International Standard 649/2

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Laboratory glassware — Density hydrometers for general purposes — Part 2 : Test methods and use

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 649/2 was developed by Technical Committee ISO/TC 48, *Laboratory glassware and related apparatus*, and was circulated to the member bodies in September 1979.

It has been approved by the member bodies of the following countries :

Australia	India	Portugal
Brazil	Italy	Romania
Canada	Korea, Rep. of	South Africa, Rep. of
Czechoslovakia	Libyan Arab Jamahiriya	Spain
France	Mexico	United Kingdom
Germany, F.R.	Netherlands	USSR
Hungary	Poland	

No member body expressed disapproval of the document.

International Standards ISO 649/1 and ISO 649/2 cancel and replace ISO Recommendation R 649-1968, of which they constitute a technical revision.

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Laboratory glassware — Density hydrometers for general purposes — Part 2 : Test methods and use

1 Scope and field of application

This part of ISO 649 specifies the test methods and use of density hydrometers for general purposes.

Part 1 of this International Standard gives the specification for density hydrometers for general purposes.

2 References

ISO 91/1, *Petroleum measurement tables — Part 1 : Tables based on reference temperatures of* 15 °C *and* 60 °F.[1)]

ISO 649/1, *Laboratory glassware — Density hydrometers for general purposes — Part 1 : Specification.*

ISO 650, *Relative density* 60/60 *degrees F hydrometers for general purposes.*

ISO 653, *Long solid-stem thermometers for precision use.*

ISO 654, *Short solid-stem thermometers for precision use.*

ISO 655, *Long enclosed-scale thermometers for precision use.*

ISO 656, *Short enclosed-scale thermometers for precision use.*

ISO 3507, *Pyknometers.*

ISO 4788, *Laboratory glassware — Graduated measuring cylinders.*

3 Methods of determination of density by means of ISO hydrometers

3.1 General

To obtain the highest precision when using a particular hydrometer, the following general procedures should be adhered to :

3.1.1 Read the hydrometer in the liquid at a known temperature.

3.1.2 Apply corrections (when significant) to the observed reading for :

a) the meniscus height (if the test liquid is opaque see 3.6.1);

b) the scale error of the hydrometer at the observed reading (see 3.6.2);

c) the difference between the temperature of the liquid and the standard temperature of the hydrometer (see 3.6.3);

d) the difference between the surface tension of the liquid and that for which the hydrometer is graduated (see 3.6.4).

3.2 Apparatus

3.2.1 Hydrometer

Select a hydrometer appropriate to the surface tension of the liquid to be examined. Table 3 of ISO 649/1 gives a guide to the range of liquids suitable for the appropriate hydrometer category. Surface tensions of other liquids may be obtained from appropriate tables of physical properties of substances, for example "International Critical Tables".

3.2.2 Hydrometer vessel

Select a hydrometer vessel as described in clause 6.

3.2.3 Thermometer

For high precision work, select a total immersion thermometer graduated in 0,1 °C, with a certificate of scale correction. A thermometer complying with ISO 653, ISO 654, ISO 655 or ISO 656 is suitable.

1) At present at the stage of draft. (Revision of ISO/R 91 and its Addendum 1.)

3.3 Preliminaries

3.3.1 Clean all apparatus before use.

3.3.2 Allow the liquid to attain thermal equilibrium with its surroundings and pour it into the hydrometer vessel, allowing a small quantity to overflow if an overflow vessel is used. Avoid the formation of air bubbles in the liquid by pouring down the side of the vessel. Stir the liquid vertically with a loop stirrer, again avoiding the formation of bubbles. Record the temperature of the liquid to the nearest 0,2 °C.

3.3.3 Insert the hydrometer carefully into the liquid, holding it by the top of its stem. Release the hydrometer when it is approximately in its position of equilibrium and, if an overflow vessel is used, add a further amount of sample to the vessel by way of the filling tube until a volume approximately equal to 15 % of the nominal capacity has overflowed. A little experience soon enables the user to appreciate when the hydrometer is approaching equilibrium and to release it in such a position that the hydrometer rises or falls by only a small amount when released. This is important with viscous liquids, for otherwise excess liquid will adhere to the stem and the hydrometer will thereby be weighted down.

3.3.4 When the hydrometer is steady, press the top of the stem downwards a few millimetres beyond the position of equilibrium or, if the liquid is viscous, only one scale division, gripping the stem very lightly with a finger and thumb. Withdraw the hand and observe the meniscus as the hydrometer oscillates to equilibrium. If the stem and liquid surface are clean, the meniscus shape will remain unchanged as the hydrometer rises and falls. If the meniscus shape changes, for example if it wrinkles or is distorted by the motion of the hydrometer, lack of cleanliness is indicated and the hydrometer and vessel shall be cleaned and the test repeated with a fresh sample. This precaution becomes increasingly important with increasing surface tension of the liquid.

3.4 Reading the hydrometer

When the hydrometer, which must not be touching the side of the vessel, has settled down to its equilibrium position (in the case of viscous liquids this may take some time), record the reading as follows.

3.4.1 Transparent liquids

Record the scale reading corresponding to the plane of intersection of the horizontal liquid surface and the stem. When taking the reading, view the scale through the liquid, adjusting the line of sight so that it is in the plane of the liquid surface.

3.4.2 Opaque liquids

Record the scale reading where the meniscus merges into the stem of the hydrometer.

3.5 Reading of temperature

Immediately after taking the reading, measure the temperature of the liquid to the nearest 0,2 °C. The mean of this temperature and the initial temperature referred to in 3.3.2 shall be used in the calculation of corrections (3.6).

NOTE — This is particulary important in the case of liquids having high values of coefficient of cubical thermal expansion.

The difference between the two temperatures shall not exceed 1 °C and, if a larger difference is found, lack of thermal equilibrium is indicated and the procedure shall be repeated from 3.3.2.

3.6 Application of the corrections

3.6.1 Meniscus height

In cases where a hydrometer adjusted for readings taken at the level of the horizontal liquid surface has been read in an opaque liquid (i.e. at the line where the liquid merges into the stem of the hydrometer), it is necessary to correct the reading for the meniscus height by adding the appropriate value from table 3 or 4.

3.6.2 Instrument error

By "instrument error" is meant the difference between the reading of the hydrometer and the reading of a similar but ideal hydrometer used under precisely the same conditions. If known, the corrections for instrument error may be applied with equal validity under all conditions of use. It is, however, additional to other corrections, for example those for temperature and surface tension, which vary according to conditions of use. For many purposes it is sufficient to know that the instrument error does not exceed the maximum error permitted by clause 13 of ISO 649/1. Where greater accuracy is required, the instrument error should be known and allowed for.

In this case the hydrometer shall be tested. The linear dimension shall be checked with suitable graduated metal scales and outside micrometer calipers to verify that they comply with the requirements of clause 12 of ISO 649/1.

a) The scale of a hydrometer of the L20, L50 and L50SP series shall be calibrated on at least five points within the nominal limits, which shall include at least 80 % of the graduated interval of the scale.

Neither of the extreme points shall be further from the nearest end of the graduated scale than a distance equal to 15 % of the graduated scale.

No two adjacent points shall be further apart than a distance equal to 25 % of the graduated scale.

b) The scale of hydrometers of all other series shall be calibrated in a similar way following the same order as in a) but at three points, which shall include at least 60 % of the graduated interval of the scale.

Neither of the extreme points shall be futher from the nearest end of the graduated scale than a distance equal to 25 % of the graduated scale.

No two adjacent points shall be further apart than a distance of 50 % of the graduated scale.

When the scale is tested, it shall be verified that the scale has not shifted since manufacture, and the hydrometer shall be examined subsequently, from time to time, to ascertain than there has been no displacement of the scale.

Alternatively, testing the hydrometer at one point will serve the same purpose.

3.6.3 Temperature correction

If the hydrometer reading is taken at a temperature other than the reference temperature for the hydrometer, then the reading will be in error due to the change in volume of the hydrometer between the two temperatures.

Appropriate corrections making allowance for this temperature effect are given in table 1. When positive in sign the temperature correction given is to be added to, and when negative subtracted from, the hydrometer reading at the temperature in question. The table has been computed using a nominal coefficient of cubical thermal expansion of the glass of the hydrometer having a value of 25 × 10^{-6} °C^{-1}.

3.6.4 Surface tension correction

Attention has already been drawn to the fact that the reading of a hydrometer depends to some extent on the surface tension of the liquid in which it is used. In general it is possible, by choosing a hydrometer graduated for the most appropriate of the surface tension categories available[1)] and having a suitable open scale, to avoid any necessity for surface tension corrections. Table 2 gives an indication of possible errors in the form of corrections which may be applied on account of difference between the surface tension of the liquid and the surface tension for which the hydrometer is adjusted. They relate to hydrometers of average dimensions permitted under this specification[1)].

It is important to note that the density obtained by applying this correction is that of the liquid at the temperature of observation. If the density is required at some other temperature, an allowance must be made for the expansion or contraction of the liquid with change of temperature.

Table 1 — Correction for temperature applicable to hydrometers adjusted for a reference temperature of 20 °C or 15 °C

Unit : kg/m³ or 10^{-3} g/ml

Reference temperature 20 °C	Reference temperature 15 °C	Reading kg/m³	600	800	1 000	1 200	1 400	1 600	1 800	2 000
Temperature of liquid, °C		g/ml	0,6	0,8	1,0	1,2	1,4	1,6	1,8	2,0
0	—		+ 0,3	+ 0,4	+ 0,5	+ 0,6	+ 0,7	+ 0,8	+ 0,9	+ 1,0
5	0		+ 0,2	+ 0,3	+ 0,4	+ 0,5	+ 0,5	+ 0,6	+ 0,7	+ 0,8
10	5		+ 0,2	+ 0,2	+ 0,3	+ 0,3	+ 0,4	+ 0,4	+ 0,5	+ 0,5
15	10		+ 0,1	+ 0,1	+ 0,1	+ 0,2	+ 0,2	+ 0,2	+ 0,2	+ 0,3
20	15		0	0	0	0	0	0	0	0
25	20		− 0,1	− 0,1	− 0,1	− 0,2	− 0,2	− 0,2	− 0,2	− 0,3
30	25		− 0,2	− 0,2	− 0,3	− 0,3	− 0,4	− 0,4	− 0,5	− 0,5
35	30		− 0,2	− 0,3	− 0,4	− 0,5	− 0,5	− 0,6	− 0,7	− 0,8
40	35		− 0,3	− 0,4	− 0,5	− 0,6	− 0,7	− 0,8	− 0,9	− 1,0
45	40		− 0,4	− 0,5	− 0,6	− 0,8	− 0,9	− 1,0	− 1,1	− 1,3

NOTE — These corrections when applied to the hydrometer reading at t °C give the density of the liquid in kg/m³ or g/ml at t °C. They are based on the relationship

$$C = 0{,}000\,025\,R\,(t_o - t)$$

where

C is the correction;

R is the reading at the level of the horizontal liquid surface;

t_o is the reference temperature;

t is the temperature of the liquid being measured.

1) See ISO 649/1.

Table 2 — Surface tension corrections

Unit : kg/m³ or 10^{-3} g/ml

Surface tension of liquid minus that for which the hydrometer is adjusted mN/m		Series L20				Series L50 and L50SP				Series M50 and M50SP				Series M100				Series S50 and S50SP			
		Hydrometer reading				Hydrometer reading				Hydrometer reading				Hydrometer reading				Hydrometer reading			
	kg/m³	600	1 000	1 500	2 000	600	1 000	1 500	2 000	600	1 000	1 500	2 000	600	1 000	1 500	2 000	600	1 000	1 500	2 000
	g/ml	0,6	1,0	1,5	2,0	0,6	1,0	1,5	2,0	0,6	1,0	1,5	2,0	0,6	1,0	1,5	2,0	0,6	1,0	1,5	2,0
− 40		—	− 0,54	− 0,45	− 0,39	—	− 1,2	− 0,9	− 0,8	—	− 1,9	− 1,5	− 1,4	—	− 3,0	− 3,0	− 2,0	− 3,0	− 2,5	− 2,0	− 2,0
− 30		—	− 0,41	− 0,34	− 0,30	—	− 0,9	− 0,7	− 0,6	—	− 1,4	− 1,1	− 1,0	—	− 2,0	− 2,0	− 2,0	− 2,5	− 2,0	− 1,5	− 1,5
− 20		—	− 0,27	− 0,22	− 0,20	—	− 0,6	− 0,5	− 0,4	—	− 0,9	− 0,8	− 0,7	—	− 2,0	− 1,0	− 1,0	− 1,5	− 1,5	− 1,0	− 1,0
− 10		− 0,18	− 0,14	− 0,11	− 0,10	− 0,3	− 0,3	− 0,2	− 0,2	− 0,6	− 0,5	− 0,4	− 0,3	− 1,0	− 1,0	− 1,0	− 1,0	− 1,0	− 0,5	− 0,5	− 0,5
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+ 10		+ 0,18	+ 0,14	+ 0,11	+ 0,10	+ 0,3	+ 0,3	+ 0,2	+ 0,2	+ 0,6	+ 0,5	+ 0,4	+ 0,3	+ 1,0	+ 1,0	+ 1,0	+ 1,0	+ 1,0	+ 0,5	+ 0,5	+ 0,5
+ 20		—	+ 0,27	+ 0,22	+ 0,20	—	+ 0,6	+ 0,5	+ 0,4	—	+ 0,9	+ 0,8	+ 0,7	—	+ 2,0	+ 1,0	+ 1,0	+ 1,5	+ 1,5	+ 1,0	+ 1,0
+ 30		—	+ 0,41	+ 0,34	+ 0,30	—	+ 0,9	+ 0,7	+ 0,6	—	+ 1,4	+ 1,1	+ 1,0	—	+ 2,0	+ 2,0	+ 2,0	+ 2,5	+ 2,0	+ 1,5	+ 1,5
+ 40		—	+ 0,54	+ 0,45	+ 0,39	—	+ 1,2	+ 0,9	+ 0,8	—	+ 1,9	+ 1,5	+ 1,4	—	+ 3,0	+ 3,0	+ 2,0	+ 3,0	+ 2,5	+ 2,0	+ 2,0

NOTE — For hydrometers not of average dimension, the surface tension allowances may differ from the above amounts by up to approximately ± 10 %.

4 Meniscus corrections

Table 3 gives the approximate amounts to be added to readings taken where the top of the meniscus appears to meet the stem, in order to obtain the corresponding indications at the level of the horizontal liquid surface. They have been calculated for hydrometers having the mean dimensions permitted by the specification and are based on an equation due to Langberg which, rearranged, is equivalent to

$$\varrho - \varrho_o = \frac{1\,000\,\Delta d\,\sigma}{g\,\Delta l\,D\,\varrho_o}\left(\sqrt{1 + \frac{2\,g\,D^2\,\varrho_o}{1\,000\,\sigma}} - 1\right)$$

where

ϱ is the density reading at the level of the horizontal liquid surface, in kilograms per cubic metre;

ϱ_o is the density reading at the top of the meniscus, in kilograms per cubic metre;

Δd is the scale interval, in kilograms per cubic metre;

σ is the surface tension, in millinewtons per metre;

g is the acceleration due to gravity, in metres per second squared, taken as the standard acceleration of 9,806 65 m/s²;

D is the stem diameter, in millimetres;

Δl is the scale spacing, in millimetres.

Table 3 — Average meniscus corrections expressed in units of density

Unit : kg/m³ or 10⁻³ g/ml

Series of hydrometers			L20	L50 and L50SP	M50 and M50SP	M100	S50	S50SP
Value of smallest scale division			0,2	0,5	1	2	2	1
Assumed scale length (mm)			113 127	125 145	78 99	87 102	50 62	50 62
Density of liquid kg/m³	g/ml	Surface tension (mN/m)						
600	0,600	15	0,32 0,28	0,8 0,7	1,2 1,0	2,0 2,0	2,0 1,6	1,8 1,6
800	0,800	25	0,36 0,32	0,8 0,7	1,4 1,0	2,4 2,0	2,0 1,6	2,0 1,6
1 000	1,000	35	0,36 0,32	0,8 0,7	1,4 1,0	2,4 2,0	2,0 1,6	2,2 1,6
		55	0,44 0,40	1,0 0,8	1,6 1,2	2,8 2,4	2,4 2,0	
		75	0,48 0,44	1,0 0,9	1,8 1,4	3,2 2,8	2,8 2,4	
1 500	1,500	35	0,32 0,28	0,7 0,6	1,0 0,8	2,0 1,6	2,0 1,2	
		55	0,36 0,32	0,8 0,7	1,2 1,0	2,4 2,0	2,0 1,6	
		75	0,40 0,36	0,9 0,8	1,4 1,0	2,8 2,4	2,4 2,0	
2 000	2,000	55	0,32 0,28	0,7 0,6	1,0 1,0	2,0 1,6	2,0 1,6	
		75	0,36 0,32	0,8 0,7	1,2 1,0	2,4 2,0	2,4 1,6	

NOTES

1 Those requiring to know the corrections for meniscus height more closely than can be obtained from the above table of average values may derive them, having regard to the diameter of the stem of the particular hydrometer concerned, from table 4 which is also computed from Langberg's equation.

2 Table 3 has been calculated for the scale lengths indicated on the third line. The left-hand and right-hand entries refer, respectively, to the lower and upper limits of the range of scale lengths normally found in practice for hydrometers complying with the requirements of ISO 649/1.

3 The corrections have been rounded off to the nearest one-fifth off the scale interval.

Table 4 — Average meniscus correction expressed in units of length

Unit : 1 mm

Density of liquid kg/m³	g/ml	Surface tension mN/m	Stem diameter mm 4	5	6	7
600	0,6	15	1,7	1,8	1,9	1,9
700	0,7	20	1,8	1,9	2,0	2,0
800	0,8	25	1,9	2,0	2,0	2,1
900	0,9	30	1,9	2,0	2,1	2,2
1 000	1,0	35	1,9	2,1	2,1	2,2
		55	2,2	2,4	2,5	2,6
1 300	1,3	35	1,8	1,9	1,9	2,0
		55	2,1	2,2	2,3	2,4
1 500	1,5	55	2,0	2,1	2,2	2,3
2 000	2,0	55	1,8	1,9	1,9	2,0

5 Table for use in calculation quantities of liquid in bulk

NOTES

1 It is essential that the correction referred to in 3.6.3 is carried out before that described in this clause.

2 In the petroleum industry special calculation procedures based on the reference temperature 15 °C are used, and the necessary tables are included in petroleum measurement tables ISO 91/1.

At a given temperature t °C, the volume V_t in cubic metres or millilitres of a quantity of liquid can be obtained by dividing its apparent mass in air, W kilograms or grams, by the apparent mass in air of the liquid per cubic metre or per millilitre respectively. Alternatively, the total apparent mass in air of the liquid at t °C, W kilograms or grams, can be found by multiplying together the total volume of the liquid V_t cubic metres or millilitres, and the apparent mass in air at t °C, in kilograms per cubic metre or grams per millilitre respectively. In both instances, the apparent mass in air per unit volume at t °C is required and table 5 enables these quantities to be obtained in a simple way from the density (kg/m^3 or g/ml) at t °C.

Table 5 — Conversion of density (kg/m^3 or g/ml) to apparent mass (in air) in kg or g of the liquid occupying 1 m^3 or 1 ml at a given temperature, t °C

The correction in the third or fourth column, whichever is appropriate, is to be applied to the corresponding value in the first or second column.

Density at t °C		Correction to give apparent mass in air of liquid	
kg/m^3	g/ml	Occupying 1 m^3 at t °C	Occupying 1 ml at t °C
		kg/m^3	g/ml
600 to 1 100	0,6 to 1,1	− 1,1	− 0,001 1
1 200 to 1 700	1,2 to 1,7	− 1,0	− 0,001 0
1 800 to 2 000	1,8 to 2,0	− 0,9	− 0,000 9

NOTES

3 These figures are based on 1,217 kg/m^3 and 8 136 kg/m^3, the densities of the atmosphere and of the weights used.

4 The equivalence of the cubic decimetre and the litre (1964 CGPM definition) is assumed.

When the temperature of observation of the density is not the same as the temperature at which the volume of the liquid is required or measured, the expansion or contraction of the liquid between the two temperatures must be taken into account. The volume $V_{t'}$ at t' °C can be obtained from V_t (found as indicated above) by using the relationship :

$$V_{t'} = V_t [1 + \gamma (t' - t)]$$

where γ is the mean coefficient of cubical thermal expansion of the liquid over the temperature range t to t' °C.

Similarly, when the total apparent mass W is required, the density being known at t °C and the total volume $V_{t'}$ at t' °C, then the volume V_t at t °C can be found from $V_{t'}$ by dividing it by $1 + \gamma (t' - t)$.

6 Vessels for hydrometer observations

For all liquids, a cylindrical hydrometer vessel is normally suitable, but for results of the highest precision of liquids of high surface tension an overflow vessel should be used so that the surface film can be removed.

6.1 Cylindrical vessels

The cylinder should stand firmly on its base and should be free from local irregularities producing distortion. In table 6, the capacities of suitable graduated cylinders complying with ISO 4788, are given. Graduated, or preferably ungraduated, cylinders of these sizes will doubtless be available to hydrometer users. Larger cylinders are of course at least equally satisfactory when sufficient liquid is available. Shorter cylinders can be used when the length of the hydrometer is not near the maximum permitted, or when the scale reading is not near the top of the stem. The diameter of the cylinder employed should be several millimetres (preferably at least 10 mm) greater than the hydrometer bulb diameter.

Table 6 — ISO 4788 — Cylinders suitable for observations on ISO hydrometers

Hydrometer series	Maximum bulb diameter	Maximum length of hydrometer to top graduation mark	Nominal capacity of cylinder
	mm	mm	ml
L20	40	320	1 000
L50 and L50SP	27	320	1 000
M50 and M50SP	24	255	500
M100	20	235	250
S50 and S50SP	20	175	250

6.2 Overflow vessels

Overflow vessels suitable for hydrometers are shown in figure 1. The internal diameter of the vessel and the distance of the overflow level from the top and bottom of the vessel should be kept within the limiting values shown, but small variations in the remaining dimensions are unimportant. The vessels illustrated can be made easily from glass tubing; they require a stand to hold them. Type A is suitable for series L20 and L50, type B for series M100 and type C for series S50 hydrometers.

7 Density of air-free distilled water

Although the density of water at 4 °C is not a fundamental quantity in the International System of Units, water is still used as a standard substance for precise volume and density measurements. The tables for the density of water used up to now, based on the International Practical Temperature Scale of 1948 and on the litre in the definition valid up to 1964, have been recalculated by Wagenbreth and Blanke using the unit of volume of the International System of Units and the International Practical Temperature Scale (1968) (IPTS-68).

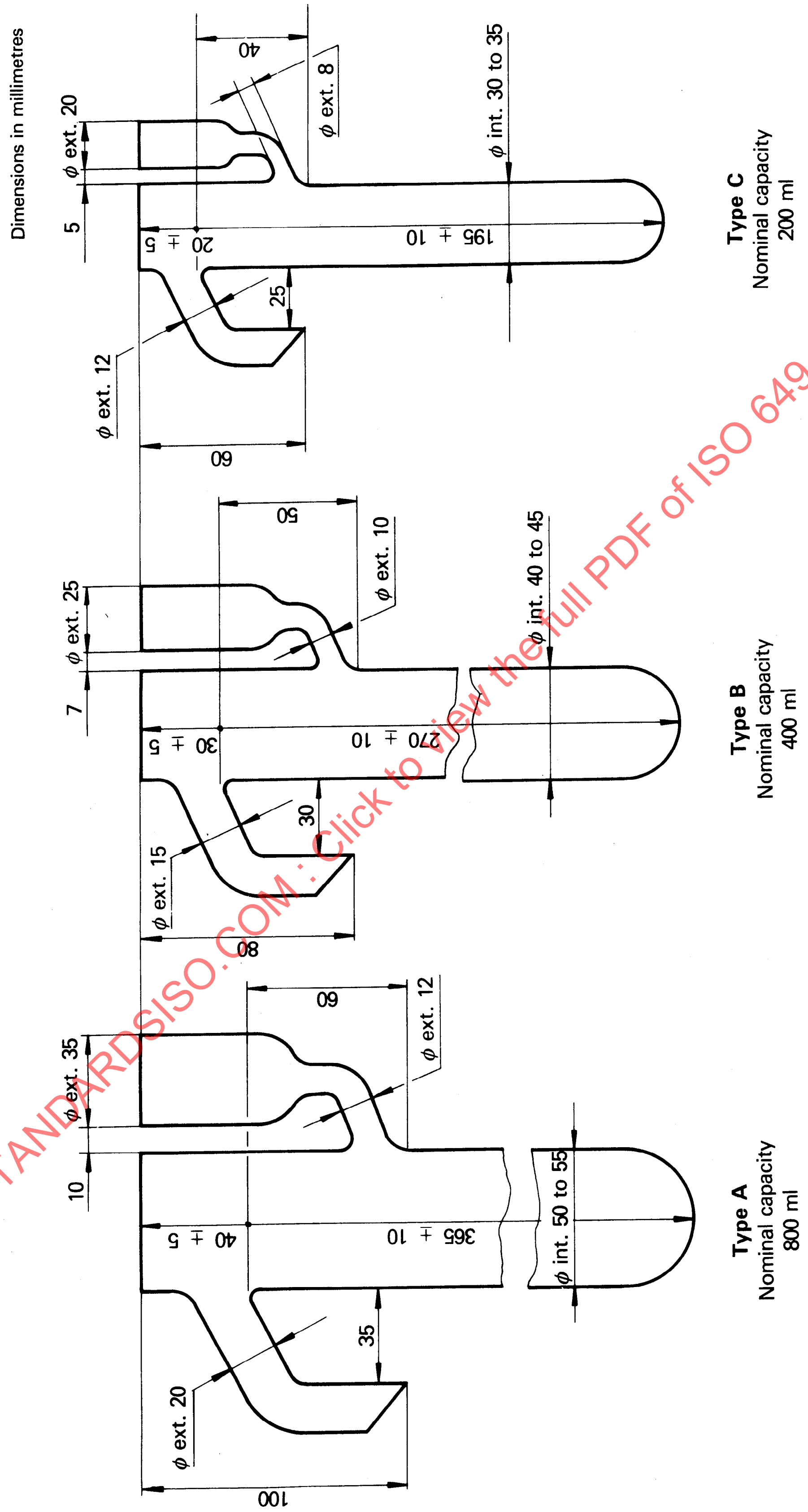

Figure — Overflow vessels suitable for observations on hydrometers