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**Determination of pH value —  
Reference buffer solutions for  
the calibration of pH measuring  
equipment**

*Détermination de la valeur pH — Solutions tampons de référence  
pour l'étalonnage des appareils de mesure du pH*

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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](http://www.iso.org/directives)).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 35, *Paints and varnishes*, Subcommittee SC 9, *General test methods for paints and varnishes*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

# Determination of pH value — Reference buffer solutions for the calibration of pH measuring equipment

## 1 Scope

This document specifies reference buffer solutions for the calibration of pH measuring equipment.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4793, *Laboratory sintered (fritted) filters — Porosity grading, classification and designation*

ISO 19396-1, *Paints and varnishes — Determination of pH value — Part 1: pH electrodes with glass membrane*

ISO 80000-9, *Quantities and units — Part 9: Physical chemistry and molecular physics*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 80000-9 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

### 3.1

#### pH

measure for the acidic or basic character of an aqueous solution

Note 1 to entry: Notation of pH: the "p" and the "H" are upright on one line.

Note 2 to entry: The acidic character is determined by the activity of the existing "hydrogen ions".

### 3.2

#### pH value

decimal logarithm of the hydrogen ion activity multiplied with (-1)

$$\text{pH} = -\lg \left( \frac{a_{\text{H}^+}}{m^0} \right) = -\lg \left( \frac{m_{\text{H}^+} \cdot \gamma_{m,\text{H}^+}}{m^0} \right)$$

where

- $a_{\text{H}^+}$  is the activity of the hydrogen ion, in mol/kg;
- $m^0$  is the standard molality (1 mol/kg);
- $\gamma_{m,\text{H}^+}$  is the activity coefficient of the hydrogen ion;
- $m_{\text{H}^+}$  is the molality of the hydrogen ion, in mol/kg.

Note 1 to entry: Molality is understood as moles per kilogram solvent.

Note 2 to entry: The pH value is not measurable as a measure of a single ion activity. Therefore, pH(PR) values of solutions of primary reference material are determined, which are approximate to it and can be attributed to it. This is based on a worldwide agreement, see ISO 80000-9:2009, Annex C.

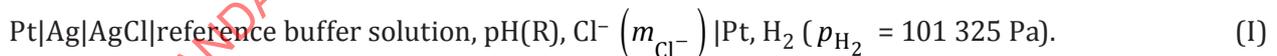
## 4 Basic information

### 4.1 General

Reference buffer solutions are prepared using primary or secondary reference materials. The pH values of the reference buffer solutions are determined using the methods described in 4.2 and 4.3. The pH value of a reference buffer solution and the associated uncertainty of measurement are documented in a calibration certificate as the result of calibration. pH values of primary reference buffer solutions form the basis of pH measurements in practice and are generally determined by national metrology institutes. Secondary reference buffer solutions are commercially available. The reference buffer solutions prepared according to the methods described in Clause 5 serve as a material measure of the pH value.

### 4.2 pH values of primary reference buffer solutions

The pH value based upon the activity of single ions according to the formula in 3.2 cannot be measured. The pH value is assigned to reference buffer solutions outlined in Table 1. This is achieved using an electrochemical method of measurement that is based on the thermodynamic dependence of the potential of the platinum/hydrogen electrode on the hydrogen ion activity. Through the use of cells without transference, diffusion voltages arising from liquid junctions do not appear and therefore do not need to be considered when calculating the voltage of the cell. The cell (I) for this purpose shall consist of a platinum/hydrogen and a silver/silver chloride electrode, immersed in the reference buffer solution to which chloride in a low concentration ( $m_{\text{Cl}^-}$ ) has been added.



The pH value of the reference buffer solution is calculated according to Formula (1):

$$\text{pH} = \lim_{m_{\text{Cl}^-} \rightarrow 0} \left[ \frac{(E - E^0)}{k} + \lg \left( \frac{m_{\text{Cl}^-}}{m^0} \right) \right] + \lg \gamma_{\text{Cl}^-} \quad (1)$$

where

- $E$  is the voltage of cell (I);
- $E^0$  is the standard potential of the Ag/AgCl electrode;
- $k$  is the Nernst slope ( $k = RT(\ln 10) / F$ );

- $m^0$  is the standard molality (1 mol/kg);
- $m_{\text{Cl}^-}$  is the molality of the chloride ions in the solution;
- $\gamma_{\text{Cl}^-}$  is the activity coefficient of the chloride ion.

Chloride is added to the reference buffer solution in a minimum of three different molalities less than or equal to 0,02 mol/kg. To calculate the pH value,  $m_{\text{Cl}^-} \rightarrow 0$  is extrapolated according to [Formula \(1\)](#).

The activity coefficient of the chloride ions is estimated according to [Formula \(2\)](#) for solutions with an ionic strength of less than or equal to 0,1 mol/kg<sup>[2]</sup>.

$$\lg \gamma_{\text{Cl}^-} = -\frac{AI^{1/2}}{1 + 1,5(I/m^0)^{1/2}} \quad (2)$$

where

- $A$  is the Debye-Hückel constant;
- $\gamma_{\text{Cl}^-}$  is the activity coefficient of the chloride ion;
- $m^0$  is the standard molality (1 mol/kg);
- $I$  is the ionic strength.

pH values of primary reference buffer solutions are often referred to as pH(R) (R = Reference). The expanded uncertainty of measurement  $U(\text{pH})$  when determining a pH(R) value has been shown to be 0,002 to 0,005 at 25 °C depending on the primary reference buffer solution. As agreed, this uncertainty of measurement does not take into consideration the uncertainty of the Bates-Guggenheim convention for estimating the ionic activity of the chloride ion [see [Formula \(2\)](#)]<sup>[3]</sup>.

The expanded uncertainty of measurement of many pH(R) value measurements of primary reference buffer solutions prepared according to [Clause 5](#) is  $U(\text{pH}) = 0,005$  at 25 °C and  $U(\text{pH}) = 0,008$  at 50 °C, due to the method of measurement and the purity and homogeneity of the materials used for different batches depending on the buffer solution. Accordingly, the pH(R) values of each batch can vary. Therefore, the pH(R) value is only valid for an individual batch with a corresponding calibration certificate. For buffer solution G, the expanded uncertainty of measurement of the pH(R) values is  $U(\text{pH}) = 0,006$  at 25 °C and  $U(\text{pH}) = 0,01$  for temperatures higher than 25 °C<sup>[4]</sup>. Contributions to uncertainty are a result of the method of measurement used as well as the purity and homogeneity of the material used.

Typical pH values of reference buffer solutions for the temperature range of 0 °C to 50 °C are given in [Table 1](#).

### 4.3 pH values of secondary reference buffer solutions

The differential potentiometric method<sup>[5]</sup> is suitable for determining the pH values of secondary reference buffer solutions using primary reference buffer solutions with the same chemical composition. The isothermal cell used for this purpose (II) shall consist of two electrodes separated by a P 40 glass frit given in ISO 4793, and containing the primary and secondary standard buffer solutions and identical platinum hydrogen electrodes at exactly the same hydrogen pressure, i.e.



The cell voltage  $E$  of cell (II) is a measure of the difference in the pH values of the solutions and enables the pH(R) value of the secondary reference buffer solution to be determined using [Formula \(3\)](#), provided the absolute difference is  $|\text{pH(R)} - \text{pH}| \leq 0,02$  and the pH of the solutions is between 3 and 11.

The diffusion voltage is then less than 10 % of the measured cell voltage and the cell is virtually without transference.

$$\text{pH} = \text{pH(R)} - E / k \quad (3)$$

where

$k$  is the Nernst slope ( $k = RT(\ln 10) / F$ );

$E$  is the voltage of cell (II).

Measured cell voltages are in the order of magnitude of a few hundred microvolts ( $\mu\text{V}$ ). Consequently, pH differences down to 0,001 can be determined. The expanded uncertainty of measurement  $U$  of the pH value of the secondary reference buffer solution ranges from 0,003 to 0,006 at 25 °C when determining a single pH value depending on the type of secondary reference buffer solution, and is only slightly greater than that of the pH(R) values of primary reference buffer solutions determined using cell (I).

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Table 1 — Typical values of primary and secondary reference buffer solutions

Reference buffer solution	A	B	C	D	E	F	G	H	I
Buffer material	Potassium tetraoxalate dihydrate $\text{KH}_3(\text{C}_2\text{O}_4)_2 \cdot 2 \text{H}_2\text{O}$	Potassium hydrogen tartrate $\text{KHC}_4\text{H}_4\text{O}_6$	Potassium hydrogen phthalate $\text{KHC}_8\text{H}_4\text{O}_4$	Potassium dihydrogen phosphate + Disodium hydrogen phosphate $\text{KH}_2\text{PO}_4$ + $\text{Na}_2\text{HPO}_4$	Potassium dihydrogen phosphate + Disodium hydrogen phosphate $\text{KH}_2\text{PO}_4$ + $\text{Na}_2\text{HPO}_4$	Disodium tetraborate decahydrate $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}$	Calcium hydroxide $\text{Ca}(\text{OH})_2$	Potassium dihydrogen citrate $\text{KH}_2\text{C}_6\text{H}_5\text{O}_7$	Sodium carbonate + Sodium hydrogen carbonate $\text{Na}_2\text{CO}_3$ + $\text{NaHCO}_3$
Molality mol/kg	0,05	Saturated at 25 °C	0,05	0,025 $(\text{KH}_2\text{PO}_4)$ + 0,025 $(\text{Na}_2\text{HPO}_4)$	0,008 695 $(\text{KH}_2\text{PO}_4)$ + 0,030 43 $(\text{Na}_2\text{HPO}_4)$	0,01	Saturated at 25 °C	0,05	0,025 $(\text{Na}_2\text{CO}_3)$ + 0,025 $(\text{NaHCO}_3)$
Temperature °C	<b>pH(R) values</b>								
0	1,666	—	4,000	6,984	7,534	9,464	—	3,863	10,317
5	1,668	—	3,998	6,951	7,500	9,395	13,207	3,840	10,245
10	1,670	—	3,997	6,923	7,472	9,332	13,003	3,820	10,179
15	1,672	—	3,998	6,900	7,448	9,276	12,810	3,802	10,118
20	1,675	—	4,000	6,881	7,429	9,225	12,627	3,788	10,062
25	1,679	3,557	4,005	6,865	7,413	9,180	12,454	3,776	10,012

Table 1 (continued)

Reference buffer solution	A	B	C	D	E	F	G	H	I
Temperature °C	pH(R) values								
30	1,683	3,552	4,011	6,853	7,400	9,139	12,289	3,766	9,966
35	1,688	3,549	4,018	6,844	7,389	9,102	12,133	3,759	9,926
37	—	3,548	4,022	6,841	7,386	9,088	—	3,756	9,910
38	1,691	—	—	—	—	—	12,043	—	—
40	1,694	3,547	4,027	6,838	7,380	9,068	11,984	3,754	9,889
45	—	—	—	—	—	—	11,841	—	—
50	1,707	3,549	4,050	6,833	7,367	9,011	11,705	3,749	9,828

NOTE The data for buffers A and G are taken from Reference [4] and the data for the buffers B, C, D, E, F, H and I are taken from Reference [6].

Working reference buffer solutions for use in daily practice are measured in accordance with ISO 19396-1 and characterized with regard to measurement uncertainty.

Examples of pH(R) values as a function of temperature at temperatures from 55 °C to 95 °C are shown in [Annex A](#).

## 5 Preparation of primary and secondary reference buffer solutions

### 5.1 General

The reference buffer solutions in [Table 1](#) form the basis of practical pH measurements. They are prepared gravimetrically according to the following guidelines using reference materials appropriate for use in pH reference buffer solutions.

The pH value of reference buffer solutions prepared according to [5.2](#) to [5.10](#) shall be determined with one of the methods given above (see [4.2](#) and [4.3](#)) or a similar method.

The numbers given for pH(R) values are designations of the particular reference buffer solutions and are to be understood as names. Consequently, they can differ from those given in [Table 1](#). The values stated on the calibration certificates of the reference materials are binding.

When preparing the saturated solutions (see [5.3](#) and [5.8](#)) care shall be taken that a temperature of  $(25,0 \pm 0,5)$  °C is maintained.

Fully desalinated water shall be used. For solutions of pH > 7 CO<sub>2</sub>-free water shall be used.

For the description of the volumetric methods used to prepare the reference buffer solutions, see [Annex B](#).

### 5.2 Reference buffer solution A, pH(R) = 1,67<sub>9</sub><sup>1)</sup> (25 °C), Potassium tetraoxalate dihydrate

Dissolve 12,74 g of potassium tetraoxalate dihydrate,  $\text{KH}_3(\text{C}_2\text{O}_4)_2 \cdot 2 \text{H}_2\text{O}$ , in 1 000 g water.

### 5.3 Reference buffer solution B, pH(R) = 3,55<sub>7</sub> (25 °C), Potassium hydrogen tartrate

Add 6,40 g of potassium hydrogen tartrate,  $\text{KHC}_4\text{H}_4\text{O}_6$ , to 1 000 g water. After shaking or stirring vigorously until the solution is saturated, filter off the excess salt.

These solutions tend to be affected by fungal infestation and a fresh batch shall be prepared every day.

### 5.4 Reference buffer solution C, pH(R) = 4,00<sub>5</sub> (25 °C), Potassium hydrogen phthalate

Dry potassium hydrogen phthalate,  $\text{KHC}_8\text{H}_4\text{O}_4$ , for 2 h at 110 °C. Dissolve 10,21 g of this material in 1 000 g water. The solution has a shelf life of approximately 6 weeks. Solutions affected by fungal infestation shall not be used.

### 5.5 Reference buffer solution D, pH(R) = 6,86<sub>5</sub> (25 °C), Phosphate

Dry anhydrous potassium dihydrogen phosphate,  $\text{KH}_2\text{PO}_4$ , and anhydrous disodium hydrogen phosphate,  $\text{Na}_2\text{HPO}_4$ , for 2 h at 110 °C. Dissolve 3,40 g of potassium dihydrogen phosphate and 3,55 g of disodium hydrogen phosphate in 1 000 g water.

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1) The last digit is not significant and therefore printed as subscript.

### 5.6 Reference buffer solution E, $\text{pH(R)} = 7,41_3$ (25 °C), Phosphate

Dry anhydrous potassium dihydrogen phosphate,  $\text{KH}_2\text{PO}_4$ , and anhydrous disodium hydrogen phosphate,  $\text{Na}_2\text{HPO}_4$ , for 2 h at 110 °C. Dissolve 1,184 g of potassium dihydrogen phosphate and 4,322 g of disodium hydrogen phosphate in 1 000 g water.

### 5.7 Reference buffer solution F, $\text{pH(R)} = 9,18_0$ (25 °C), Borax

Dissolve 3,82 g of disodium tetraborate decahydrate,  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}$ , in 1 000 g water.

### 5.8 Reference buffer solution G, $\text{pH(R)} = 12,45_4$ (25 °C), Calcium hydroxide

Add 5 g of calcium hydroxide,  $\text{Ca(OH)}_2$ , to 1 000 g water. After shaking or stirring vigorously until the solution is saturated, filter off the excess calcium hydroxide. The solution is very sensitive to  $\text{CO}_2$  and shall be discarded if it becomes turbid.

### 5.9 Reference buffer solution H, $\text{pH(R)} = 3,77_6$ (25 °C), Potassium dihydrogen citrate

Dry anhydrous potassium dihydrogen citrate,  $\text{KH}_2\text{C}_6\text{H}_5\text{O}_7$ , for 24 h over dry calcium chloride at ambient temperature. Dissolve 11,51 g of potassium dihydrogen citrate in 1 000 g water.

### 5.10 Reference buffer solution I, $\text{pH(R)} = 10,01_2$ (25 °C), Sodium carbonate/sodium hydrogen carbonate

Dry anhydrous sodium carbonate,  $\text{Na}_2\text{CO}_3$ , for 2 h at 250 °C and then store over dry calcium chloride. Dry sodium hydrogen carbonate,  $\text{NaHCO}_3$ , for two days over a molecular sieve. Dissolve 2,65 g of sodium carbonate and 2,10 g of sodium hydrogen carbonate in 1 000 g water.

## 6 Storage and shelf life

Guidelines from the manufacturer should be followed.

## 7 Examples of $\text{pH(R)}$ values of reference buffer solutions

[Table 1](#) lists examples of  $\text{pH(R)}$  values for primary reference buffer solutions as a function of temperature.

## 8 Additional properties of reference buffer solutions

[Table 2](#) lists some of the additional properties of the reference buffer solutions. For a definition of the buffer capacity,  $\beta$ , and the effect of dilution, see DIN 19261<sup>[8]</sup>.

Table 2 — Properties of reference buffer solutions

Reference buffer solution	Molality mol·kg <sup>-1</sup>	Buffer capacity, $\beta$ mol·l <sup>-1</sup>	Effect of dilution	Temperature dependence <sup>a</sup> at 25 °C K <sup>-1</sup>
A	0,05 (KH <sub>3</sub> (C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub> ·2 H <sub>2</sub> O)	0,070	+0,186	+0,001
B	0,034 (KHC <sub>4</sub> H <sub>4</sub> O <sub>6</sub> ) saturated at 25 °C	0,027	+0,049	-0,001 4
H	0,05 (K <sub>3</sub> C <sub>6</sub> H <sub>5</sub> O <sub>7</sub> )	0,034	+0,024	-0,002 2
C	0,05 (KHC <sub>8</sub> H <sub>4</sub> O <sub>4</sub> )	0,016	+0,052	+0,001 2
D	0,025 (KH <sub>2</sub> PO <sub>4</sub> ) 0,025 (Na <sub>2</sub> HPO <sub>4</sub> )	0,029	+0,080	-0,002 8
E	0,008 695 (KH <sub>2</sub> PO <sub>4</sub> ) 0,030 43 (Na <sub>2</sub> HPO <sub>4</sub> )	0,016	+0,07	-0,002 8
F	0,01 (Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·10 H <sub>2</sub> O)	0,020	+0,01	-0,008 2
I	0,025 (Na <sub>2</sub> CO <sub>3</sub> ) 0,025 (NaHCO <sub>3</sub> )	0,029	+0,079	-0,009 6
G	0,02 Ca(OH) <sub>2</sub> saturated at 25 °C	0,09	-0,28	-0,033

<sup>a</sup> (dpH/dT).

NOTE The data on buffers is taken from Reference [Z].

## Annex A (informative)

### Examples of pH(R) values as a function of temperature at temperatures from 55 °C to 95 °C

Table A.1 lists examples of pH(R) values as a function of temperature at temperatures from 55 °C to 95 °C<sup>[4]</sup>. They are intended for guidance only since such values have not been recorded in calibration certificates and related to a particular batch.

**Table A.1 — Examples of pH(R) values of reference buffer solutions as a function of temperature at temperatures from 55 °C to 95 °C**

Reference buffer solution	A	B	C	D	F	G
	Potassium tetraoxalate dihydrate	Potassium hydrogen tartrate	Potassium hydrogen phthalate	Potassium dihydrogen phosphate + Disodium hydrogen phosphate	Disodium tetraborate decahydrate	Calcium hydroxide
Molality mol·kg <sup>-1</sup>	0,05	Saturated at 25 °C	0,05	0,025 (KH <sub>2</sub> PO <sub>4</sub> ) 0,025 (Na <sub>2</sub> HPO <sub>4</sub> )	0,01	Saturated at 25 °C
Temperature °C	pH(R) values					
55	1,715	3,554	4,075	6,834	8,985	11,574
60	1,723	3,560	4,091	6,836	8,962	11,449
70	1,743	3,580	4,126	6,845	8,921	—
80	1,766	3,609	4,164	6,859	8,885	—
90	1,792	3,650	4,205	6,877	8,850	—
95	1,806	3,674	4,227	6,886	8,833	—