF-F, manual, DN 40 CF	**B8070201GG**
HPI 010, DN 40 CF-F, electropneumatic, 24 VDC	**B8071104EH**

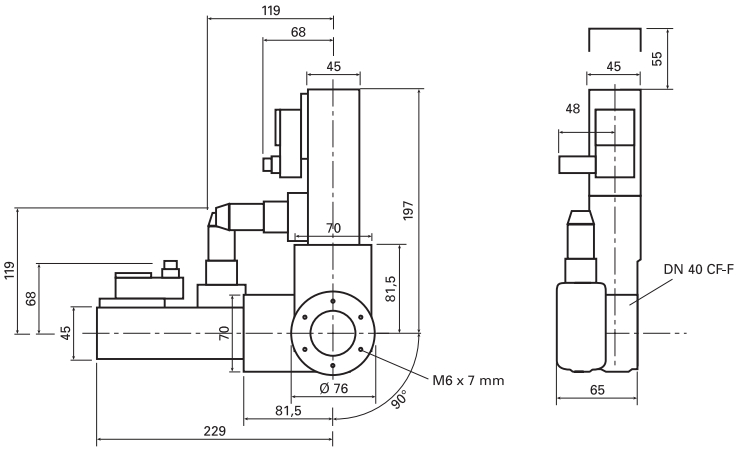
Dimensions in mm



UDV 040



Double gate valve, manual

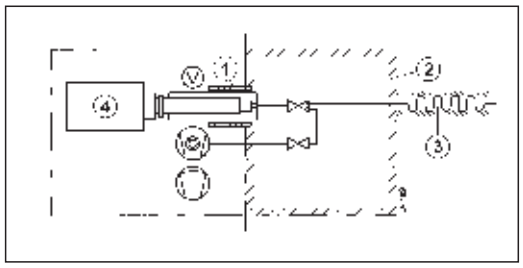


Double gate valve, electropneumatic

3.3 Gas Analysis at Pressure Range up to 1 bar

OmniStar™ GSD 301 O, for general gas analysis at atmosphere pressure

Quantitative gas analysis – incl. non-polar molecules, inert gases, etc.
Low detection threshold (<1 ppm) even for condensable gases.
Temperature-controlled gas line (st. steel capillary)
Software controlled shutter valve.
Certain identification of unknown gases.
Control of up to 64 gas components
As good as no memory effects
Short response time
Online process control
Mass ranges 1–100 amu, 1–200 amu, 1–300 amu



Principle construction of OmniStar with shutter valve at gas inlet

1 Heating for conditioning of analysis chamber
2 Heated gas inlet chamber
3 Temperature-controlled gas line (capillary)
4 Prisma™ quadrupole mass spectormeter

QuadStar™ Analysis Software

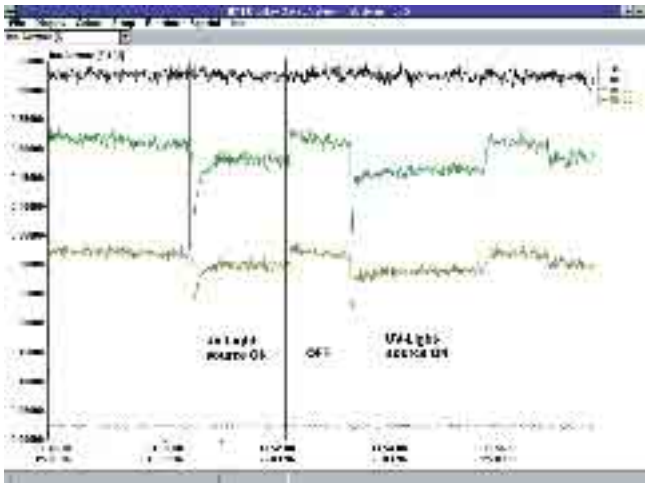
- Qualitative analysis of all gases
- Quantitative analysis with on-line calculationn of concentration
- Simultaneous process data acquisition via analog inputs (e.g. temperature)
- Presentation of mass spectrometric data as a function of process data
- Definition of process windows and setting of alarms
- Convenient data evaluation supported by a spectrum library, statistical and magnifying functions, and a cursor
- Data exchange with other programs, QuadStar™ suppoorts DDE
- Application specific user interface can be easily created

Examples of application

Air analysis

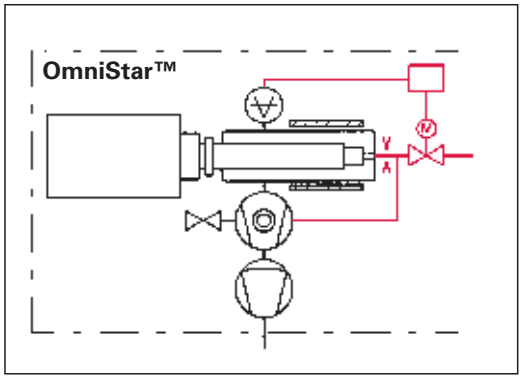
Analog scan of air. Mass range 1–200 amu. Average of 14 scans at 10s/amu each. N_2 = 78.1% (28 amu). ^{136}Xe = 7.8 ppb (136 amu).
The OmniStar™ has a very wide dynamic range of more than 8 orders of magnitude.

Air cleaning analysis



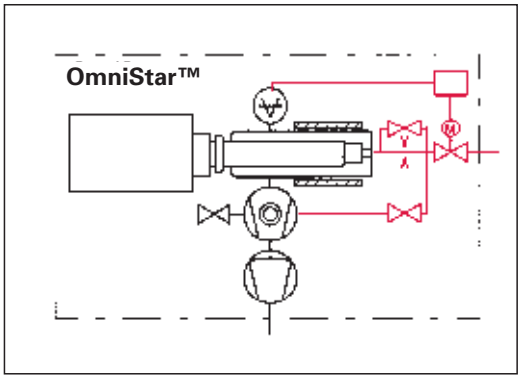
Concentration of toluene (91 and 92 amu) as a function of time. Argon (36 amu) and krypton (84 amu) from the air serve as reference gases to verify the stability. Measurement at atmospheric pressure in Multiple Ion Detection (MID) mode with the OmniStar™.

Deliverable options of GSD 301 O for customized applications



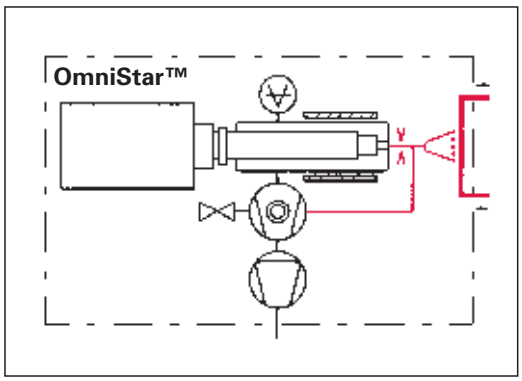
Pressure range of 1 to 1000 mbar

The pressure in the analysis chamber is automatically controlled.
Connection: DN 16 ISO-KF.



Pressure range of 5 · 10^{-3} to 1000 mbar

The pressure in the analysis chamber is automatically controlled.
Connection: DN 16 ISO-KF.



Analysis of liquids

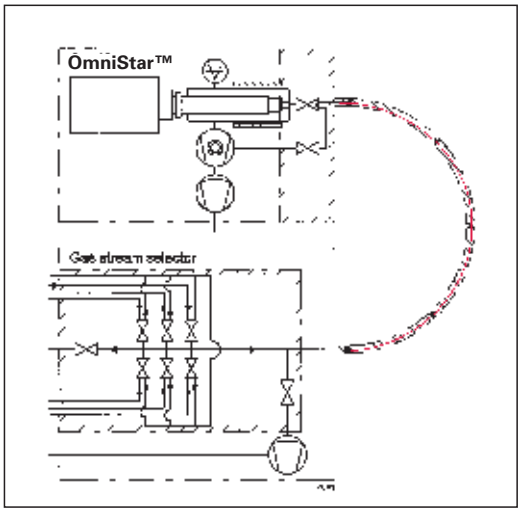
Membrane gas inlet for measuring e. g. gases dissolved in water.

For corrosive and explosive gas
e.g. CDD exhaust monitoring

Version with controlled purge gas system. Effective protection against corrosion and explosive gas mixtures.

Gas Stream Selector GSS 300

Heated gas inlet system for up to 12 gas streams – sample gases and calibration or zero gases QuadStar™ for arbitrary switching of gas streams.



ThermoStar™ GSD 301 T for coupling to thermobalance

Reactive and condensable gases are detectable even in small concentrations.

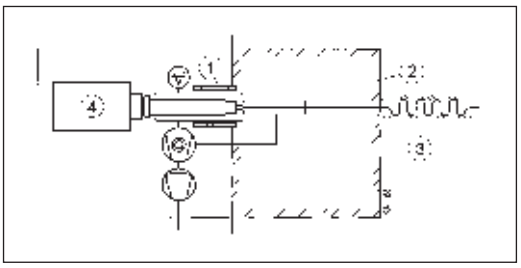
Minimal contact of medium with metal parts.

Temperature-controlled gas line (quartz capillary)

No chemical reaction.

Certain identification of unknown gases.

Mass ranges 1–100 amu, 1–200 amu, 1–300 amu

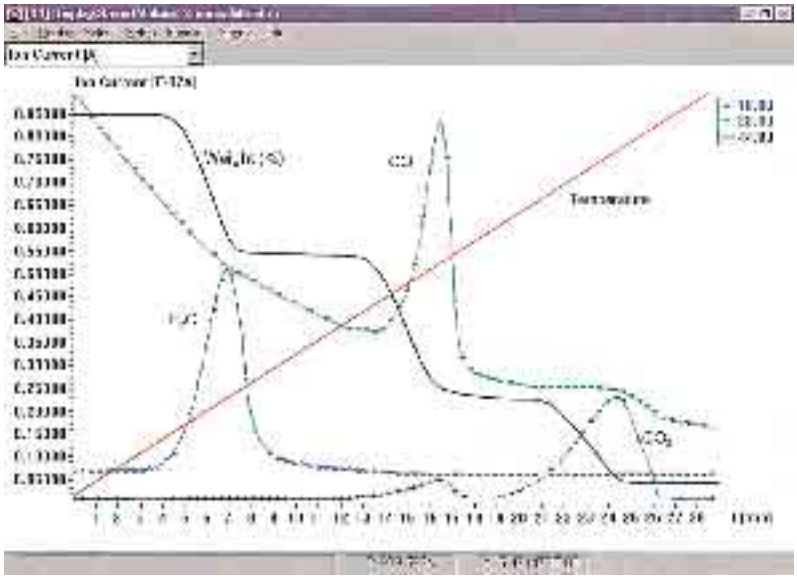


Principle construction of ThermoStar™ with open gas inlet

1 Heating for conditioning of analysis
2 Heated gas inlet chamber
3 Temperature-controlled test gas line (capillary)
4 Prisma™ quadrupole mass spectrometer

QuadStar™ Analysis Software

- Qualitative analysis of all gases evolving during thermal analysis.
- Simultaneous data acquisition from a thermal analyzer via Analog Input Module (e. g. temperature, sample weight, differential weight loss).
- Presentation of mass spectrometric data as a function of the thermobalance temperature.
- Convenient data evaluation supported by a spectrum library, statistical and magnifying functions and a cursor.
- Data exchange with other programs via binary code or ASCII files. QuadStar™ supports also DDE.



TA of calcium oxalate. The evolving gases water vapour (18), carbon monoxide (28), and carbon dioxide (44) are shown together with the weight and temperature as a function of time.

Technical Data		OmniStar™	ThermoStar™
Mass range	amu	1–100/1–200/1–300	1–100/1–200/1–300
Gas connection		st. steel capillary	quartz capillary
Gas inlet		software controlled inlet valve	continuously open
Pressur reduction		2 stages, fractionation-free	2 stages, fractionation-free
Gas flow rate	sccm	1–2	1–2
Sample pressure	mbar	1000	1000
Operating temperature capillary	°C	up to 200	up to 200
Analyzer		QMA 200 M	QMA 200 M
Rod system, material/diameter/length	mm	st. steel/6/100	st. steel/6/100
Detector		C-SEM/Faraday	C-SEM/Faraday
Mass spectrometer electronics		QME 200 M	QME 200 M
Software		QuadStar™	QuadStar™
Dimensions (L x W x H)	mm	720 x 280 x 420	720 x 280 x 420
Weight	kg	45	45

Inputs and Outputs of GSD 301:

Analog output: 2 outputs –5.12 bis +5.12 V, 16 bit.
Output of measured data (e.g. ion current) or ratios (e.g. concentrations).
For process control and data output via oscilloscope or recorder.

Analog input: 2 inputs –5.12 bis +5.12 V, 11 bit.
Reading of data e.g. pressure, gas flow, temperature, weight.
For correlation of spectrometer data and process data.

Digital output: 1 relay, N.O., 24 VDC with free allocation of switching functions
1 relay, forward brake-over for pump status. Switched at 90 % of the rated turbo speed.
For monitoring the pumping station.

Digital input: 1 contact, 5 VDC; for starting the measurement cycle.

GSD 301-Ordering number

Capillary		Mass range	
1 Meter	1	1-100 amu	1
2 Meter	2	1-200 amu	2
without	3	1-300 amu	3
		1-100 amu, corrosive gas[1)]	4
		1-200 amu, corrosive gas[1)]	5
		1-300 amu, corrosive gas[1)]	6

Voltage	
230 V, 50 ... 60 Hz	6
115 V, 50 ... 60 Hz	7

PT M00 000

Version	
ThermoStar™, Standard	1
ThermoStar™ with calibration device	2
OmniStar™, Standard	3

Filament	
Tungsten	1
yttr. Iridium	2

Other versions, e.g. for other inlet pressures, on request

[1)] Corrosive gas version only with OmniStar™

Accessories

GSD 301	Ordering number
Cathode unit	
Tungsten	**BN846281-T**
yttr. Iridium	**BN846395-T**
Connection für 1/4" pipe	**BG442778-T**
Gas Stream Selector GSS 300 (only for OmniStar™)	
for 6 gas inlets, 230 V, 50/60 Hz	**PT444750-T**
for 6 gas inlets, 115 V, 50/60 Hz	**PT444751-T**
for 12 gas inlets, 230 V, 50/60 Hz	**PT444760-T**
for 12 gas inlets, 115 V, 50/60 Hz	**PT444761-T**
Adapter for usual thermobalances (only for ThermoStar™)	**on request**

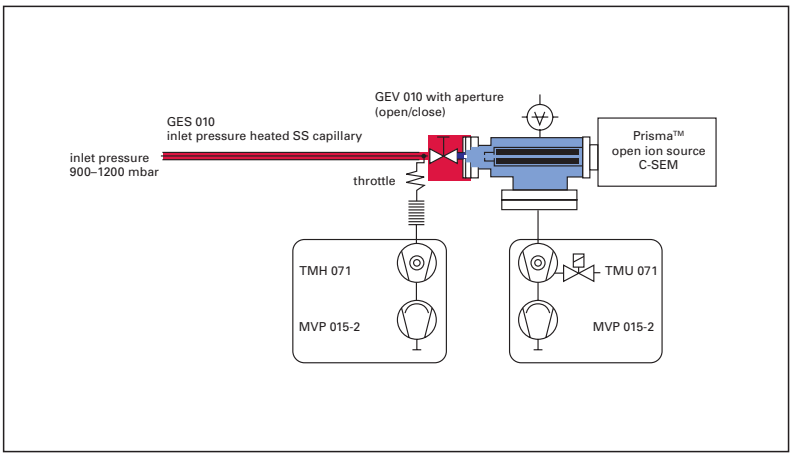
Examples for Combination of Stand-alone Components

Mass spectrometer configurations for gas analysis at pressure range up to 1 bar.

By an optimize configuration of gas inlet system, mass spectrometer and pumping units for pressure stage and analyzer chamber it is possible to meet a multitude of applications at pressure range up to 1000 mbar.

Information to the respective components you can find at the followed pages.

See also chapter 1.3.2 Mass spectrometer arrangements for pressure > 10 mbar.



Example with gas inlet system GES 010

for general determination of gas concentration in range of 100 % - 10 ppm.

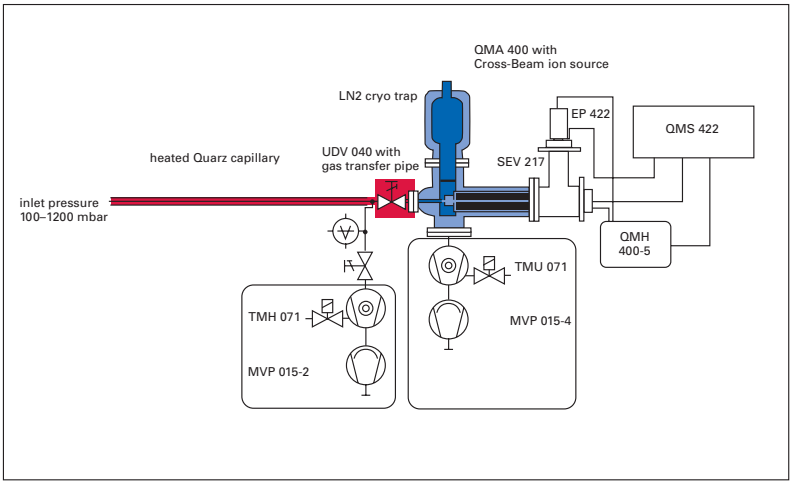
Inlet pressure range 900 - 1200 mbar.

Sample gas stream approx. 2 - 3 sccm.

With valve GEV 010 the gas inlet could be closed/opened. The adaption to the inlet pressure is be done by changing the orifice of the GEV 010.

Depending on the application the mass spectrometer Prisma™ or QMG 422 could be used.

The sketch shows an oil-free turbo pumping station for the pressure stage at the GEV 010.



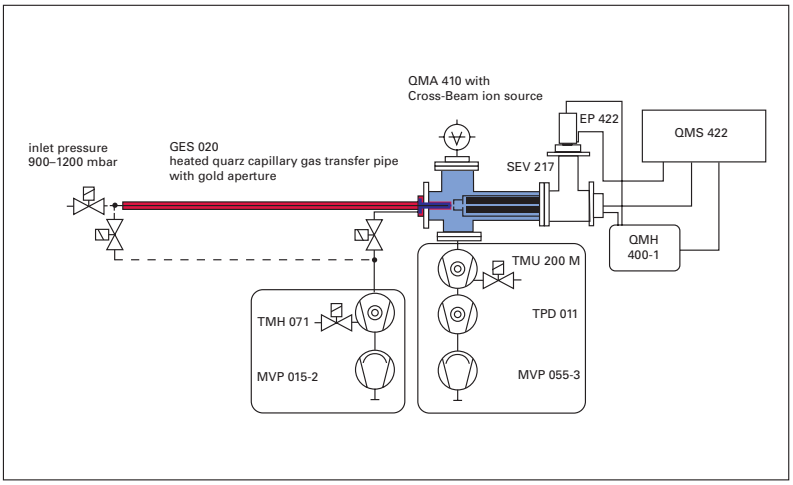
Example with gas inlet system UDV 040

with adjustable gas inlet valve UDV 040 and valve EVB 016 SX at the pumping line of the pressure stage for adjustment to inlet pressure and sample gas consumption.

Inlet pressure range 100 - 1200 mbar.

The simplified sketch show the gas inlet, 90 degree turned. A gas tube feeds the sample gas as a beam direct to the Cross-Beam ion source of the analyzer.

Depending on the application the mass spectrometer Prisma™ or QMG 422 could be used.



Example with gas inlet system GES 020

Optimized for trace analysis of pure gas by minimization of the internal surfaces and volume.

Inlet pressure range 900 - 1200 mbar.

With that gas inlet system constiting of quartz capillary and gold orifice it is possible to verify reactive gases (e.g. O_2) in a range < 10 ppm.

The sketch shows a combination of turbo-drag pump TPD 011 and diaphragm pump as backing pump unit of the magnetic bearing turbo pump TMU 200 M. This combination of pumps is complete oil-free and features highest compression ratio for light gases.

Vacuum chambers and LN_2 cold trapp

Low background – requisities for solving many different analytical problems.

High-quality, slit-free model.

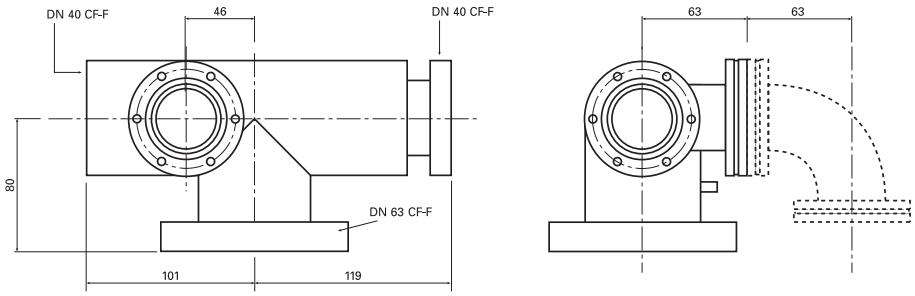
No memory effects.

Reproducible measurement data.

	Ordering number
Chamber for Prisma™ QMS 200 F and QMS 200 M, and QMA 125 with Faraday	PT442830-T

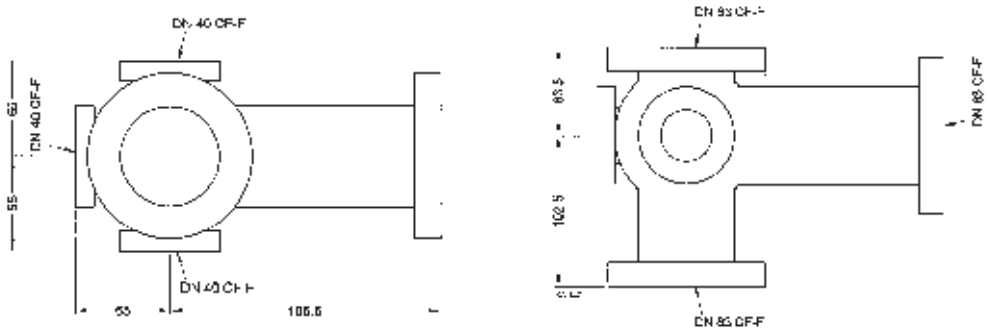
(include elbow 90°)

Dimensions in mm



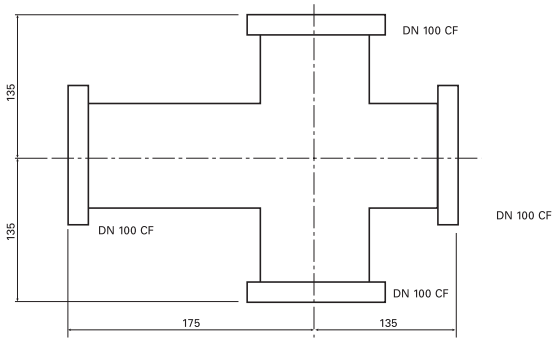
	Ordering number
Chamber for QMA 125 with 90°-off-axis SEM and for QMA 400 and QMA 430	BG442540-X

Dimensions in mm



	Ordering number
Chamber for QMA 410 with Cross-Beam ion source	PF000025

Dimensions in mm



	Ordering number
LN_2-Cold trapp, DN 63 CF, with cooling finger for reduction of residual gas background at the area of the ion source LN_2-capacity 1.9 l	PT160001

Gas Inlet Systems

Two-stage gas inlet system for demixing-free inlet of gas mixtures at pressure range up to 1000 mbar for analysis with quadrupole mass spectrometer.

First pressure stage is a capillary in st. steel (GES 010/052) or quartz (GES 020/UDV 040). By heating of the capillary, most condensation of vapor can be prevented.

The second pressure stage is an orifice (GES 010/020/052) or opening of valve (UDV 040).

Summary Gas Inlet Systems

Gas Inlet System		GES 010	GES 052	GES 020[1]	UDV 040
Actuation		manual	electromagn. 24 VDC	open	manual [2]
Inlet pressure	mbar	1000	1000	1000	1000
Capillary, heated		st. steel	st. steel	Quarz	Quarz
inner diameter/length	mm	0.15/1000	0.15/1000	0.15/1000	0.15/1000
Operating temperature, max	°C	200	120	200	200
Connection flange					
High vacuum side		DN 40 CF	DN 40 CF	DN 40 CF	DN 40 CF
Roughing side		DN 16 ISO-KF	DN 16 ISO-KF	1/4" VCR male	1/4" VCR male
Materials with media contact		st. steel, gold, PTFE	st. steel, Viton	quartz, gold	quartz, st. steel, sapphire, Cu-alloy
Scope of delivery		Valve GEV 010 with heating jacket, throttle line, capillary hose, assembly components,	Valve GEV 052, capillary with heater, shut-off valve in pump piping	Flange with orifice and pumping connection, capillary with heater	Gas dosing valve UDV 040 with heating jacket, capillary with heater and pumping connection
		Ordering number			
Ordering number		**BG444530-T**	**BG444540-T**	**BK355370-T**	**BK355366-T**

Stand-alone Components

	Ordering number	
Capillary with heating jacket, length 1 m, ID 0.15 mm/AD 1/16"	**BK353584-T**	**BK353584-T**
Orifice holder, for GEV 010	**BK375004-T**	

Accessories

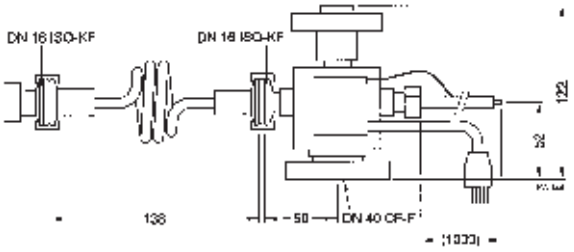
Gas Inlet Systems	Ordering number			
Orifice – 0.005 mm	**BK362334**	**BK362334**		
Orifice – 0.01 mm	**BK212573**	**BK212573**		
Orifice – 0.02 mm	**BK212574**	**BK212574**		
Orifice – 0.03 mm	**BK212575**	**BK212575**		
Orifice – 0.05 mm	**BK212576**	**BK212576**		
Orifice – 0.1 mm	**BK212577**	**BK212577**		
Conversion kit for gas tight ion source/QMA 400	**BK375579-T**	**BG442259-T**		
Gas tube for chamber BG442540-X and Cross-Beam ion source				**PT160000-T**
Gas connection on the customer's side			**BK353995-T**	**BK353995-T**

Pumps/pumping stations for first pressure stage see page 90

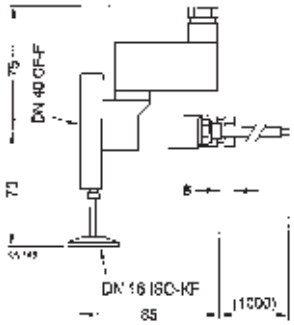
[1] Immersion depth of orifice designed to match chamber BG442540-X and Cross-Beam ion source

[2] UDV for automatic control on request

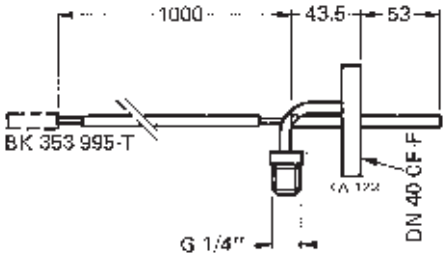
Dimensions in mm



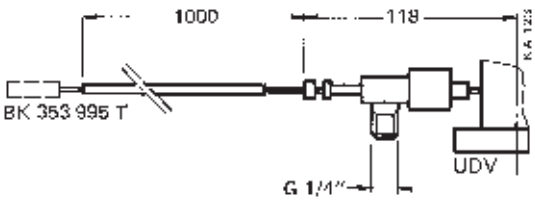
GES 010 (BG 444530-T)



GES 052 (BG 444540-T)



GES 020 (BK 355370-T)



UDV 040 (BK 355366-T)

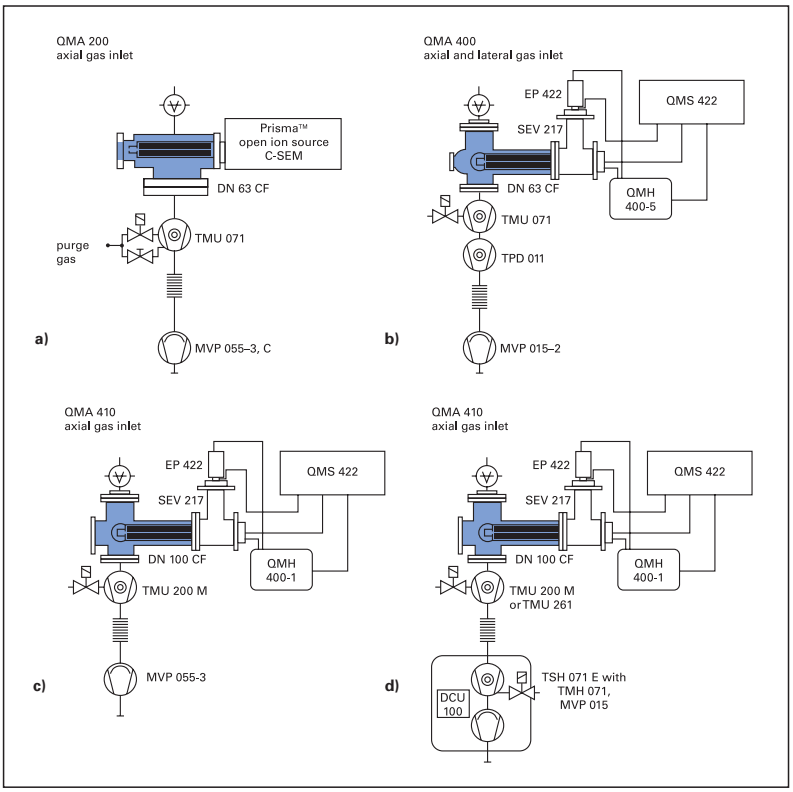
Pumping Systems

The right selection of pumping systems for the analysis vacuum system is important for the efficiency of the quadrupole mass spectrometer.

Pfeiffer Vacuum-turbomolecular pumps and their accessories could be optimal configurated to the different analytical applications.

See also chapter 1.3.1

Examples for special configurated pumping systems for the analyzer vacuum system.



a) Turbo-Drag-Pumping system for gas mixtures with corrosive or explosive components

With inert gas the bearings of the turbo pump and the fore line pump will be protected and the sample gas will be rarefied. This reduces load of corrosion and protects the system against explosive gases.

b) und d) Turbo-Drag-Pumping system with an additional turbo pump at the foreline side

With such a pump combination the compression ratio for light gases (H_2, He) will increased. This reduces the background and increases the detection limits for these gases.

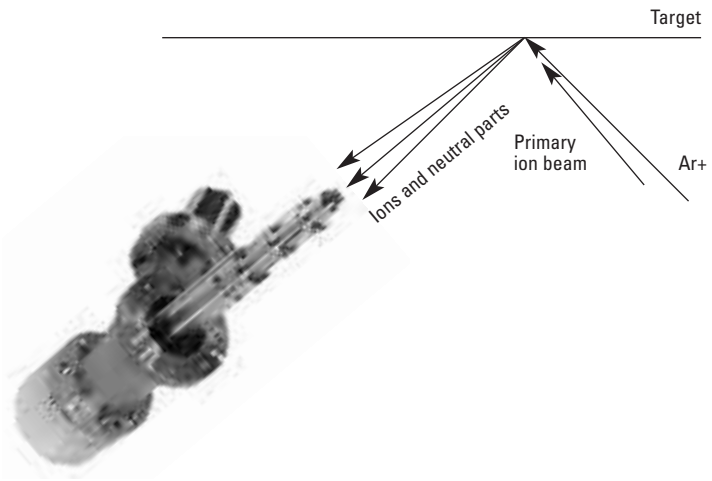
c) und d) Turbo-Drag-Pumping system with magnetic bearing Turbo-Drag-Pump TMU 200 M

For evacuation of large analyzer chambers (QMA 410).
These pumping systems with magnetic bearing turbo pumps are absolute free of oil and free of maintenance.

Our complete program of turbo pumps with detailed information you can find at our Pfeiffer-Vacuum catalogue.

4 Mass spectrometer for ion analysis

Contents



QMG 422 Secondary Ions Mass Spectrometer

Mass ranges 1-340 amu, 1-512 amu and 1-1024 amu, option 1-2048 amu.

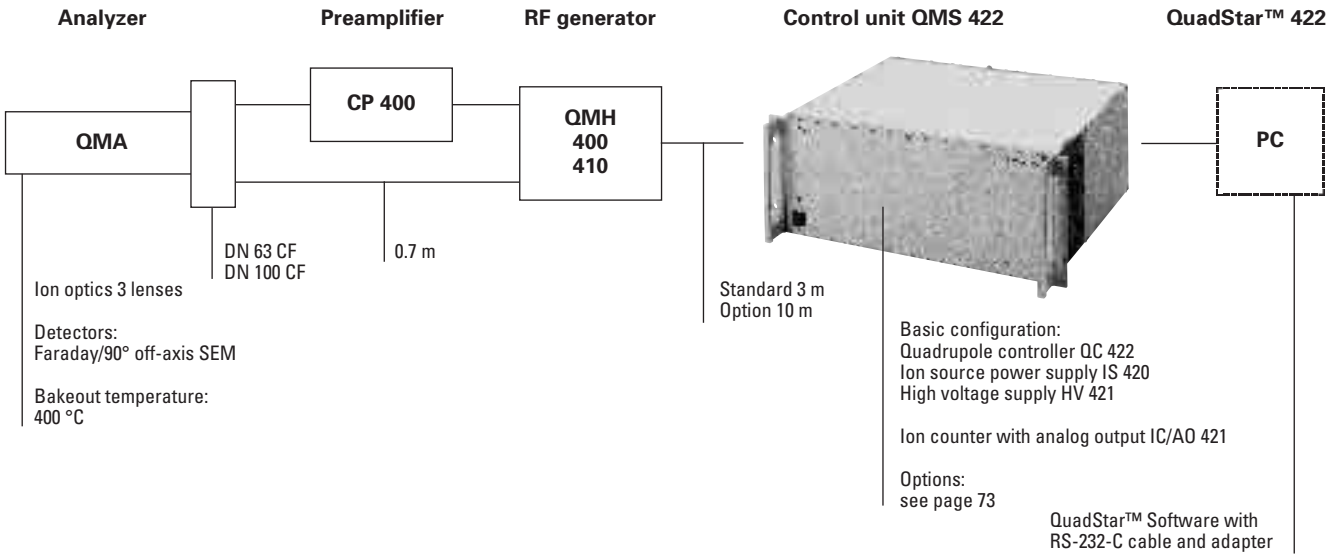
Detection of positive and negative ions.

3-linses ion optics with beam stop, insulated

Ion counter with integrated 12-channel analog output

SIMS (Secondary Ion Mass Spectrometry) is a proven technique for surface analysis. It can be used either as an independent method of measurement or in conjunction with other surface analysis methods such as ESCA (Electron Spectroscopy for Chemical Analysis) and AES (Auger Electron Spectroscopy). SIMS is always chosen when its high sensitivity and the capability to detect isotopes are crucial to the result of the analysis.

Scope of delivery



Summary QMG 422 Secondary Ions Mass Spectrometer

Mass range in amu			1–340	1–512	1–1024
Detection limit	for positive particles	cps	0.1	0.1	0.1
	for negative particles	cps	10	10	10
dynamic range	for positive particles	cps	10^7	10^7	10^7
	for negative particles	cps	10^5	10^5	10^5
Operating pressure, max.		mbar	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
Analyzer			QMA 410	QMA 400	QMA 400
Rod system, material/diameter/length		mm	Mo/16/300	Mo/8/200	Mo/8/200
90° off-axis SEM			SEM 217	SEM 217	SEM 217
Ion optics with beam stop, isolated			3 lenses	3 lenses	3 lenses
High voltage supply			HV 421	HV 421	HV 421
RF-generator			QMH 410-3	QMH 400-5	QMH 410-1
Ion counter preamplifier			CP 400	CP 400	CP 400
Ion counter			IC/AO 421	IC/AO 421	IC/AO 421
Operating temperature/analyzer		°C	150	150	150
Bakeout temperature/analyzer		°C	400	400	400
Connection flange			DN 100 CF-F	DN 63 CF-F	DN 63 CF-F

	Ordering number		
QMG 422 Secondary Ions Mass Spectrometer	**PTM27312**	**PTM27337**	**PTM27342**

Also deliverable verions with
– 2-lenses ion optics
– 3-lenses ion optics with Cross-Beam ion source
– 2-lenses ion optics with Cross-Beam ion source

Stand-alone components, technical data and dimensions of control unit QMS 422, Analyzer QMA 400/410, RF-generator QMH 400/410 and ion counter preamplifier CP 400 see pages 70 till 75.

Accessories

AS 420 Adapter-SIMS	Ordering number
for extension of the energy range of the detected ions	**BG572672-T**

Input/output board for QMS 422	Ordering number
AI 421 analog input, 16 channels, ±10.24 V, 12 bit	**BG442240-T**
DI 420 digital input, 32 inputs	**BG574700-T**
DO 420 digital output, 32 outputs	**BG546004-T**

For LAN- and multiplex mode

Technical data see page 65	Ordering number
OHA 200, Optical HUB, 5 Ports	**PT442510-T**
OHA 200, Optical HUB, 10 Ports	**PT442520-T**
ArcNet-PCMCIA adapter set	**PT442530-T**
PCI-PCMCIA Bridge for PC	**PT442540-T**
Fiber optic cable, 10 m	**P51596152H**
Fiber optic cable, 20 m	**P51596152K**
Fiber optic cable, 50 m	**P51596152Q**

PPM 422 (without cover at vacuum side)

PPM 422 Plasma Process Monitor

Detection of neutral particles and of positive and negative ions in plasma.

Energy analysis of neutral particles and positive and negative ions.

Measurement of radicals.

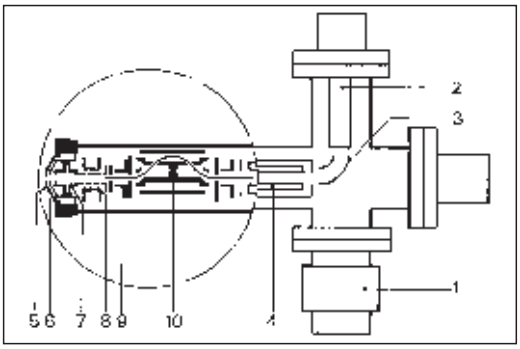
Endpoint detection of plasma processes.

Wide dynamic range.

High measurement speed.

Mass ranges 1–512 amu, 1–1024 amu and 1–2048 amu.

Energy range –512 till +512 eV.



Principle construction of PPM 422

1 Turbopump
2 Secondary electron multiplier SEM
3 Deflection unit
4 Quadrupole mass filter
5 Extraction diaphragm
6 Flahover shield
7 Input optics
8 Ion source
9 Adapter optics
10 Energy analyzer

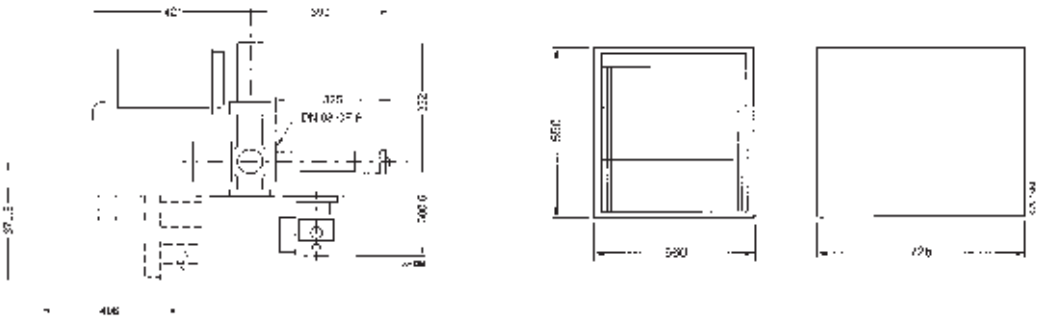
The PPM 422 is a differentially pumped mass spectrometer unit with integrated energy analyzer for measuring of neutral particles, positive and negative ions and for energy analysis of ions and neutral particles at plasma processes.

The diagram above shows the complete analyzer. The extraction orifice is in direct contact with the plasma. To avoid disturbance of the plasma, the electrical potential of the extraction orifice could adjusted to the application (positive, negative, ground, floated).

The energy filter is a CMA with 0.3 eV FWHM. For the analysis of neutral particles a field-free ion source with a very low energy distribution is used.

The optimized software package QuadStar™ PPM is part of delivery.

Dimensions in mm



PPM 422

Summary PPM 422 Plasma Process Monitor

Mass range		1–512	1–1024	1–2048
Detection limit / sensitivity		[1]	[1]	[1]
Energy range	eV	-512 bis +512	-512 bis +512	-512 bis +512
Energy resolution	eV	0.3	0.3	0.3
Operating pressure, max.	mbar	0.1	0.1	0.1
Analyzer with energy analyzer		QMA 400	QMA 400	QMA 400
Rod system, material/diameter/length	mm	Mo/8/200	Mo/8/200	Mo/8/200
Detector		SEM 217/Faraday	SEM 217/Faraday	SEM 217/Faraday
Quadrupole control unit		QMS 422	QMS 422	QMS 422
Cable length QMA/QMS	m	10	10	10
Software		QuadStar™ PPM	QuadStar™ PPM	QuadStar™ PPM
Turbomolecular pump, air cooled		TMU 071-03	TMU 071-03	TMU 071-03
Diaphragm pump		MVP 015-2	MVP 015-2	MVP 015-2
Weight, analyzer incl. Turbo	kg	26	26	26
Connection flange		DN 63 CF	DN 63 CF	DN 63 CF

	Ordering number		
PPM 422, 230 V	**PTM26605**	**PTM26607**	**on request**
PPM 422, 115 V	**PTM26606**	**PTM26608**	**on request**

Two stage version, other mass and energy ranges on request.

Stand-alone Components

PPM 422	Ordering number
Cathode unit, yttr. Iridium, for PPM 422	**BN845983-T**

Accessories

PPM 422	Ordering number
SVV 063 PF, safety gate valve, electropn. 24 VDC (Mounted between analyzer and turbo pump)	**PFF68231**

[1] High-end mass spectrometer QMG 422 is used at PPM 422. For the mass spectrometer measurements the technical data of the QMG 422 are valid.
The extracted ion currents from the plasma depends on the experimental construction. So it isn't possible to give data for all measurement parameter of the PPM 422.
All PPM 422-systems are tested before delivery with a DC-plasma in an application lab.

EPD 400 Endpoint Detector

The EPD 400 is a differentially pumped mass spectrometer unit with ion optics for measurement of external generated positive ions.

Endpoint detection and process monitoring at ion milling and other etching processes at vacuum conditions.

Detection of positive ions of condensable materials, as e.g. metall ions at sputter processes.

Mass range 1–512 amu.

Summary EPD 400 Endpoint Detector

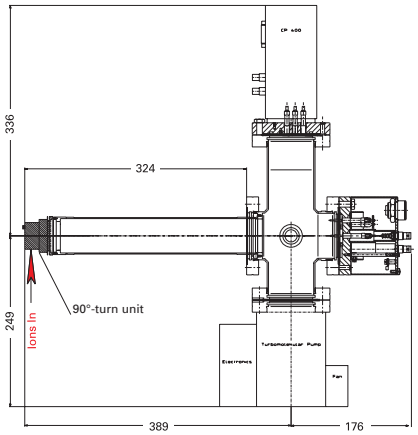
Mass range in amu		**1–512**
for detection of		positive ions
Analyzer		QMA 400
Rod system, material/diameter/length	mm	Mo/8/200
Detector		SEM 218/Faraday
Ion counter preamplifier		CP 400
RF-Generator		QMH 400-5
Quadrupole control unit		QMS 422
with ion source power supply		IS 420
High voltage supply		HV 420
Ion counter		IC 421
Software		QuadStar™
Turbomolecular pump, air cooled		TMU 071-03
Diaphragm pump		MVP 015-2
Connection flange		DN 63 CF

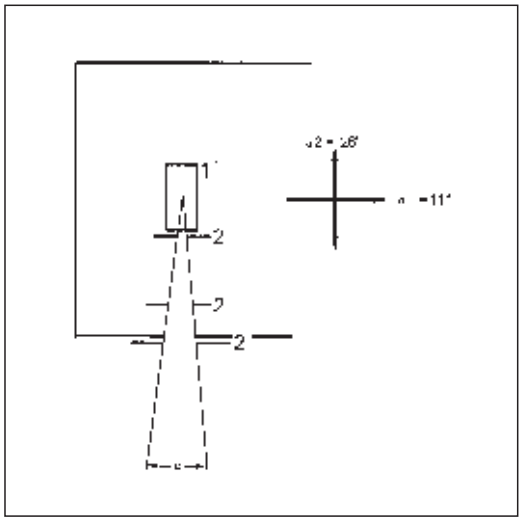
	Ordering number
EPD 400, with 90°-turn unit	**PTM26630**

Accessories

EPD 400	**Ordering number**
AS 420 for extension of the energy range of the detected ions	**BG572672-T**

Dimensions in mm





DMM 422 Deposition Material Monitor

Measurement of material flow from: electron-beam evaporators, effusion sources, Knudsen cells and evaporator boats.

Measurement of impurities in evaporation materials.

Mass range 1–512 amu.

1 Ion source
2 Orifice

The DMM 422 is an high-end mass spectrometer with integrated water cooling (water consumption 15 l/h) for highest stability. It is used for measurement of material vapour from various sources in a high vacuum < 10^{-6} mbar.

For analysis a vapour beam is leaded by the orifices system and the water cooled shield direct to the Cross-Beam ion source and passed it without contact. The generated ions will extracted perpendicular to the material beam.

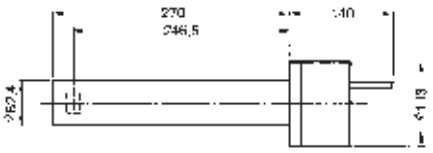
While the integration to the deposition chamber the orifice system must be adjusted to the given geometry. Configuration and localisation will by done with help of a product specialist.

Scope of delivery of DMM 422 is include control unit QMS 422, analyzer QMA 400, DN 100 CF-F, Cross-Beam ion source, Faraday detector and water cooled shield and Quadstar software package.

With standard orifices following sensitivities are met at the location of the ion source (e.g. Cu, m/e 63, insertion depth 246.5 mm):

– evaporator source, perpendicular under analyzer: $5 \cdot 10^{-13}$ A/nm s^{-1}
– evaporator source, at a = 10°: $2.5 \cdot 10^{-13}$ A/nm s^{-1}.

Dimensions in mm



DMM 422

5 Appendix

Contents

Tables

Relative probalities of ionization

reffered to nitrogen, appr. 100 eV electron energy

He	0.15
Ne	0.30
D_2	0.35
H_2	0.44
Air	1.0
N_2	1.0
O_2	1.0
H_2O	1.0
CO	1.05
Ar	1.2
NO	1.2
NH_3	1.3
HF	1.4
CO_2	1.4
HCl	1.6
N_2O	1.7
Kr	1.0
SO_2	2.1
SF_6	2.3
Xe	2.4
CH_4	1.6
C_2H_6	2.6
C_3H_8	3.7
C_4H_{10}	4.9
n-C_5H_{12}	6.0
C_6H_{14}	6.6
C_6H_6	5.9
C_6H_5Cl	7.0
$C_6H_5CH_3$	6.8
$C_6H_4(CH_3)_2$	7.8
CH_3OH	1.8
CH_3Cl	3.1
CH_2Cl_2	3.7
$CHCl_3$	4.8
CCl_4	6.0
CCl_2F_2	2.7
C_2H_5OH	3.6
C_2H_5Cl	4.0

Mass spectrum of CO_2

at 70 eV electron energy

m/e	Intensity	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	$^{12}C^{16}O_2^+$
45	1.16	$^{13}C^{16}O_2^+$
46	0.41	$^{12}C^{16}O^{18}O^+$

Key fragment ions

Mass number	Key fragments		
1	H^+		
2	H_2^+	(He^{++})	
4	He^+		
6	C^{++}		
7	N^{++}		
8	O^{++}		
12	C^+		
13	CH^+		
14	N^+	CH_2^+	CO^{++}
15	CH_3^+	NH^+	
16	O^+	CH_4^+	NH_2^+
17	OH^+	NH_3^+	
18	H_2O^+		
19	F^+	H_3O^+	
20	HF^+	$^{20}NE^+$	Ar^{++}
22	CO_2^{++}	$^{22}NE^+$	
24	C_2+		
26	$C_2H_2^+$		
27	$C_2H_3^+$		
28	N_2	$C_2H_4^+$	CO^+
29	$C_2H_5^+$	$^{15}N^{14}N^+$	
30	$C_2H_6^+$	NO^+	
31	CF^+	CH_2OH^+	
32	O_2^+	$^{32}S^+$	
34	$H_2{}^{32}S^+$	$^{34}S^+$	$^{18}O^{16}O^+$
35	$^{35}Cl^+$		
36	$H^{35}Cl^+$	$^{36}Ar^+$	
37	$^{37}Cl^+$	C_3H^+	
38	$H^{37}Cl^+$	$C_3H_2^+$	$^{38}Ar^+$
39	$C_3H_3^+$	$^{39}K^+$	
40	Ar^+	$C_3H_4^+$	
41	$C_3H_5^+$	$^{41}K^+$	
42	$C_3H_6^+$		
43	$C_3H_7^+$	CH_3CO^+	
44	$C_3H_8^+$	CO_2^+	N_2O^+
45	$C_2H_5O^+$ (Alcohol)		
46	NO_2^+	$C_2H_5OH^+$	
48	SO^+		
50	CF_2^+		
55	$C_4H_7^+$		
57	$C_4H_9^+$		
58	$(CH_3)_2$ CO^+ (Aceton)		
64	SO_2^+		
69	CF_3^+		
77	$C_6H_5^+$ (Phenyl)		
78	$C_6H_6^+$ (Benzol)		
85	$C^{35}ClF_2^+$ (Freon)		
87	$C^{37}ClF_2^+$ (Freon)		
92.5	$^{185}Re^{++}$		
93.5	$^{187}Re^{++}$		
101	$C^{35}Cl_2F^+$ (Freon)		
103	$C^{35}Cl^{37}ClF^+$ (Freon)		
105	$C^{37}Cl_2F^+$ (Freon)		
130	$C_2HCl_3^+$ (Trichlor)		
132	$C_2HCl_3^+$ (Trichlor)		
134	$C_2HCl_3^+$ (Trichlor)		
136	$C_2HCl_3^+$ (Trichlor)		
149	Phthalic ester (Softening agent)		
151	$C_2{}^{35}Cl_2F_3^+$ (Freon)		
153	$C_2{}^{35}Cl^{37}ClF_3^+$ (Freon)		
155	$C_2{}^{37}Cl_2F_3^+$ (Freon)		
182	W^+		
183	W^+		
184	W^+		
185	Re^+		
186	W^+		
187	Re^+		

Relative ion currents of fragment ions

90 eV energy of ionization

Mass number	H_2	He	CH_4	H_2O	Ne	N_2	CO	C_2H_6	O_2	Ar	CO_2	C_3H_8
1	3		16.5	2.4				9.6				5.0
2	100											
3		100										
12			3.0				6.3	0.7			9.7	0.6
13			7.8					1.2				0.9
14			16.0			14	0.8	3.3				2.3
15			85.0					4.7				7.2
16			100	1.8			2.8		18		16.0	
17			1.2	26								
18				100								
20					100					22.6		
22					10.2						2.1	
25								3.8				0.8
26								22.2				9.8
27								33.4				43.5
28						100	100	100			13.0	61.0
29						0.7	1.2	20.0				100
30								22.2				21.7
31												
32									100			
34									0.4			
36										0.34		
37												4.6
38										0.06		6.7
39												20.2
40										100		2.6
41												15.0
42												4.8
43												22.8
44											100	24.0
45											1.2	0.8

Table of naturally occuring isotopes

Atomic number	Element	Chem. symbol	Mass number	Relative abundance [%]
1	Hydrogen	H	1	99.985
		D	2	0.01492
2	Helium	He	3	0.000137
			4	99.999863
3	Lithium	Li	6	7.42
			7	92.58
4	Beryllium	Be	9	100
5	Boron	B	10	19.61
			11	80.39
6	Carbon	C	12	98.893
			13	1.107
7	Nitrogen	N	14	99.6337
			15	0.3663
8	Oxygen	O	16	99.759
			17	0.0374
			18	0.2039
9	Fluorine	F	19	100
10	Neon	Ne	20	90.92
			21	0.26
			22	8.82
11	Sodium	Na	23	100
12	Magnesium	Mg	24	78.70
			25	10.13
			26	11.17
13	Aluminium	Al	27	100
14	Silicon	Si	28	92.21
			29	4.70
			30	3.09
15	Phosphorus	P	31	100
16	Sulfur	S	32	95.0
			33	0.76
			34	4.22
17	Chlorine	Cl	35	75.53
			37	24.47
18	Argon	Ar	36	0.337
			38	0.063
			40	99.600
19	Potassium	K	39	93.1
			40	0.0118
			41	6.88
20	Calcium	Ca	40	96.97
			42	0.64
			43	0.15
			44	2.06
			46	0.003
			48	0.18
21	Scandium	Sc	45	100
22	Titanium	Ti	46	7.93
			47	7.28
			48	73.94
			49	5.51
			50	5.34

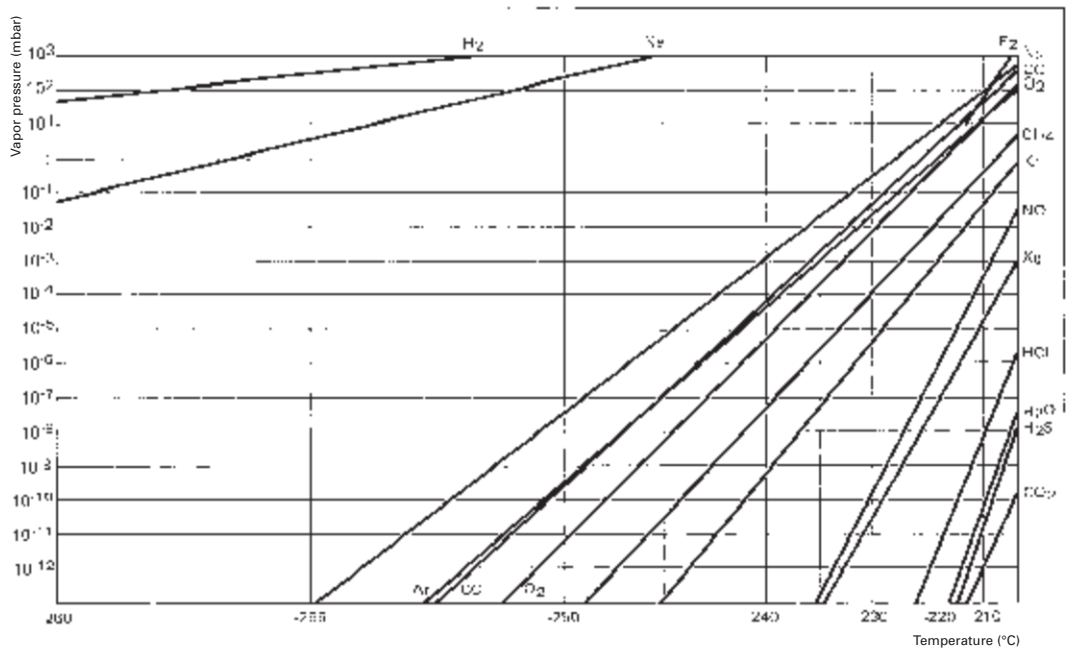
Atomic number	Element	Chem. symbol	Mass number	Relative abundance [%]
23	Vanadium	V	50	0.24
			51	99.76
24	Chrome	Cr	50	4.31
			52	83.76
			53	9.55
			54	2.38
25	Manganese	Mn	55	100
26	Iron	Fe	54	5.82
			56	91.66
			57	2.19
			58	0.33
27	Cobalt	Co	59	100
28	Nickel	Ni	58	67.88
			60	26.23
			61	1.19
			62	3.66
			64	1.08
29	Copper	Cu	63	69.09
			65	30.91
30	Zinc	Zn	64	48.89
			66	27.81
			67	4.11
			68	18.57
			70	0.62
31	Gallium	Ga	69	60.4
			71	39.6
32	Germanium	Ge	70	20.52
			72	27.43
			73	7.76
			74	36.54
			76	7.76
33	Arsenic	As	75	100
34	Selenium	Se	74	0.87
			76	9.02
			77	7.58
			78	23.52
			80	49.82
			82	9.19
35	Bromine	Br	79	50.54
			81	49.46
36	Krypton	Kr	78	0.35
			80	2.27
			82	11.56
			83	11.55
			84	56.90
			86	17.37
37	Rubidium	Rb	85	72.15
			87	27.85
38	Strontium	Sr	84	0.56
			86	9.86
			87	7.02
			88	82.56
39	Yttrium	Y	89	100
40	Zirconium	Zr	90	51.46
			91	11.23
			92	17.11
			94	17.40
			96	2.80
41	Niobium	Nb	93	100
42	Molybdenum	Mo	92	15.84
			94	9.04
			95	15.72
			96	16.53
			97	9.46
			98	23.78
			100	9.63
43	Technetium	Tc	–	–

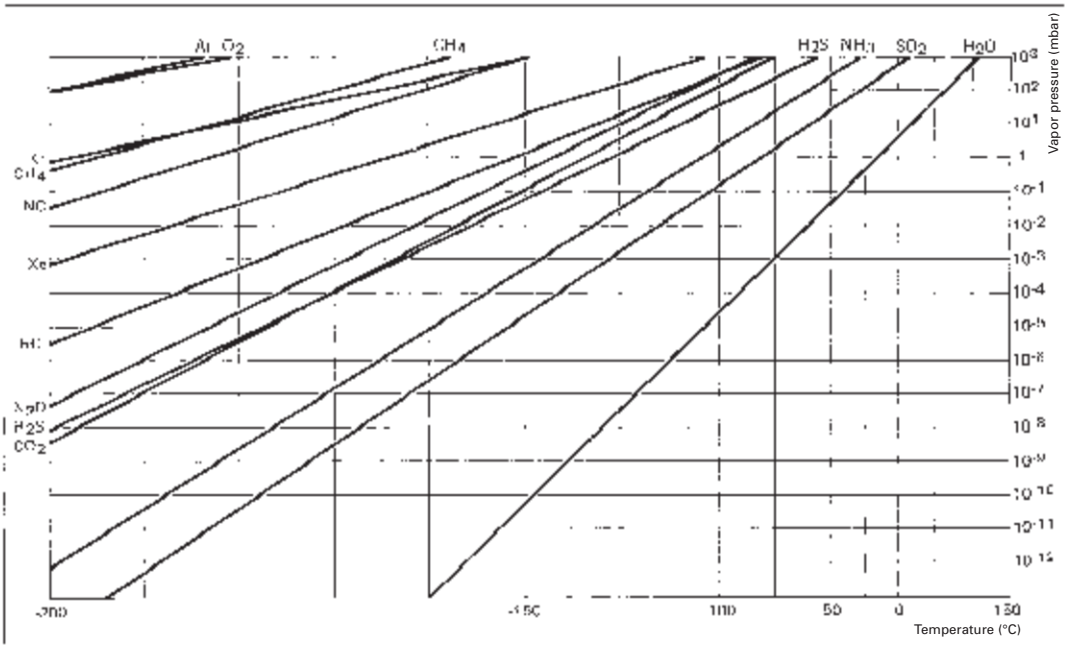
Atomic number	Element	Chem. symbol	Mass number	Relative abundance [%]
44	Ruthenium	Ru	96	5.51
			98	1.87
			99	12.72
			100	12.62
			101	17.07
			102	31.61
			104	18.58
45	Rhodium	Rh	103	100
46	Palladium	Pd	102	0.96
			104	10.97
			105	22.23
			106	27.33
			108	26.71
			110	11.81
47	Silver	Ag	107	51.35
			109	48.65
48	Cadmium	Cd	106	1.22
			108	0.875
			110	12.39
			111	12.75
			112	24.07
			113	12.26
			114	28.86
			116	7.58
49	Indium	In	113	4.28
			115	95.72
50	Tin	Sn	112	0.96
			114	0.66
			115	0.35
			116	14.30
			117	7.61
			118	24.03
			119	8.58
			120	32.85
			122	4.72
			124	5.94
51	Anthimony	Sb	121	57.25
			123	42.75
52	Tellurium	Te	120	0.09
			122	2.46
			123	0.87
			124	4.61
			125	6.99
			126	18.71
			128	31.79
			130	34.48
53	Iodine	J	127	100
54	Xenon	Xe	124	0.09
			126	0.09
			128	1.92
			129	26.44
			130	4.08
			131	21.18
			132	26.89
			134	10.44
			136	8.87
55	Cesium	Cs	133	100
56	Barium	Ba	130	0.10
			132	0.09
			134	2.42
			135	6.59
			136	7.81
			137	11.32
			138	71.66
57	Lanthanum	La	138	0.09
			139	99.91
58	Cerium	Ce	136	0.19
			138	0.25
			140	88.48
			142	11.07
59	Praseo-dymium	Pr	141	100

Atomic number	Element	Chem. symbol	Mass number	Relative abundance [%]
60	Neodymium	Nd	142	27.11
			143	12.17
			144	23.85
			145	8.30
			146	17.22
			148	5.73
			150	5.62
61	Promethium	Pm	–	–
62	Samarium	Sm	144	3.09
			147	14.97
			148	11.24
			149	13.83
			150	7.44
			152	26.72
			154	22.71
63	Europium	Eu	151	47.82
			153	52.18
64	Gadolinium	Gd	152	0.20
			154	2.15
			155	14.73
			156	20.47
			157	15.68
			158	24.87
			160	21.90
65	Terbium	Tb	159	100
66	Dysprosium	Dy	156	0.05
			158	0.09
			160	2.29
			161	18.88
			162	25.53
			163	24.97
			164	28.18
67	Holmium	Ho	165	100
68	Erbium	Er	162	0.14
			164	1.56
			166	33.41
			167	22.94
			168	27.07
			170	14.88
69	Thulium	Tm	169	100
70	Ytterbium	Yb	168	0.14
			170	3.03
			171	14.31
			172	21.82
			173	16.13
			174	31.84
			176	12.73
71	Luthetium	Lu	175	97.41
			176	2.59
72	Hafnium	Hf	174	0.18
			176	5.20
			177	18.50
			178	27.14
			179	13.75
			180	35.24
73	Tantalum	Ta	180	0.01
			181	99.99
74	Tungsten	W	180	0.13
			182	26.41
			183	14.40
			184	30.64
			186	28.41
75	Rhenium	Re	185	37.07
			187	62.93
76	Osmium	Os	184	0.02
			186	1.59
			187	1.64
			188	13.3
			189	16.1
			190	26.4
			192	41.0

Atomic number	Element	Chem. symbol	Mass number	Relative abundance [%]
77	Iridium	Ir	191	37.3
			193	62.7
78	Platinum	Pt	190	0.01
			192	0.78
			194	32.9
			195	33.8
			196	25.3
			198	7.21
79	Gold	Au	197	100
80	Mercury	Hg	196	0.15
			198	10.02
			199	16.84
			200	23.13
			201	13.22
			202	29.80
			204	6.85
81	Thallium	Ti	203	29.50
			205	70.50
82	Lead	Pb	204	1.48
			206	23.6
			207	22.6
			208	52.3
83	Bismuth	Bi	209	100
84	Polonium	Po		
85	Astatine	At		
86	Radon	Rn		
87	Francium	Fr		
88	Radium	Ra		
89	Actinium	Ac		
90	Thorium	Th	232	100
91	Protactnium	Pa		
92	Uranium	U	234	0.0056
			235	0.7205
			238	99.2739

Curves of vapor pressure





Composition of atmospheric air

The relative humidity is usually listed separately for a given temperature. For periodic checking of the mass spectrometer it is convenient ot use air (main components). To demonstrate the limit of detection and the detectable partial pressures, the rare gases (He, Xe and Kr) are often used with entry of air.

	Percent by weight	Percent by volume (x 10 = pressure [mbar])	
N_2	76.5	78.1	
O_2	23.0	20.9	
Ar	1.29	0.93	Main
Co_2	0.04	0.03	components
Ne	$1.2 \cdot 10^{-3}$	$1.8 \cdot 10^{-3}$	
He	$7 \cdot 10^{-5}$	$5.2 \cdot 10^{-4}$	
Kr	$3 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$	
Xe	$4 \cdot 10^{-5}$	$8.7 \cdot 10^{-6}$	Rare gases
Ch_4			Together appr. 2 ppm
H_2			for mass spectrometry of minor
N_2O			significance

Sensitivity for QMA 120

Gas	Mass number of base peak	Total sensitivity for base peak x 10^{-5} [A/mbar]	Sum of fragment ions x 10^{-5} [A/mbar]
He	4	6.4	–
Ne	20	6.4	7.2
Ar	40	24	34
Kr	84	6.8	17
H_2	2	13	–
N_2	28	20	23
CO	28	20	22
O_2	32	14	16
CO_2	44	13	19
CH_4	16	28	54
C_2H_6	28	34	68
C_3H_8	29	26	74
C_4H_{10} (n)	43	22	74
C_4H_{10} (iso)	43	24	68
H_2O	18	20	26

Natural constants

Velocity of light in vacuum	$c = 2.997925 \cdot 10^8\ m \cdot s^{-1}$
Acceleration due to gravity (standard value)	$g = 9.80665\ m \cdot s^{-2}$
Avogadro's constant	$N_A = 6.0221 \cdot 10^{23}\ mol^{-1}$
Electron charge	$e = 1.6022 \cdot 10^{-19}\ C$
Faraday's constant	$F = N_A e = 96485\ C \cdot mol^{-1}$
Planck's constant	$h = 6.6262 \cdot 10^{-34}\ J \cdot s$
Boltzmann's constante	$k = 1.3806 \cdot 10^{-23}\ J \cdot K^{-1}$
Universal gas constante	$R = kN_A = 8.3143\ J \cdot K^{-1}\ mol^{-1}$
Absolute zero	$T_0 = O\ K$ or $\vartheta_0 = -273.15\ °C$
Normal molar volume of an ideal gas (0 °C and 1013 mbar)	$V_{molar.0} = 0.022414\ m^3 \cdot mol^{-1}$
Atomic mass unit	$1\ u = 10^{-3}\ kg\ mol^{-1} \cdot 1/N_A = 1.66055 \cdot 10^{-27}\ kg$
Rest mass of Electron	$m_e = 9.1095 \cdot 10^{-31}\ kg = 0.548580 \cdot 10^{-3}\ u$
Proton	$m_p = 1.6726 \cdot 10^{-27}\ kg = 1.007277\ u$
Neutron	$m_n = 1.6749 \cdot 10^{-27}\ kg = 1.008665\ u$
Deuteron	$m_d = 3.3436 \cdot 10^{-27}\ kg = 2.013554\ u$
Alpha particle	$m_\alpha = 6.6447 \cdot 10^{-27}\ kg = 4.001506\ u$
Hydrogen atom	$m_H = 1.6735 \cdot 10^{-27}\ kg = 1.007825\ u$
Helium atom	$m_{He} = 6.6465 \cdot 10^{-27}\ kg = 4.002603\ u$
Mass ratio proton/electron	$m_p/m_e = 1836$
Specific charge of Electron	$e/m_e = 1.7588 \cdot 10^{11}\ A \cdot s \cdot kg^{-1}$
Proton	$e/m_p = 9.5788 \cdot 10^7\ A \cdot s \cdot kg^{-1}$
Rest energy of Electron	$m_e c^2 = 0.5110\ MeV$
Proton	$m_p c^2 = 938.3\ MeV$
Compton wavelength of electron	$\lambda_c = 2.4263 \cdot 10^{-12}\ m$

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Trade names

OmniStar™*	PacLine
ThermoStar™*	PackageLine
Prisma™*	DigiLine
FullRange™*	SplitFlow™ Turbo
QualyTest™	MagneticTurbo
TurboCube	Compact Turbo
UniDry™	CorrosiveTurbo
DuoLine	OnToolDryPump™

* Trade names Inficon

Notices

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Note

Information and advertising statements in this product catalog are, regardless of type, and in particular descriptions, figures, drawings, samples, information on quality, procurement, composition, performance, consumption and usability as well as measurements and weights of the product lines, without engagement if not expressly being designated otherwise. Such information does not provide an assurance or warranty commitment of any kind.

Slight deviations from the product information are considered as accepted, in-as-much as these are not unacceptable to the ordering party.

We expressly reserve the right of introducing changes in case of error and for technical reasons.

Pfeiffer Vacuum GmbH, January 2005

Tradenames

Inficon:
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TalkStar™
Prisma™
OmniStar™
ThermoStar™
SingleGauge™
FullRange™

Imprint

Mass spectrometer catalog
Pfeiffer Vacuum GmbH, June 2005
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General Terms and Conditions of Sales and Supply

I. Tender

In the absence of any separate contractual agreements, Pfeiffer Vacuum will, as supplier only effect deliveries and provide services under the terms and conditions set forth hereunder. Any divergent purchasing conditions of the purchaser will under no circumstances, even if not expressly refuted – and neither by acceptance of an order –, become part of the contract. These General Standard Terms and Conditions shall apply both to the present business as well as to any future business.

II. Tender and Conclusion of a Contract

The information contained in price lists, catalogues and advertising media referring to Pfeiffer Vacuum's performances do not represent any tenders. Documents like figures, drawings, weight and measure information pertaining to a tender are subject to change without notice and only approximately relevant, unless they have not explicitly been declared as binding. Any verbal advice, collateral agreements and promises of whatever nature shall be ineffective, unless these are confirmed on Pfeiffer Vacuum's part as agreed upon in writing. Minor deviations from product specifications shall be accepted as approved of. In the absence of a special agreement, a contract will only be formed upon receipt of Pfeiffer Vacuum's written order confirmation or upon the supply of the merchandise. With regard to Pfeiffer Vacuum's samples, cost estimates, plans, drawings and similar information, either of material or immaterial nature – also in electronic form –, as well as all other documents Pfeiffer Vacuum will reserve all proprietary rights and copyrights; these may only be made accessible to third parties with Pfeiffer Vacuum's prior written consent.

III. Delivery Content

Pfeiffer Vacuum's signed order confirmation forms the basis for determining the contents and all other details concerning the merchandise, and in case of a tender limited in time from Pfeiffer Vacuum and the acceptance of the tender by the purchaser within the period stipulated, this will be the tender, unless an order confirmation is available from Pfeiffer Vacuum in time. Any collateral agreements and changes must be confirmed by Pfeiffer Vacuum in writing.

IV. Prices and Payments

1. Prices are either ex works or, if applicable, the consigning sales office, including loading, but excluding packaging and official value-added tax. Pfeiffer Vacuum is entitled to invoice costs incurred in packaging and reserves the right to require return of transport packaging materials free of charge, providing such packaging has been provided free of charge. Returned packaging will not be credited.
2. In the absence of any special agreements, payment is to be made in cash without deductions to Pfeiffer Vacuum at its place of business. As for systems and plants, the following payment terms will be applicable:
   30 % prepayment after receipt of the order confirmation,
   40 % once the purchaser has been advised that the main parts are ready for dispatch,
   20 % after delivery of the goods, and the remainder within the period of one month after transfer of risk.
3. The purchaser shall only be entitled to withhold payments or set them off against any counterclaims, if these counterclaims are undoubted and legally effective.
4. The minimum order value amounts to Euro 100,–.
5. As for goods returned Pfeiffer Vacuum will invoice for the necessary function testing and other processing costs at the rate of 10 % of the net value of the merchandise, but at least Euro 100,–.
6. With the cancellation of an order we will charge a 15 % cancellationfee of the cancelled order value. A cancellation has to take place in writing and is possible within 14 days after our order acknowledgement only.

V. Delivery Time/Delayed Delivery

1. The delivery time is based on the agreements reached between the contracting parties. To be able to observe the delivery time from Pfeiffer Vacuum, it has to be ensured, that all commercial and technical questions between the contracting parties are clarified, and that the purchaser has fulfilled all of his obligations, for example the presentation of the documents, approvals, releases to be procured by the purchaser, or that the prepayment agreed upon has been made. If this is not the case, the delivery time shall be appropriately extended. Insofar as the delay falls under the responsibility of Pfeiffer Vacuum, this will not apply.
2. The observance of the delivery period is subject to the proviso that the raw materials and supplies are supplied to Pfeiffer Vacuum correctly.
3. The delivery period is deemed observed, when the goods have left Pfeiffer Vacuum's works at the time the delivery period would normally expire, or when it is at that time reported to be ready for dispatch. As far as an acceptance test has to be made prior to delivery, then the date of the acceptance test will – except for a justified refusal to take delivery – be decisive or alternatively the notification that the merchandise is ready for the acceptance test.
4. If the dispatch or the acceptance of the goods to be delivered is delayed due to reasons falling under the responsibility of the purchaser, he will be charged for the costs incurred by the delay, beginning one month after the notification that the merchandise is ready for dispatch or for the acceptance test.
5. If the nonobservance of the delivery period has been caused by force majeure, strikes, lock-outs or any other events beyond the control of Pfeiffer Vacuum, the delivery period will be appropriately extended. This also applies when a sub-contractor is subjected to such events. Nor are the circumstances described above the responsibility of Pfeiffer Vacuum when they arise during an existing delay. In important cases, Pfeiffer Vacuum will inform the purchaser as soon as possible with regard to when such hindrance begins and ends.
6. The purchaser shall be entitled to withdraw from the contract without notice, if the entire performance has prior to the transfer of risk finally been made impossible for us. Furthermore the purchaser shall be entitled to withdraw from the contract, if in the case of an order the execution of same has in part become impossible, and if he has a legitimate interest in rejecting the partial delivery. If this does not prove to be true, then the purchaser shall have to pay the contractual price referring to the partial delivery. The same shall apply in case of Pfeiffer Vacuum's inability to perform. Apart from this paragraph IX. 2 will apply. In the event the impossibility or the inability to perform occurs during the default in accepting the delivery of merchandise, or if these circumstances fall solely or predominantly under the responsibility of the purchaser, he shall be obliged to quid pro quo.
7. If Pfeiffer Vacuum causes a delay in delivery and the purchaser suffers damage therefrom, he shall be subject to the exclusion of further claims and entitled to claim a flat-rate compensation for delayed performance. The compensation will amount to 0.5 % of the invoice amount per full week of the delay, up to a maximum of 5 % of the value of that part of the total delivery, which due to the delay, can not be delivered in time or not be used according to the contract. Any further claims resulting from default of delivery may only be derived from paragraph IX. 2. If the purchaser concedes the supplier being in default – with due regard of legal exceptions – an adequate period of time for performance and this period of time is not observed, the purchaser shall within the framework of legal provisions be entitled to withdraw from the contract.
8. If the dispatch of the merchandise is delayed upon the request of the purchaser, he will be charged the costs incurred by the storage, beginning one month after the notification of readiness for dispatch, in case of storage in Pfeiffer Vacuum's factory or sales office, however, at least 0.5 % of the invoice amount for each month. Pfeiffer Vacuum shall in addition to this have the right, to otherwise dispose of the merchandise to be delivered after a lapse of an appropriate period of time and to effect the delivery to the purchaser subject to a reasonably extended period of time.

VI. Transfer of Risk and Acceptance

1. The risk is transferred to the purchaser at the latest at the time of dispatch of the merchandise. This also applies to partial deliveries or where Pfeiffer Vacuum has agreed to render other performances e. g. to meet the costs of freight or the delivery and installation. The purchaser can request at his own cost Pfeiffer Vacuum to arrange insurance to cover theft, breakage, transport/fire/water damage as well as other insurable risks. As far as an acceptance test has to be made, the date scheduled for this will determine the transfer of risk. The acceptance test must be performed without delay on the fixed date, or alternatively after Pfeiffer Vacuum's notification of readiness for the acceptance test. The purchaser may not refuse acceptance in the absence of any essential fault or deficiency.
2. If the dispatch or the acceptance is delayed or not initiated due to circumstances not falling under the responsibility of Pfeiffer Vacuum, the risk will be transferred to the purchaser by the day on which the readiness for dispatch or for the acceptance test has been notified. Pfeiffer Vacuum commits itself to take out the insurances requested by the purchaser at his expense.
3. The purchaser is obliged to accept merchandise supplied, even when negligible imperfections are involved and without prejudice to his rights under paragraph VIII.
4. Partial deliveries will be permissible, as far as the purchaser can be reasonably expected to accept these.

VII. Retention of Property Rights

1. Pfeiffer Vacuum retains ownership of the merchandise until full payment has been received and up to the settlement of any outstanding receivables due to Pfeiffer Vacuum or to other companies within the Pfeiffer Vacuum Group from the purchaser or from companies within the purchaser's Group. If the purchaser is a trader or a manufacturer, he is revocably empowered to associate the merchandise delivered within proper business transactions and/or to dispose of and/or re-work the merchandise supplied in a proper commercial manner. The purchaser hereby already assigns his title to the proceeds arising from the sale or manufacture to Pfeiffer Vacuum in the proportion that Pfeiffer Vacuum's goods bear to the manufacturing costs of the whole product. As far as the assignment exceeds 120 % of the secured claim, at the written request of the purchaser, Pfeiffer Vacuum will release the surety.
2. Pfeiffer Vacuum is entitled to insure the merchandise, at the cost of the purchaser, against theft, breakage, transport/fire/water damage as well as other insurable risks where the purchaser has not himself taken out such insurance.
3. The purchaser is not allowed to pledge nor use the merchandise as surety. If the merchandise becomes subject to an attachment or seizure order or other actions by third parties, the purchaser is required to inform the supplier immediately.
4. If the purchaser breaks the terms of this contract, in particular in the case of non-payment, Pfeiffer Vacuum is entitled, after having issued a warning, to retrieve, and the purchaser required to surrender, the merchandise. The assertion of property rights and the impounding of the merchandise on the part of Pfeiffer Vacuum does not constitute a withdrawal from the contract.
5. The application for the commencement of bankruptcy proceedings shall entitle Pfeiffer Vacuum to withdraw from the contract and to demand the immediate return of the merchandise delivered.

VIII. Warranty

Subject to the exclusion of further claims, Pfeiffer Vacuum gives warranty for material defects and deficiencies in title with regard to the delivery – and with the proviso of paragraph IX. – as follows:

Material defects

1. As for all such parts that prove to be deficient due to circumstances prior to the time of the transfer of risk, Pfeiffer Vacuum undertakes at its own choice either to remedy defects free of charge or to effect a new delivery. Pfeiffer Vacuum has immediately upon detection of any such defects and deficiencies to be informed in writing thereof. Article 377 of the HGB (German Commercial Code) applies accordingly. Parts returned for replacement or modification become the property of Pfeiffer Vacuum. As for major bought-in products, Pfeiffer Vacuum's liability is restricted to the assignment of those claims Pfeiffer Vacuum is entitled to assert against the supplier of the bought-in product, provided these claims are not statute-barred and are not considerably lower than those claims being asserted against Pfeiffer Vacuum.
2. The purchaser will be obliged to concede to Pfeiffer Vacuum after written notification sufficient time and opportunity to remedy defects or to effect replacement deliveries deemed necessary by Pfeiffer Vacuum; otherwise Pfeiffer Vacuum will be relieved from any liability with regard to the consequences resulting thereof. The purchaser shall only in urgent cases such as in the event of endangering of the operational safety or for the defense of unproportionately high damages, and under the condition that Pfeiffer Vacuum will immediately be informed thereof, have the right to remedy defects on his own or to have them repaired by third parties, and to put forward a claim for compensation of the expenses incurred.
3. Pfeiffer Vacuum will bear the direct costs of retouches and replacements arising from legitimate claims, including despatch costs (excluding express deliveries and deliveries abroad) and also the reasonable costs associated with dismantling and assembly and the provision by the purchaser of personnel which the particular case may necessitate.
4. The purchaser will within the framework of legal provisions have a right to withdraw from the contract, if Pfeiffer Vacuum – with due regard to legal exceptions – lets lapse an appropriate period of time, alloted in writing, to remedy defects or to effect a replacement delivery. In case of minor deficiencies the purchaser shall only be entitled to claim a reduction of the sales price. The right to demand a reduction of the sales price will otherwise be excluded.
5. No warranty will in particular be given in the following cases:
   Unsuitable or improper use, faulty or defective assembly or commissioning by the purchaser or by third parties, natural wear, faulty or neglectful treatment, improper maintenance, unsuitable pump fluid, poor construction work, unsuitable building ground, chemical, electrochemical, radio-active or electric influences, unless they fall under the responsibility of Pfeiffer Vacuum.
6. If the purchaser or a third party remedies any defect improperly, Pfeiffer Vacuum shall not be liable for the consequences resulting thereof. The same shall apply for any alterations of the merchandise initiated by the purchaser or by third parties without prior written consent of Pfeiffer Vacuum.

Deficiencies in Title

7. Should any use of the merchandise lead to a violation of any domestic industrial property rights or copyrights, Pfeiffer Vacuum will make sure at its own expense, that the purchaser will principally be given the right of further use or that the merchandise will be modified in such a way, as it might reasonably be expected of the purchaser to be acceptable to him, so that the violation of industrial property rights will no longer exist. Should this be impossible in terms of commercially adequate conditions or within a reasonable period of time, the purchaser shall have the right to withdraw from the contract. Under the conditions mentioned, Pfeiffer Vacuum shall in turn also be entitled to withdraw from the contract. Furthermore Pfeiffer Vacuum will indemnify the purchaser for undoubted and legally effective claims asserted by respective owners of industrial property rights.
8. Pfeiffer Vacuum's obligations stated under paragraph VIII. 7 are with the proviso of paragraph IX. 2 as for the event of a violation of protected rights or copyrights all-inclusively settled.
   They will only be applicable, if and when
   - the purchaser undertakes to inform Pfeiffer Vacuum immediately of any asserted claims with regard to the
   - violation of any protected rights or copyrights;
   - the purchaser undertakes to support Pfeiffer Vacuum to such an extent that will be appropriate for a defense of
   - the asserted claims or that will enable Pfeiffer Vacuum to proceed with the modification measures as outlined
   - in paragraph VIII. 7;
   - all defense measures, including out-of-court settlements, are reserved to Pfeiffer Vacuum;
   - the deficiency in title is not caused by an instruction on the part of the purchaser; and
   - the violation of law has not been caused by the fact, that the purchaser has independently modified the
   - merchandise or used it in a way not complying with the contract.

IX. Liability

1. If the merchandise can not be used by the purchaser according to the intents of the contract, and this is due to Pfeiffer Vacuum's fault as a result of a neglected or faulty performance in connection with proposals and consultations prior to or after the conclusion of the contract or due to the violation of any other contractual collateral obligations – in particular with regard to instructions for the operation and maintenance of the merchandise –, the regulations under paragraphs VIII. and IX. 2 will apply accordingly to the exclusion of any further claims of the purchaser.
2. As for damages not incurred at the merchandise itself as such Pfeiffer Vacuum will – for whatever legal reasons – only be liable
   - in case of intent;
   - in case of gross negligence on part of the owner or managerial employees;
   - in case of culpable personal injury to human life, body and health;
   - in case of deficiencies, where Pfeiffer Vacuum may be blamed of malicious silence, or where the absence of
   - deficiencies has been guaranteed;
   - in case of defects of the merchandise, as far as the manufacturer will in accordance with the product liability
   - law be liable for personal injury or for damages to property incurred in connection with privately used objects.

   In case of a culpable violation of major contractual obligations Pfeiffer Vacuum will also be liable in case of gross negligence on part of non-managerial employees as well as in case of minor negligence, in the latter case limited to the reasonably foreseeable, typical damage under the contract.

   Any further claims for compensation shall be excluded.

X. Statutory limitation

Any claims of the purchaser – pertaining to whatever legal reasons – will be statute-barred within a period of 12 months. When it comes to intentional or fraudulent conduct as well as to claims resulting from the product liability law, the statutory time limits will be applicable. They will also be applicable in case of defects and deficiencies of a structure or of the merchandise, that has according to its customary manner of usage been employed and used for the construction of a structure, and has caused the structure's defectiveness.

XI. Use of Software

As far as the delivery comprises any software, the purchaser will be conceded the right to use the software delivered, including the documentation pertaining thereto. It is provided for utilisation with the respective designated merchandise. The usage of the software on more than one system is prohibited. The purchaser is only entitled to copy, re-work, translate or convert from the object code to the source code within the legally permissible scope (Articles 69 a ff. of the Copyright Law (UrhG)). The purchaser commits himself not to eliminate or change the manufacturer's information or Pfeiffer Vacuum's information – especially copyright information – without Pfeiffer Vacuum's explicit prior approval. All other rights relating to the software and the documentation, including the copies thereof, shall remain with Pfeiffer Vacuum or with the software supplier. The issuance of sub-licences is not permissible.

XII. Applicable Law/Place of Jurisdictioin

1. All legal relations between Pfeiffer Vacuum and the purchaser are subject to the substantive laws of the Federal Republic of Germany. This applies also for foreign business transactions. The application of the UN purchase right will be excluded.
2. The place of jurisdiction is the court competent for Pfeiffer Vacuum's company seat. Pfeiffer Vacuum shall, however, be entitled to file a suit at the purchaser's head office.

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