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**Vacuum gauges — Definitions and  
specifications for quadrupole mass  
spectrometers**

*Manomètres à vide — Définitions et spécifications des spectromètres  
de masse quadripolaires*

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ISO copyright office  
Case postale 56 • CH-1211 Geneva 20  
Tel. + 41 22 749 01 11  
Fax + 41 22 749 09 47  
E-mail [copyright@iso.org](mailto:copyright@iso.org)  
Web [www.iso.org](http://www.iso.org)

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 14291 was prepared by Technical Committee ISO/TC 112, *Vacuum technology*.

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## Introduction

Quadrupole mass spectrometers (QMSs) are nowadays used not only for leak detection and residual gas analysis in vacuum but also as instruments to provide quantitative analysis in processes and control processes such as physical and chemical vapor deposition, and etch processes.

Total pressure, composition of the gas mixture, QMS settings, environment conditions, etc., have a significant influence on the measured signal, its uncertainty and interpretation. For this reason, it is not possible to calibrate QMS for all its possible applications. Instead, it has either to be calibrated for the particular conditions of use or for a standardized condition.

There is also some need for standardization in order to enable QMS users to compare devices of different manufacturers and to use the QMS properly.

In continuation of efforts of TC 112 during the 1990s, this International Standard takes a first step towards establishment of a standardized calibration procedure for QMS by defining the terms and parameters.

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# Vacuum gauges — Definitions and specifications for quadrupole mass spectrometers

## 1 Scope

This International Standard defines terms relevant to quadrupole mass spectrometers (QMSs) and specifies the parameters required for specification by QMS manufacturers necessary for proper calibration and for maintaining the quality of partial pressure measurement.

This International Standard applies to QMSs with an ion source of the electron impact ionization type. Such QMSs are designed for the measurement of atomic mass-to-charge ratios  $m/z$  typically  $< 300$ . QMSs with other ion sources, such as those of the chemical ionization, photoionization, and field ionization types, as well as the measurements of  $m/z$  above 300, which are mainly used to specify organic materials, lie outside the scope of this International Standard.

## 2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

### 2.1 Definitions of components

#### 2.1.1

##### **quadrupole mass spectrometer** **QMS**

mass spectrometer in which ions are injected axially into a quadrupole lens consisting of a system of four electrodes, usually rods, to which radio frequency and d.c. electric fields in a critical ratio are applied, so that only ions with a certain mass/charge ratio emerge

[SOURCE: ISO 3529-3:1981,<sup>[2]</sup> 3.5.2.2]

Note 1 to entry Such a QMS consists of a sensor head and electronic unit.

#### 2.1.2

##### **sensor head** **analyser tube** **sensor** **sensor unit** **sensing head** **gauge head**

equipment consisting of an ion source, quadrupole mass filter, and ion detector in one enclosure

#### 2.1.3

##### **ion source**

part of the QMS in which ions of gas molecules and atoms are produced

Note 1 to entry For the production of positive ions, the ion source generally uses an electron impact ionization process.

#### 2.1.3.1

##### **open ion source**

ion source with a high conductance to the surrounding vacuum environment, often designed as an open grid structure

Note 1 to entry All of the operational components of this ionization hardware are exposed to the same vacuum region.

### 2.1.3.2

#### **closed ion source**

#### **enclosed ion source**

#### **differential pressure ion source**

ion source that uses a nearly sealed container to ionize the gas to be analysed with openings only for passing; sample gas; energetic electrons (for impact ionization); and exciting ions

Note 1 to entry This type of ion source permits ionization at pressures that are higher than the mass filter and detector. It should be used in a sample pressure reduction system with a high vacuum pump on the mass filter.

### 2.1.3.3

#### **molecular beam ion source**

#### **crossed beam ion source**

ion source that accepts a focused beam of neutral gas molecules directed at the ion formation region without interference from any ion source components

Note 1 to entry The molecular beam traverses the ion formation region and is usually at right angles to the electron beam and mass filter axes.

Note 2 to entry For molecular beam epitaxy, the crossed beam ion source is also designed to accept molecular beams at various acceptance angles. Some molecular beam ion source designs include a protective shroud around the ion source with an aperture to the ion formation region. As the molecular beam exits the ion source, it may be trapped or pumped to minimize contribution to background from scattered molecules.

### 2.1.4

#### **quadrupole mass filter**

device consisting of four parallel conductive rods arranged in a square array with opposite rods connected electrically in parallel

Note 1 to entry A quadrupole mass filter separates the ions coming from the ion source on the basis of their mass-to-charge ratios by a critical ratio of radio frequency (r.f.) and direct current (d.c.) electrical fields applied to the rods. The rod pairs are driven with opposite r.f. phase and d.c. polarity.

### 2.1.5

#### **ion detector**

#### **ion collector**

device collecting the positive ions that have passed through the mass filter to measure the ion current

Note 1 to entry Two types of ion detectors are common: Faraday cup and secondary electron multiplier (SEM).

#### 2.1.5.1

##### **Faraday cup**

metal plate or open cylinder or similar on which the ions from the mass filter are collected

Note 1 to entry An actual Faraday cup ion detector is illustrated in Figure 1 a). However, a metal plate, Figure 1 b), open cylinder, Figure 1 c), or similar on which the ions from the mass filter are collected is usually called a Faraday cup-type ion detector. A Faraday cup generally has a gain of unity, i.e. for each ion collected, one electron flows from the detecting electrometer.

#### 2.1.5.2

##### **secondary electron multiplier**

##### **SEM**

detector in which the ions from the mass filter strike the entrance surface and release electrons

Note 1 to entry The released electrons are accelerated and strike another surface of the SEM resulting in multistage amplification of the electron current. SEMs can use discrete dynodes or a continuous dynode surface with a potential gradient to increase the electron current and microchannel plate electron multiplier.

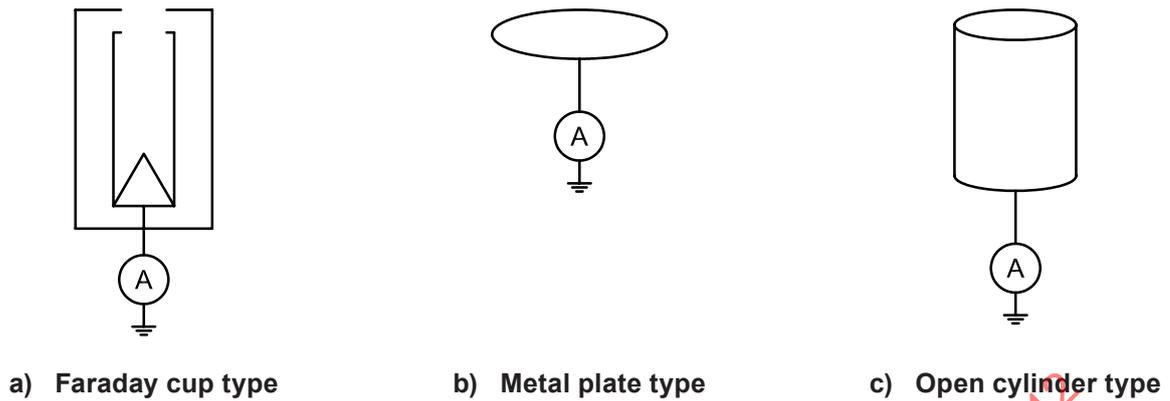


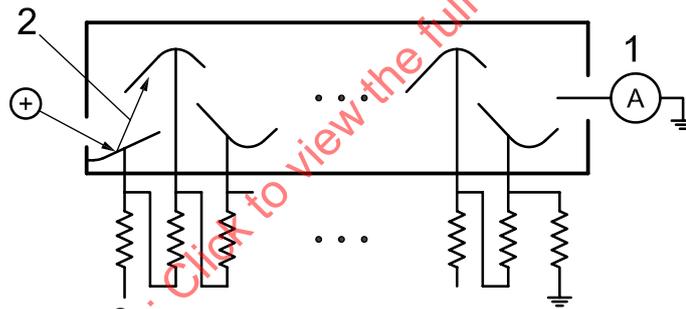
Figure 1 — Faraday cup type ion detector

2.1.5.2.1

**discrete dynode electron multiplier**

secondary electron multiplier that uses discrete dynodes between which secondary electrons are accelerated

Note 1 to entry The voltages applied to each dynode establish the potential gradients that accelerate the secondary electrons and lead to increased numbers of electrons at each stage. Figure 2 is a schematic diagram of a discrete dynode electron multiplier.



**Key**

- 1 ammeter
- 2 electron
- 3 negative high voltage

Figure 2 — Discrete dynode electron multiplier

2.1.5.2.2

**continuous dynode electron multiplier<sup>1)</sup>**

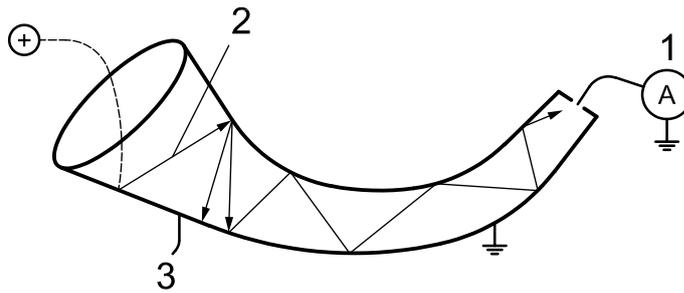
**CEM**

type of secondary electron multiplier with a continuous dynode, often with a horn-like channel

Note 1 to entry See Figure 3.

Note 2 to entry The applied voltage from entrance to exit of the channel establishes the potential gradient along the channel which accelerates secondary electrons and leads to increased numbers of electrons from entrance to exit.

1) One of the original CEMs is known as Channeltron®. Channeltron® is the trademark of a product supplied by Burle. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.



- Key**
- 1 ammeter
  - 2 electron
  - 3 negative high voltage

**Figure 3 — Continuous dynode electron multiplier (CEM)**

**2.1.5.2.3**  
**microchannel plate electron multiplier**  
**MCP electron multiplier**

type of secondary electron multiplier which consists of a large number of small, parallel continuous-dynode channels (typically 5 µm to 25 µm in diameter), in a planar array, or “plate”

**2.1.6**  
**electronic unit**

unit consisting of a radio frequency source and several regulated power supplies and amplifiers which operate the ion source and mass filter as well as measure detected ion current

Note 1 to entry The electronic unit usually incorporates a microprocessor and firmware to control the electronics and usually pass data to an external computer. Electronic units may be integrated or separate.

**2.1.6.1**  
**integrated type**

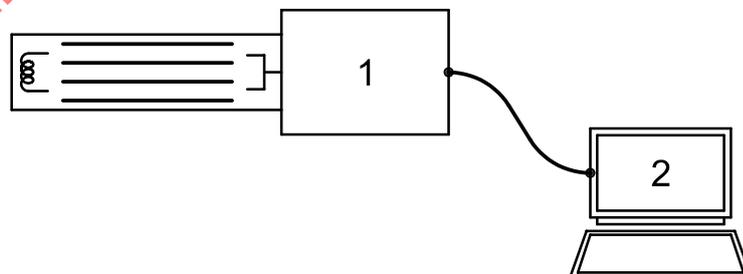
electronic unit mounted directly on sensor head

Note 1 to entry See Figure 4.

**2.1.6.2**  
**separated type**

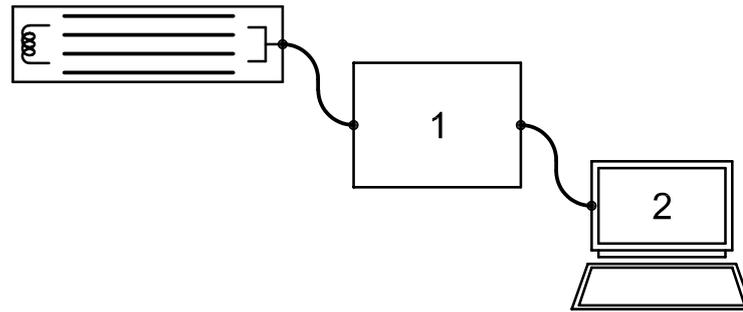
electronic unit separated from the sensor head but connected to it via one or more cables

Note 1 to entry See Figure 5.



- Key**
- 1 electronic unit
  - 2 computer

**Figure 4 — Integrated electronic unit**

**Key**

- 1 electronic unit  
2 computer

Figure 5 — Separated electronic unit

## 2.2 Definitions of physical parameters

### 2.2.1

#### sensitivity

$S$

ratio of the change in spectrum peak height (ion current),  $I - I_0$ , to the corresponding change in partial pressure,  $p - p_0$

$$S(p) = \frac{I - I_0}{(p - p_0)} \quad (1)$$

where

$I$  is the ion current measured at partial pressure  $p$ ;

$I_0$  is the ion current measured at residual pressure  $p_0$

Note 1 to entry Sensitivity is expressed in amperes per pascal.

Note 2 to entry Sensitivity is defined differently in ISO 27894:2009<sup>[4]</sup> for an ionization gauge with an emissive cathode. The sensitivity of a hot-cathode ionization gauge is defined as

$$S = \frac{I_c - I_0}{I_e (p - p_0)} \quad (2)$$

where

$I_c$  is the ion current measured at pressure  $p$ ;

$I_0$  is the ion current measured at residual pressure  $p_0$ ;

$I_e$  is the emission current.

### 2.2.2

#### relative sensitivity factor

$r_x$

sensitivity  $S_x$  for a specified gas species,  $x$ , divided by sensitivity  $S_{N_2}$  for nitrogen for the same device at the same pressure and the same operation conditions:

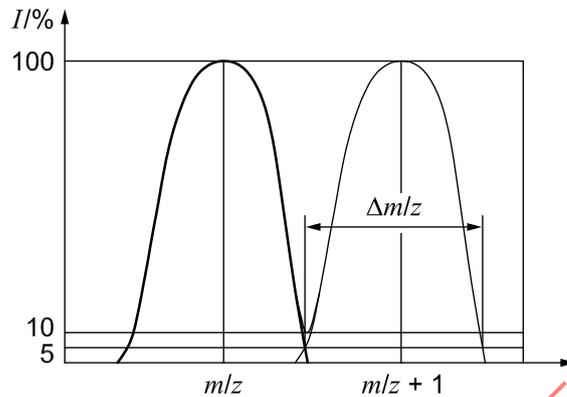
$$r_x = \frac{S_x}{S_{N_2}} \quad (3)$$

Note 1 to entry Relative sensitivity factors depend on the operational parameters of QMS as shown in References [13][16][17]. If necessary for reasons of accuracy, it is recommended that relative sensitivity factors be measured before each measurement.

**2.2.3 mass resolution**

smallest mass difference  $\Delta m$  between two equal magnitude peaks so that the valley between them is a specified fraction of the peak height

Note 1 to entry See Figure 6.



**Key**

$I$	ionic current
$m/z$	mass-to-charge ratio
$m/z + 1$	mass-to-charge ratio plus one
$\Delta m/z$	mass difference to charge ratio

**Figure 6 — Mass resolution defined at 10 % valley of neighbouring mass/charge ratios**

Note 2 to entry Mass resolution defined at 10 % valley is technically close to the peak width at 5 % of peak height.

Note 3 to entry Peak shape (i.e. asymmetry) has influence on mass resolution.

**2.2.4 mass resolving power**

ratio of the mass,  $m$ , to the mass resolution  $\Delta m$ :

$$\frac{m}{\Delta m}$$

Note 1 to entry See Reference [13].

**2.2.5 mass number stability**

extent to which a position of a peak of a single charged ion is stable within a specified time on the mass scale

**2.2.6 minimum detectable partial pressure MDPP**

$p_{p, \text{min det}}$  partial pressure of a specific gas which produces a peak height equal to three times its current noise limit  $\sigma_I$  in a given period of time divided by its sensitivity  $S$

$$p_{p, \text{min det}} = \frac{3\sigma_I}{S} \tag{4}$$

Note 1 to entry The standard deviation of the current can be used for current noise.

Note 2 to entry The noise limit depends on the integration time. It is recommended that an integration time of 1 s be used because this time is typical for current measurement in a mass spectrum peak.

Note 3 to entry Minimum detectable partial pressure is usually determined at the base pressure of the vacuum system.

Note 4 to entry Background noise or peak overlap from other gases of a gas mixture can influence MDPP substantially.

### 2.2.7

#### amount of substance fraction

ratio of the number of molecules of a given constituent of a mixture to the total number of molecules in the mixture

Note 1 to entry For ideal gases and for the conditions applicable for QMS, the mole fraction has the same value as the fraction based on volume.

### 2.2.8

#### minimum detectable concentration

minimum detectable partial pressure in a specified carrier gas

Note 1 to entry Generally, minimum detectable concentration is expressed as a volume fraction, e.g. as a percentage volume fraction or in microlitres per litre.

Note 2 to entry The MDPP to be used here is different to the one at base pressure. It shall be determined at the operating pressure.

Note 3 to entry Background noise or peak overlap from other gases of a gas mixture can influence minimum detectable concentration substantially.

### 2.2.9

#### mass range

range from the lightest to the heaviest single charged ion which can be detected

### 2.2.10

#### scan

##### mass scan

act or process of varying the scanning parameters over all or part of the mass range of QMS

Note 1 to entry The mass scan is also identified with the output of the QMS that shows the kinds and relative amounts of the ions produced from the gas. The scan is usually displayed as a graph on a PC monitor; the abscissa is ion mass per charge,  $m/z$ , or time and the ordinate represents the ion current on a linear or logarithmic scale. Typical scan parameters are mass range, scan speed, time per separated signal, resolution.

### 2.2.11

#### peak number

##### mass number

position of the maximum ion current of a certain mass/charge ratio

Note 1 to entry It is referred to, for example, as the "peak number 28". For single charged ions it is called mass number.

### 2.2.12

#### peak height

##### peak intensity

distance from baseline to the apex of a given peak

Note 1 to entry The peak height is expressed in amperes or pascals.

Note 2 to entry The output in pascals is a calculated value and not the originally measured signal (raw data).

### 2.2.13

#### peak tail

$\Delta_{\pm}$

position on the mass scale where mass peak has dropped to  $v$  % of the peak height

Note 1 to entry Since peaks are not, in general, perfectly symmetrical, the + and – subscripts are to distinguish values of peak tails obtained on the positive side and negative side of a mass peak.

**2.2.14**

**baseline**

reference level from which peak height is measured

Note 1 to entry The baseline is determined from the signal in mass ranges where no ions arrive at the detector.

**2.2.15**

**fragmentation pattern**

**cracking pattern**

pattern (i.e. kinds and relative amounts) of ions produced by a given pure gas in a given mass spectrometer under given conditions

Note 1 to entry The term derives from the fact that molecules are decomposed, cracked or multi-charged in the ion source and produce a characteristic set of atomic or molecular fragments.

Note 2 to entry The cracking pattern in a pure gas may be different from the one of the same gas species in a gas mixture.

**2.2.16**

**fragmentation factor**

**cracking factor**

**“relative abundance”**

$f_i$

ratio of an ion signal  $I_i$  at a mass number  $m_i$  originating from the fragmentation of an molecule to the ion signal  $I_0$  at the main mass number peak  $m_0$

$$f_i = \frac{I_i}{I_0} \tag{5}$$

Note 1 to entry Cracking factors depend on the operational parameters of a QMS as shown in References [12][14][15]. It is recommended that relative sensitivity factors be measured before each measurement.

**2.2.17**

**non-linearity**

extent to which the change in ion current is not proportional to the corresponding change in partial pressure

Note 1 to entry The non-linearity is equal to the change of sensitivity in a given range.

**2.2.18**

**linear response range**

partial pressure range over which the non-linearity is within a specified limit

**2.2.19**

**stability of peak height**

**stability of peak intensity**

change of the peak height at constant partial pressure in a specified time period

**2.2.20**

**maximum operational pressure**

maximum pressure specified to avoid damages of filament, detector or others, and to ensure a reasonable lifetime of the QMS

**2.2.21**

**warm-up time**

time after start of operation of QMS when measurement signal with stability as specified by the manufacture is achieved

### 3 Symbols and abbreviated terms

See Table 1.

Table 1 — Symbols and abbreviated terms

Symbol	Designation	Unit
$f$	fragmentation factor	1
$p$	pressure or partial pressure	Pa
$p_0$	residual pressure or residual partial pressure	Pa
$r_x$	relative sensitivity for a specified gas species $x$ divided by sensitivity $S_{N_2}$ for nitrogen	1
$I$	ion current at partial pressure $p$	A
$I_0$	ion current at residual pressure $p_0$	A
$p_{p, \text{min det}}$	minimum detectable partial pressure	Pa
$S$	sensitivity (coefficient)	A/Pa
$S_{N_2}$	sensitivity for nitrogen	A/Pa
CEM	continuous dynode electron multiplier	
MCP	micro-channel plate	
MDPP	minimum detectable partial pressure	Pa
QMS	quadrupole mass spectrometer	
SEM	secondary electron multiplier	

#### 4 Principle of QMS

Positive ions are produced in the ion source. These ions are accelerated towards the mass filter consisting of four symmetrically arranged hyperbolic, cylindrical rods or rods with a square cross-section. The combination of a direct current (d.c.) potential and radio-frequency (r.f.) potential applied to the rods separates the ions according to their mass-to-charge ratios which are detected by QMS detector. For more details see, for example, Reference [12].

Some types of QMS also allow the generation of negative ions and the measurement of their masses by changing the potentials accordingly.

When the pressure of the gas to be analysed is higher than the maximum operating pressure of the QMS, a separate pumping system plus a number of conductances are used to maintain a low enough pressure inside of the QMS. This method is usually done by using a differential pumping system.

#### 5 Specifications for a QMS to be provided by manufacturers

The following features and specifications shall be provided by the manufacturer in order to enable users of their QMS to minimize measurement error and to give guidance on safe operation. A QMS supplier can be mandated by the manufacturer to provide these specifications or part of them.

##### 5.1 Mass range

The mass range of the supplied QMS shall be specified in  $m/z$ .

##### 5.2 Type of ion source

The type of ion source shall be specified: open ion source; closed ion source; molecular-beam ion source; etc.

##### 5.3 Type of ion detector

The type of detector, such as Faraday cup or SEM, shall be specified.

#### 5.4 Mass resolution

The mass resolution should be specified in  $m/z$ . In order to have comparable specifications, it is strongly recommended that the value at 5 % of the peak height be given over a specified mass range or at a  $m/z$ . In addition, the mass resolution may be given at any other suitable percentage of the peak height (e.g. 50 %). Since mass resolution is normally adjustable, the best (lowest value) under the specific conditions shall be given.

#### 5.5 Mass number stability

Mass number stability is the extent to which a position of a mass peak is stable within a specified time on mass scale. It should be given for the main mass peak of Ar or for He.

#### 5.6 Sensitivity

The sensitivity shall be provided at least for  $N_2$  and for the available detector or detectors in a pressure range to be specified and at a given mass resolution. The sensitivity shall be expressed in amperes per pascal. Other units are also allowed. The supplier shall describe the conditions such as pressure, emission current and temperature, and the settings to evaluate the sensitivity.

#### 5.7 Linear response range

Minimum and maximum limit of the partial pressure over which the non-linearity is within a specified limit defined by manufacturer. The pressure range shall be expressed in pascals. Other units are also allowed.

The linear response range should be given at least for  $N_2$ .

As the linear response range depends on many adjustable parameters, e.g. emission current, the parameters should be specified.

#### 5.8 Minimum detectable partial pressure

MDPP shall be provided for a specified gas and a detector. It shall be expressed in pascals. Other units are also allowed.

This quantity should be given for at least He, optionally also for Ar.

#### 5.9 Minimum detectable concentration

MDC shall be provided for a specified gas mixture and a detector. The minimum detectable concentration can be determined from the measurement of minor constituents of the atmosphere, i.e. He, Ar, and Kr.

#### 5.10 Maximum operational pressure

The maximum operational pressure shall be specified. Maximum operational pressure should be expressed in pascals. Other units are also allowed.

Automatic shut down point of overpressure should be provided.

NOTE Highest allowable pressure under operation depends on the gas (composition), filament materials, and detector type or setting. It is generally provided for  $N_2$ .

#### 5.11 Scanning parameter

Scanning parameters shall be specified which are scan speed, scan time, point per  $m/z$ , resolution, number of scan, emission current, and SEM voltage, etc. If they are changeable, the ranges shall be specified.

### 5.12 Signal output

Signal output shall be specified, e.g. ion current, in amperes, partial pressure, in pascals, and/or total pressure, in pascals.

### 5.13 Potentials

The potentials of electrodes such as cathode, anode, extraction, field axis or ion energy, detector shall be specified.

If the potentials can be adjusted, this fact should be stated. Restrictions or recommendations for values and ratios (e.g. ratio between repeller voltage and electron energy) shall also be mentioned.

### 5.14 Detector specifications

For SEM, the maximum ion current (up to saturation) for a mass number shall be expressed in amperes. The typical amplification factor for a given potential shall be given and also the typical loss of amplification with lifetime and bake-outs.

### 5.15 Set point

The manufacturer shall specify whether trigger signal outputs (ion current or pressure if available) can be set to control other units or processes.

### 5.16 Maximum bake-out temperature

The maximum temperatures shall be specified respectively for QMS sensing unit, electronic unit, and cables. If the electronic unit of an integrated type can be removed, this fact shall be stated and the maximum bake-out temperature for either the sensing unit or electronic unit shall be given.

### 5.17 Nominal operating conditions

Temperature and humidity range at which the QMS can be operated for reliable measurements shall be specified.

### 5.18 Warm-up time

Warm-up time shall be specified.

### 5.19 Filament material

The number and material of filament(s) shall be specified.

### 5.20 Electron emission current

The manufacturer shall specify the electron emission current or the range of the electron emission current when adjustable. The emission current is generally expressed in milliamperes.

### 5.21 Filament exchange

The manufacturer shall specify whether a filament can be replaced by the user. If replacement is possible by the user, the procedure for resetting the QMS should be provided.

### 5.22 Detector exchange

If the detector (e.g. SEM) is replaceable, the method shall be stated.