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Laboratory glass and plastics ware — Principles of design and construction of volumetric instruments

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee LBI/1/2, Laboratory Equipment.

A list of organizations represented on this committee can be obtained on request to its secretary.

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**Laboratory glass and plastics ware - Principles of design
and construction of volumetric instruments (ISO
384:2015)**

Matériel de laboratoire en verre ou en plastique -
Principes de conception et de construction
d'instruments volumétriques (ISO 384:2015)

Laborgeräte aus Glas oder Kunststoff - Grundlagen für
Gestaltung und Bau von Volumenmessgeräten (ISO
384:2015)

This European Standard was approved by CEN on 16 November 2015.

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European foreword

This document (EN ISO 384:2015) has been prepared by Technical Committee ISO/TC 48 "Laboratory equipment" in collaboration with Technical Committee CEN/TC 332 "Laboratory equipment" the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2016, and conflicting national standards shall be withdrawn at the latest by June 2016.

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

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Endorsement notice

The text of ISO 384:2015 has been approved by CEN as EN ISO 384:2015 without any modification.

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

The committee responsible for this document is ISO/TC 48, *Laboratory equipment*.

This second edition cancels and replaces the first edition (ISO 384:1978), which has been technically revised to incorporate the following modifications.

- a) Volumetric instruments made from plastics have been added to the scope.
- b) Volumetric instruments of class AS have been added.
- c) The thickness of graduation lines has been modified.
- d) The basic principles for construction have been modified such that they comply with the product standards ISO 1042, ISO 648, ISO 835, ISO 385, ISO 4788 and ISO 4787.
- e) The relation between maximum permissible error and the inner diameter has been specified by an equation.
- f) [Annex A](#), explaining that relation, has been reworded.

Laboratory glass and plastics ware — Principles of design and construction of volumetric instruments

1 Scope

This International Standard sets out principles for the design of volumetric instruments manufactured from glass or from plastics in order to facilitate the most reliable and convenient use to the intended degree of accuracy.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 383, *Laboratory glassware — Interchangeable conical ground joints*

ISO 4787, *Laboratory glassware — Volumetric instruments — Methods for testing of capacity and for use*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 99 apply.

4 Unit of volume and reference temperature

4.1 Unit of volume

The unit of volume shall be the millilitre (ml), which is equivalent to one cubic centimetre (cm³).

4.2 Reference temperature

The standard reference temperature, i.e. the temperature at which the volumetric instrument is intended to contain or deliver its volume (capacity), shall be 20 °C.

When the volumetric instrument is required for use in a country which has adopted a standard reference temperature of 27 °C, this figure shall be substituted for 20 °C.

NOTE The capacity of volumetric instruments varies with change of temperature. A volumetric instrument which was adjusted at 20 °C, but used at 27 °C or vice versa, would show an extra error of only 0,007 % if it is made of borosilicate glass having a coefficient of cubic thermal expansion of $9,9 \times 10^{-6} \text{ °C}^{-1}$ and of 0,02 % if it is made of soda-lime glass having a coefficient of cubic thermal expansion of $27 \times 10^{-6} \text{ °C}^{-1}$. These errors are smaller than the limits of error for most volumetric instruments. It follows, therefore, that the reference temperature is of minor importance in practical use when dealing with glassware. However, when performing calibrations, it is important to refer to the reference temperature, especially when considering volumetric plastic ware.

5 Volumetric accuracy

5.1 There are two classes of accuracy:

- the higher grade shall be designated “class A” or “class AS”;
- the lower grade shall be designated “class B”.

5.2 The maximum permissible error shall be specified for each type of volumetric instrument in regard to the method and purpose of use and the class of accuracy.

5.3 The numerical values of maximum permissible error for volumetric instruments for general purposes shall be preferably chosen from the series 10 – 12 – 15 – 20 – 25 – 30 – 40 – 50 – 60 – 80, or a suitable decimal multiple thereof.

NOTE This series of preferred numbers has been adopted because decimal sub-multiples of some of the unrounded numbers, for example 31,5, would appear to imply a degree of precision which is not intended and which could not be measured in practice.

5.4 The maximum permissible error specified for a series of sizes of a volumetric instrument should provide a reasonably uniform progression in relation to capacity.

5.5 The maximum permissible error permitted for class B should, in general, be approximately twice as permitted for class A or AS.

5.6 For volumetric instruments having a scale, the maximum permissible error for either class of accuracy shall not exceed the volume equivalent (see [Annex A](#)) of the smallest scale division.

5.7 The maximum permissible error MPE for class A or AS depends on the internal diameter D (in millimetres) at the related graduation line and shall not be smaller than derived by Formula (1):

$$\text{MPE} \geq \frac{\pi}{4} D^2 (0,4 + 0,01 D) \quad (1)$$

The corresponding class B limit shall be derived in accordance with [5.5](#).

NOTE The above formula applies for the most common volumetric instruments which have a circular cross-section, but may be transferred to non-circular cross-sections as well. See [Annex A](#).

5.8 In addition to [5.7](#), the maximum permissible error specified for any volumetric instrument designed to deliver shall also be not less than four times the standard deviation determined experimentally by an experienced operator from a series of at least 10 consecutive determinations of delivered capacity on the same volumetric instrument, carried out strictly in accordance with the method specified for this volumetric instrument in ISO 4787.

6 Methods of calibration and use

The method of calibration and use for each type of volumetric instrument is extensively described in ISO 4787.

The general procedure is based upon a gravimetric determination of the volume of water, either contained in or delivered by the volumetric instrument under test. This volume of water is calculated from its mass under consideration of air buoyancy and water density.

Volumetric instruments manufactured from plastics should be considered to be calibrated more often than glass instruments, because of the lower long-term stability of plastic instruments.

7 Construction

7.1 Material

Volumetric instruments shall be constructed of glass or plastic of suitable chemical and thermal properties. They shall be as free as possible from visible defects and shall be reasonably free from internal stress.

7.2 Wall thickness

The volumetric instruments shall be sufficiently robust in construction to withstand usual laboratory usage and the wall thickness shall show no gross departure from uniformity.

7.3 Shape

All volumetric instruments shall be of a shape which will facilitate the intended use, and should preferably be of circular cross-section.

7.4 Capacity

7.4.1 The numerical values of capacity of volumetric instruments for general purposes should preferably be chosen from the series 10 – 20 – 25 – 50, or a decimal multiple or sub-multiple thereof.

The capacity of volumetric instruments for special applications may have differing values; there are e.g. pipettes with capacities of 3 ml to 9 ml.

7.4.2 The numerical value of the volume equivalents of the smallest division on volumetric instruments having a scale shall be chosen from the series 1 – 2 – 5, or a decimal multiple or sub-multiple thereof.

7.4.3 In the case of a special purpose volumetric instrument which is to be graduated for direct reading of capacity when used with a specific liquid other than water, the specification should preferably indicate the corresponding capacity when used with pure water, so that the latter can be used for calibration.

7.5 Stability

Volumetric instruments provided with a flat base shall stand vertically without rocking or spinning when placed on a level surface and, unless specified otherwise, the axis of the graduated portion of the vessel should be vertical.

7.6 Delivery jets

7.6.1 Delivery jets at the lower end of volumetric instruments should be strongly constructed either with a smooth and gradual taper or a capillary end, both without sudden constriction at the orifice which could give rise to turbulent outflow.

7.6.2 The end of the jet shall be finished by one of the methods listed below in order of preference:

- a) hot finished square with the axis, slightly bevelled on the outside and polished;
- b) smoothly ground square with the axis and optionally fire-polished;
- c) cut square with the axis and polished.

A fire-polished finish of glass jets reduces the danger of chipping in use, but should not result in sudden constriction or in undue stress.

7.6.3 The jet shall be made either from glass tubing or from suitable plastics material. It shall preferably form an integral part of the volumetric instrument. Otherwise, the jet shall be clearly identified to link it to the related volumetric instrument or, if sufficient, to the nominal size of the volumetric instrument.

7.7 Stoppers

7.7.1 Glass stoppers should preferably be ground so as to be interchangeable, in which case the ground portions shall comply with ISO 383. If individually fitted, they shall be well ground so as to prevent leakage, preferably with a taper of approximately 1:10.

7.7.2 Stoppers of a suitably inert plastics material may be permitted as an alternative to glass. In such cases, the glass or plastic socket into which the stopper fits should preferably comply with ISO 383.

7.8 Stopcocks or similar devices

7.8.1 Stopcocks and similar devices shall be designed to permit smooth and precise control of outflow and to prevent a rate of leakage greater than that allowed in the specification for the volumetric instrument.

7.8.2 Stopcocks and similar devices shall be made from glass or from suitable inert plastics material.

7.8.3 All-glass stopcocks shall have the key and barrel finely ground preferably to a taper of 1:10 and shall comply with appropriate national or international specifications.

7.8.4 Glass stopcock barrels to receive plastics keys shall be polished internally and may have a taper of 1:5 or 1:10.

7.8.5 Stopcock components may be fitted with suitable retaining devices.

8 Linear dimensions

8.1 Linear dimensional requirements shall be specified for all volumetric instruments in such a way as to ensure that:

- a) the volumetric instrument is convenient and satisfactory for its intended use;
- b) in a series of sizes of a volumetric instrument, unnecessary inconsistencies in shape and proportions can be avoided;
- c) a limitation is placed on the maximum inner diameter at the graduation line or lines (see [5.7](#) and [Annex A](#)). This limitation may be a direct limitation on the inner diameter or an indirect one by a minimum limitation on scale length;
- d) the requirement for spacing of graduation lines specified in [10.1.2](#) is achieved;
- e) the stability requirements of [7.5](#) can be achieved.

8.2 Dimensional requirements should not be more restrictive than is necessary to achieve the aims listed in [8.1](#). Linear dimensions shall be specified in millimetres.

8.3 In order to permit maximum freedom in manufacture within the restrictions imposed by [8.1](#), dimensions may be divided into two categories of importance and classified as “essential dimensions” and “recommended dimensions”.

8.4 In a specification where these two categories of dimensions are used, the requirements of [8.1 c\)](#) and d) shall be included as essential dimensions.

8.5 The requirements of [8.1 b\)](#) can in many cases be ensured sufficiently by recommended dimensions.

8.6 Essential dimensions shall be expressed in specifications by one of the following ways, whichever is the most suitable or convenient:

- a) a specified figure with tolerance;
- b) a maximum and minimum figure;
- c) a maximum or a minimum figure, if the other limit is unimportant or is controlled by other factors in the specification.

9 Graduation lines

9.1 Graduation lines and ringmarks shall be clean, permanent, uniform lines of specified thickness as described below.

9.2 For volumetric instruments with or without scale, a maximum thickness δ of graduation lines shall be specified according to the inner tube diameter D (in millimetres):

$$\delta \leq 0,4 \text{ mm for inner tube diameters of } D \leq 40 \text{ mm} \quad (2)$$

and

$$\delta \leq [(0,4 + 0,01 D) / 2] \text{ mm for inner tube diameters of } D > 40 \text{ mm} \quad (3)$$

NOTE For volumetric instruments with non-circular shaped cross-sections, see [Annex A](#).

9.3 On volumetric instruments having a scale, the specified maximum thickness δ of lines shall not exceed one-half of the minimum distance h between the centres of adjacent lines:

$$\delta \leq h/2 \text{ mm} \quad (4)$$

9.4 All graduation lines shall lie in planes at right angles to the longitudinal axis of the graduated portion of the volumetric instrument. On volumetric instruments provided with a flat base, the graduation lines shall therefore lie in planes parallel to the base.

9.5 Graduation lines should preferably be situated not less than 5 mm from any change in diameter.

9.6 On volumetric instruments not having a scale, all graduation lines should extend completely round the circumference of the volumetric instrument, except that a gap, not exceeding 10 % of the circumference, may be permitted. In the case of an volumetric instrument which is restricted as to the usual direction of viewing in use, this gap should be at the right or left of the usual direction of view.

10 Scales

10.1 Spacing of graduation lines

10.1.1 There should be no evident irregularity in the spacing of graduation lines (except in special cases where the scale is on a conical or tapered portion of the volumetric instrument and a change of subdivision takes place).

10.1.2 The minimum distance h between the centres of adjacent graduation lines shall be not less than:

$$h \geq (0,8 + 0,02 D) \text{ mm} \quad (5)$$

where D is the inner diameter of the tube in millimetres.

NOTE For non-circular cross-sections, see [Annex A](#).

10.2 Length of graduation lines (see [Figure 2](#))

10.2.1 General

On volumetric instruments of circular cross-section having a scale, the length of the graduation lines shall be varied so as to be clearly distinguishable and shall be in accordance with the provisions of [10.2.2](#), [10.2.3](#) or [10.2.4](#).

10.2.2 Graduation pattern I

- a) The length of the short lines should be approximately, but not less than, 50 % of the circumference of the volumetric instrument.
- b) The length of the medium lines should be approximately 65 % of the circumference of the volumetric instrument and should extend symmetrically at each end beyond the end of the short lines.
- c) The long lines should extend completely round the circumference of the volumetric instrument, but a gap, not exceeding 10 % of the circumference, may be permitted (see [9.6](#)).

10.2.3 Graduation pattern II

- a) The length of the short lines should be not less than 10 % and not more than 20 % of the circumference of the volumetric instrument.
- b) The length of the medium lines should be approximately 1,5 times the length of the short lines and should extend symmetrically at each end beyond the end of the short lines.
- c) The long lines should extend completely round the circumference of the volumetric instrument, but a gap, not exceeding 10 % of the circumference, may be permitted (see [9.6](#)).

10.2.4 Graduation pattern III

- a) The length of the short lines should be not less than 10 % and not more than 20 % of the circumference of the volumetric instrument.
- b) The length of the medium lines should be approximately 1,5 times the length of the short lines and should extend symmetrically at each end beyond the ends of the short lines.
- c) The length of the long lines should be not less than twice the length of the short lines and should extend symmetrically at each end beyond the ends of the short and medium lines.

10.2.5 Special cases

In special cases where scales are required on non-circular cross-section or conical or tapered portions of a volumetric instrument, the requirements of [10.2.2](#), [10.2.3](#) or [10.2.4](#) should be appropriately modified.

10.3 Sequence of graduation lines (see [Figure 1](#))

10.3.1 On volumetric instruments in which the volume equivalent of the smallest scale division is 1 ml (or a decimal multiple or sub-multiple thereof):

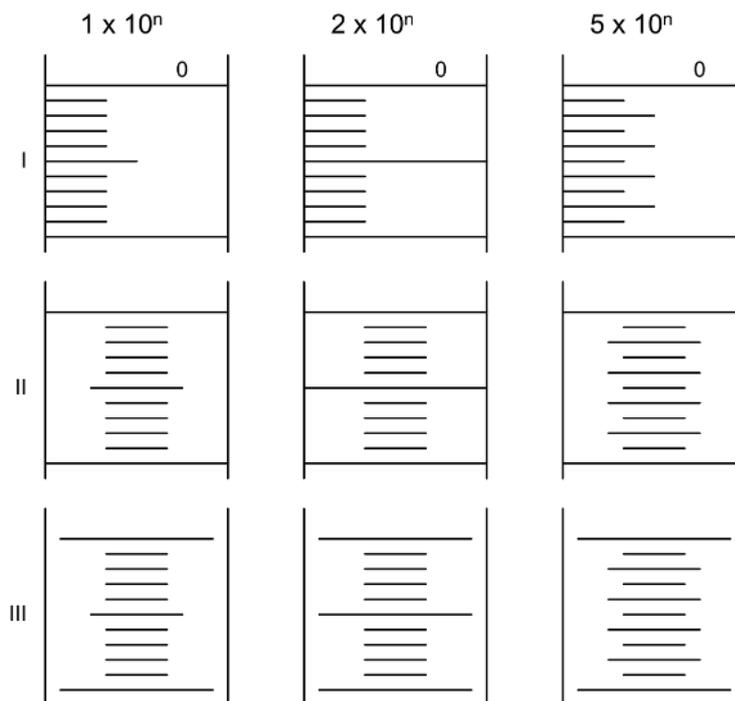
- a) every tenth graduation line is a long line;
- b) there is a medium line midway between two consecutive long lines;
- c) there are four short lines between consecutive medium and long lines.

10.3.2 On volumetric instruments in which the volume equivalent of the smallest scale division is 2 ml (or a decimal multiple or sub-multiple thereof):

- a) every fifth graduation line is a long line;
- b) there are four short lines between two consecutive long lines.

10.3.3 On volumetric instruments in which the volume equivalent of the smallest scale division is 5 ml (or a decimal multiple or sub-multiple thereof):

- a) every tenth graduation line is a long line;
- b) there are four medium lines equally spaced between two consecutive long lines;
- c) there is one short line between two consecutive medium lines or between consecutive medium and long lines.



Key

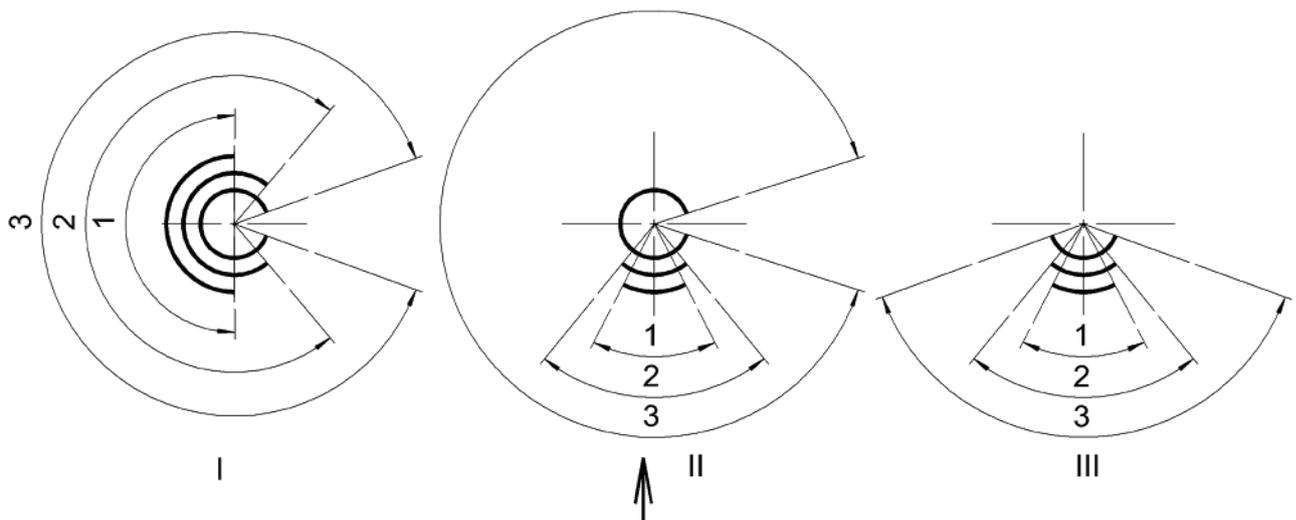
- I Graduation pattern I, see [10.2.2](#)
- II Graduation pattern II, see [10.2.3](#)
- III Graduation pattern III, see [10.2.4](#)

Figure 1 — Length and sequence of graduation lines

10.4 Position of graduation lines (see [Figure 2](#))

10.4.1 On volumetric instruments graduated according to pattern I with vertical scales in accordance with [10.2.2](#), the ends of the short graduation lines shall lie on an imaginary vertical line down the centre of the front of the volumetric instrument, the lines themselves extending preferably to the left, when the volumetric instrument is viewed from the front in the position of normal use.

10.4.2 On volumetric instruments graduated according to pattern II or III with vertical scales in accordance with [10.2.3](#) and [10.2.4](#), the mid-points of the short and medium graduation lines shall lie on an imaginary vertical line down the centre of the front of the volumetric instrument, when the volumetric instrument is viewed from the front in the position of normal use.



Key

I	Graduation pattern I, see 10.4.1	1	short line
II	Graduation pattern II, see 10.4.2	2	medium line
III	Graduation pattern III, see 10.4.2	3	long line

Figure 2 — Position of graduation lines

11 Figuring of graduation lines

11.1 On volumetric instruments with one graduation line, the number representing nominal capacity may be included with the other inscriptions and need not be adjacent to the graduation line.

11.2 On volumetric instruments having two or three graduation lines, the numbers representing nominal capacity need not be adjacent to the lines to which they relate, if a more suitable method of identification is used, e.g. in the product information, the calibration certificate or in published catalogues.

11.3 On volumetric instruments having one principal graduation line and a small number of subsidiary lines, the number representing the principal capacity may be included with the other inscriptions as in [11.1](#) provided that the subsidiary graduation lines are suitably identified.

11.4 On volumetric instruments having a scale:

- a) the scale shall be so figured as to enable the value corresponding to each graduation line to be readily identified;
- b) the scale should normally have only one set of figures;
- c) at least every tenth line shall be figured;
- d) figures shall be confined to long graduation lines and should be placed immediately above the line and slightly to the right of the adjacent shorter graduation lines;
- e) where it is necessary in special cases to use a number relating to a medium or short graduation line, the number should be placed slightly to the right of the end of the line in such a way that an extension of the line would bisect it.

Where long lines complying with 10.2.3 are used (i.e. not extending completely round the volumetric instrument), an alternative scheme of figuring may be permitted, in which the figure is placed slightly to the right of the end of the long line in such a way that an extension of the line would bisect it.

12 Marking

12.1 The following inscriptions shall be permanently marked on each volumetric instrument:

- a) a number indicating the nominal capacity (except for volumetric instruments with graduation lines figured to indicate capacity);
- b) the symbol “ml” or the symbol “cm³” to indicate the unit in terms of which the volumetric instrument is graduated;
- c) the inscription “20 °C” to indicate the standard reference temperature; where, exceptionally, the reference temperature is 27 °C, this value shall be substituted for 20 °C;
- d) the letters “In” to indicate that the volumetric instrument has been adjusted **to contain** its indicated capacity, or the letters “Ex” to indicate that the volumetric instrument has been adjusted **to deliver** its indicated capacity;
- e) the inscription “A”, “AS” or “B” to indicate the class of accuracy to which the volumetric instrument is intended to belong;
- f) on volumetric instruments intended for use with a specified waiting time, the waiting time shall be inscribed. For example: “Ex+5 s”;
- g) the manufacturer’s and/or supplier’s name and/or mark.

It is recommended to mark volumetric instruments complying with an ISO International Standard with the number of that ISO International Standard.

12.2 If required by legal metrology, additional information shall be marked on Class “A” or “AS” volumetric instruments intended for official verification or certification:

- a) an identification mark, which shall be repeated on all removable parts which might affect the volumetric accuracy;
- b) the delivery time, in seconds, may optionally be marked on the volumetric instrument’s body;
- c) in the case of a volumetric instrument which has been specially constructed for direct reading of capacity when used with a specific liquid other than water, the name or chemical formula of the liquid in question;
- d) the maximum permissible error applying for the volumetric instrument, for example “± . . ml”.

12.3 The following inscriptions shall also be marked on volumetric instruments to which they apply:

- a) in the case of an volumetric instrument made from a glass having a coefficient of (cubical) thermal expansion outside the range $25 \times 10^{-6} \text{ °C}^{-1}$ to $30 \times 10^{-6} \text{ °C}^{-1}$ (i.e. outside the range of the usual types of soda-lime glass), an indication to this effect, so that for certification purposes the appropriate correction may be done; this requirement will be met by the manufacturer’s name and/or trade mark if the material and/or coefficient of thermal expansion is given in the product information or is published in corresponding catalogues;
- b) in the case of an volumetric instrument made from plastics an indication to the material which gives reference to the (cubical) thermal expansion factor; this requirement will be met by the manufacturer’s name and/or trade mark if the material and/or coefficient of thermal expansion is given in the product information or is published in the corresponding catalogues.

- c) blow-out volumetric instruments such as blow-out pipettes shall be provided with a narrow white band below any colour coding. Additionally, they may have an inscription indicating that the instrument is for blow-out (for example, “blow-out”, “à souffler” or similar).

13 Visibility of graduation lines, figures and inscriptions

13.1 All figures and inscriptions shall be of such size and form as to be clearly legible under usual conditions of use.

13.2 All graduation lines, figures and inscriptions shall be clearly visible and permanent.

Annex A (normative)

Maximum permissible error in relation to the inner diameter at the meniscus

[Subclause 5.7](#) of this International Standard specifies a requirement that the maximum permissible error MPE for any volumetric instrument of class A and class AS shall not be less than that calculated under consideration of the inner diameter at the graduation line by means of Formula (1).

The MPE for volumetric instruments having at the graduation line a non-circular cross-section is calculated by the equation

$$\text{MPE} \geq A \cdot L \quad (\text{A.1})$$

and in case of volumetric instruments having at the graduation line a cylindrical tube with inner diameter D by the equation

$$\text{MPE} \geq \frac{\pi}{4} D^2 L \quad (\text{A.2})$$

where

MPE is the maximum permissible error, in microlitres;

A is the internal cross-section of the instrument at the meniscus;

D is the internal diameter, in millimetres, of the tube at the meniscus;

L is the linear equivalent of the MPE, in millimetres.

The linear equivalent L is the length of tube of diameter D occupied by the volume of the maximum permissible error MPE. This linear equivalent L of the MPE should not be smaller than the reading error.

The linear equivalent

$$L = L_0 + P \quad (\text{A.3})$$

can be considered to be made up of two components:

- a) a basic minimum of $L_0 = 0,4$ mm which is the lowest limit, even on tubes of very small diameter, which has proved to be satisfactory in normal use and practicable for easy reading of volume changes;
- b) an additional allowance for potential parallax error in reading, which is related to the diameter, and for which the symbol " P " is used.

The value for this parallax component P can be derived as follows. If θ is the angle between the operator's sight-line to the meniscus and the horizontal plane tangential to the meniscus, then:

$$\tan \theta = \frac{P}{D_e/2} = \frac{H}{d + D_e/2} \quad (\text{A.4})$$

which yields

$$P = \frac{HD_e}{2d + D_e} \quad (\text{A.5})$$

where

P is the error in reading, in millimetres;

d is the distance of the operator's eye from the scale, in millimetres;

H is the distance of the operator's eye above or below the horizontal plane tangential to the meniscus, in millimetres;

D_e is the tube outer diameter, neck or column which carries the scale, in millimetres.

From the above formulae, the linear equivalent L can be derived as

$$L \geq L_0 + \frac{H \cdot D_e}{2d + D_e} \quad (\text{A.6})$$

as well as the maximum permissible error MPE as

$$\text{MPE} \geq \frac{\pi}{4} \cdot D^2 \cdot \left(L_0 + \frac{H \cdot D_e}{2d + D_e} \right) \quad (\text{A.7})$$

In practical application with $d = 200$ mm and $H = 5$ mm and tube dimensions similar to ISO 4803, it follows that $D \approx D_e$ and without significant error, a good approximation can be given over the extreme range of inner diameters D from 1 mm up to 100 mm by the simplified formulae:

$$L \geq (0,4 + 0,01 D) \quad (\text{A.8})$$

and

$$\text{MPE} \geq \frac{\pi}{4} D^2 (0,4 + 0,01 D) \quad (\text{A.9})$$

where L and D are given in millimetres and the MPE in microlitres.

For the series of maximum permissible error specified in [5.3](#) of this International Standard, appropriate maximum inner diameters at the meniscus which are listed in [Table A.1](#) have been calculated by Formula (A.9).

Table A.1 — Maximum inner diameter of tube at the graduation line appropriate to selected maximum permissible error for volumetric instruments class A and class AS

Maximum permissible error	Maximum inner tube diameter at the graduation line	Maximum permissible error	Maximum inner tube diameter at the graduation line
±µl	mm	±µl	mm
0,1	0,56	80	14
0,2	0,78	100	15
0,3	0,96	120	16
0,4	1,1	150	18
0,5	1,2	200	21
0,6	1,4	250	23
0,8	1,6	300	24
1	1,8	400	27
2	2,5	500	30
3	3,0	600	32
4	3,4	800	36
5	3,8	1 000	40
6	4,2	1 200	43
8	4,8	1 500	47
10	5,3	2 000	52
12	5,8	2 500	57
15	6,4	3 000	61
20	7,3	4 000	68
25	8,1	5 000	75
30	8,7	6 000	80
40	10	8 000	89
50	11	10 000	97
60	12	-	-

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- [1] ISO 4803, *Laboratory glassware — Borosilicate glass tubing*

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