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Buffer Standards for the Physiological pH of the Zwitterionic Compound, DIPSO from 5 to 55°C

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Abstract

The values of the second dissociation constant, pK_2 , and related thermodynamic quantities of 3-[N,N-bis (2-hydroxyethyl)amino]-2-hydroxypropanesulfonic acid (DIPSO) have already been reported over the temperature range 5 to 55°C including 37°C. This paper reports the pH values of four NaCl-free buffer solutions and four buffer composition containing NaCl salt at $I = 0.16 \text{ mol} \cdot \text{kg}^{-1}$. Conventional p_{aH} values are reported for all eight buffer solutions. The operational pH values have been calculated for four buffer solutions recommended as pH standards, at 25 and 37°C after correcting the liquid junction potentials with the flowing junction cell.

Keywords

Buffers; DIPSO; Liquid junction; Ionic strength; Emf; Zwitterions; pH; Acidity function

1 Introduction

In order to obtain pH values for standard buffer solutions, it is useful to know the values of pK_2 of the buffer compound DIPSO. Recently, the pK_2 values of 3-[N,N-bis (2-hydroxyethyl) amino]-2-hydroxypropanesulfonic acid (DIPSO) [1] have been reported at temperatures from 5 to 55°C including 37°C. The structure of DIPSO is as follows:

3-[N,N-bis (2-hydroxyethyl)amino]-2-hydroxypropanesulfonic acid (DIPSO)

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This zwitterionic compound can be used as a physiological buffer for clinical fluids [2–3]. The pH of the NIST/NBS certified [4] physiological phosphate primary standard buffer is 7.415 at 25°C and 7.395 at 37°C.

There are some disadvantages [4–6] concerning the use of the phosphate buffer as an ideal pH standard for physiological fluids: (i) phosphates precipitate some polyvalent cations in the blood constituents such as Mg^{+2} and Ca^{+2} , (ii) may also act as an inhibitor to enzymatic processes, and (iii) the temperature coefficient -0.0028 pH unit / °C does not closely approximate to the whole blood (-0.015 pH unit/°C) [5–6].

Wu and coworkers [7] have published the values of $\text{p}K_2$ and pH of the zwitterionic buffer N-(2-hydroxyethyl)piperazine-N-2-ethanesulfonic acid (HEPES). For two-point calibrations of pH measurements for physiological fluids, 3-(N-morpholino)-2-hydroxypropanesulfonic acid (MOPSO), has been studied by Wu et al. [6]. In 1973, the use of tris(hydroxymethyl)methylglycine (TRICINE) was suggested by Bates et al. [8–9] as a buffer standard for the physiological range of pH 7.2 to 8.5. The pH of 0.06 *m* TRICINE + 0.02 *m* sodium TRICINate buffer solution at 37°C is 7.407, matching very closely the pH of blood. In 1978, Bates et al. [10] also reported pH values of 2-amino-2-(hydroxymethyl)-1,3-propanediol (TRIS), N-tris-(hydroxymethyl) methyl-2-aminoethanesulfonic acid (TES), and N-(2-hydroxyethyl)piperazine-N'-2-ethanesulfonic acid (HEPES) for $I = 0.16$ mol·kg⁻¹ at 25 and 37 °C. Roy et al. [11] reported results for $\text{p}K_2$ and pH for 3-(N-morpholino)propanesulfonic acid (MOPS) in the temperature range 5 to 55°C. A glass-electrode pH meter assembly can be standardized by using the pH values of the standard buffer solutions with compositions: 0.08 *m* MOPS + 0.08 *m* NaMOPSate + 0.08 *m* NaCl. In 1976, Carmen and Vega [13] published $\text{p}K_2$ values of 2-[N-morpholino]ethanesulfonic acid (MES), and N, N-bis-[2-hydroxyethyl]-2-aminoethanesulfonic acid (BES) at 5 to 55°C. The pH of these solutions closely matches that of the common biological media. In a continuation of research in this area, Roy et al. [1] have reported the second dissociation constants, $\text{p}K_2$ and related thermodynamic quantities for buffer systems of DIPSO. Goldberg et al. [12], in their comprehensive review of the thermodynamic quantities of the biological buffers, indicated that no reliable data on $\text{p}K_2$ are available for the DIPSO buffer.

In order to provide reliable pH values as standards in the pH region close to that of blood serum, we have now examined the buffer compound, DIPSO, with the following compositions in units of molality *m*, where $m = \text{mol} \cdot \text{kg}^{-1}$:

- a. DIPSO (0.02 mol·kg⁻¹) + NaDIPSO (0.02 mol·kg⁻¹), $I = 0.02$ mol·kg⁻¹
- b. DIPSO (0.04 mol·kg⁻¹) + NaDIPSO (0.04 mol·kg⁻¹), $I = 0.04$ mol·kg⁻¹
- c. DIPSO (0.06 mol·kg⁻¹) + NaDIPSO (0.06 mol·kg⁻¹), $I = 0.06$ mol·kg⁻¹
- d. DIPSO (0.08 mol·kg⁻¹) + NaDIPSO (0.08 mol·kg⁻¹), $I = 0.08$ mol·kg⁻¹
- e. DIPSO (0.08 mol·kg⁻¹) + Na-DIPSO (0.08 mol·kg⁻¹) + NaCl (0.08 mol·kg⁻¹), $I = 0.16$ mol·kg⁻¹
- f. DIPSO (0.06 mol·kg⁻¹) + Na-DIPSO (0.06 mol·kg⁻¹) + NaCl (0.10 mol·kg⁻¹), $I = 0.16$ mol·kg⁻¹
- g. DIPSO (0.04 mol·kg⁻¹) + Na-DIPSO (0.04 mol·kg⁻¹) + NaCl (0.12 mol·kg⁻¹), $I = 0.16$ mol·kg⁻¹
- h. DIPSO (0.02 mol·kg⁻¹) + Na-DIPSO (0.02 mol·kg⁻¹) + NaCl (0.14 mol·kg⁻¹), $I = 0.16$ mol·kg⁻¹

The preparations of these buffer solutions for DIPSO are described under the experimental section.

2 Experimental

DIPSO was obtained from Sigma Chemical Co. (St. Louis, Missouri). The details of the purification by further crystallization as well as the determinations of the assay have been reported in earlier papers [1]. The assays showed that the DIPSO was $(99.94 \pm 0.03) \%$ pure. All buffer solutions were prepared by weighted amounts of DIPSO, NaCl, standard solutions of NaOH in quantity sufficient to prepare NaDIPSO, and calculated amounts of CO₂-free doubly distilled water. Vacuum corrections were applied to all weighings.

The preparation of the hydrogen electrodes and the silver-silver chloride electrodes of the thermal electrolytic type whose design and function have been previously described [1,12, 18]. The errors due to residual liquid junction effects are nearly eliminated if the ionic strength of the physiological phosphate standard buffer is matched with that of the buffer solution as noted in the previous paper (HEPES) in this issue. A correction for the liquid-junction potential has been made.

Three cell types were employed in the present investigation. The schematic diagram of the Harned-type cell is given below:

where the molalities m_1 , m_2 , and m_3 indicate the respective species, and 1 atm = 101.325 kPa in SI units. The cell (B) is the flowing junction cell.

For cell (C), the NIST/NBS physiological phosphate buffer was used. This primary reference, as previously mentioned in the HEPES paper in this issue, was used. The schematic design of cell (C) is:

The values of the standard electrode potential, E°_{SCE} , and of the saturated calomel electrode were taken as: -0.2415 V, and -0.2335 V at 25 and 37°C [14–17], respectively. The value of the liquid junction potential, E_j , was obtained [7,11–12] by employing a flowing junction cell. The values of E_j for the physiological phosphate as well as for the other buffer solutions for cell (B) were calculated using the following equation [6–7,11]:

$$E_j = E + E^\circ_{\text{SCE}} - k \text{ pH}, \quad (1)$$

where $k = 0.059156$ (as defined in the HEPES paper of this issue) and $\text{pH} = 7.415$ (physiological phosphate buffer solution) at 25°; $k = 0.061538$ and $\text{pH} = 7.395$ at 37°C. The operational definition of pH, namely pH (x), is:

$$\text{pH}(x) = \text{pH}(s) + \frac{E_x - E_s - \delta E_j}{k}, \quad (2)$$

where x refers to the unknown buffers (DIPSO + NaDIPSO), s is the primary standard reference solution (NBS/NIST physiological phosphate buffer) of known pH, and $\delta E_j = E_{j(s)} - E_{j(x)}$. If

the residual liquid junction-potential is assumed to be zero for the glass electrode pH meter assembly, then Eq. (2) reduces to

$$pH(x) = pH(s) + \frac{E_x - E_s}{k} \quad (3)$$

3. Methods and Results

Accurate values of the second dissociation constants, pK_2 , and related thermodynamic quantities have been reported earlier [1]. The emf values for cell (A) containing four equimolar chloride ion-free buffer solutions, and four buffer solutions in which NaCl had been added to make $I = 0.16 \text{ mol} \cdot \text{kg}^{-1}$, have been corrected to a hydrogen pressure of 1 atm. The values of the emf at 25°C are the average of at least two readings (at the beginning and the middle) and sometimes at the end of the temperature sequence. The silver-silver chloride electrodes were used throughout the experiments in order to determine pH values of buffer solutions. Duplicate cells usually gave a reading on the average within $(0.02 \pm 0.01) \text{ mV}$ in the temperature range 5 to 55 °C. All these results are listed in Table 1 and Table 2, respectively.

3.1 The pH of DIPSO Buffer

The values of the pa_H for all buffer solutions were calculated using the method [7,9–12]. The specific compositions are listed in the introduction. Values of the acidity function $p(a_H\gamma_{Cl})$ and pa_H were derived at from the following equation:

$$p(a_H\gamma_{Cl}) = \frac{E - E^\circ}{k} + \log m_{Cl} \quad (4)$$

where k is the Nernst slope.

$$pa_H = p(a_H\gamma_{Cl})^\circ + \log \gamma_{Cl}^\circ \quad (5)$$

The selection of a reasonable estimate of γ_{Cl} for the calculation of pa_H by Eq. (5) has been described elsewhere [6–7,10–12,18]. The pH values obtained from the liquid junction cell are designated as pH, the ‘conventional’ pH is designated as pa_H . A convention [12] based on an extended Debye-Hückel equation was used for the calculation of $\log \gamma_{Cl}^\circ$ with the following form:

$$\log \gamma_{Cl}^\circ = - \frac{A \sqrt{I}}{1 + Ba^\circ \sqrt{I}} + CI \quad (6)$$

The empirical equation for the calculation of the parameter C [11] is given below:

$$C = C_{25} + 6.2 \times 10^{-4}(t - 25) - 8.7 \times 10^{-6}(t - 25)^2 \quad (7)$$

where $C_{25} = 0.032$ [11].

The values of $p(a_H\gamma_{Cl})^\circ$ and $p(a_H\gamma_{Cl})$ are listed in Table 3 and Table 4, respectively. The values of pa_H , listed in Table 5–Table 6, for buffer solutions of DIPSO without and with NaCl were computed from Eq. (4)–Eq. (7) and are represented by the following equations:

$$\text{For DIPSO (0.02 mol} \cdot \text{kg}^{-1}\text{)+NaDIPSO (0.02 mol} \cdot \text{kg}^{-1}\text{)} \\ \text{p}a_{\text{H}}=7.374 - 1.7847 \times 10^{-2}(t - 25)+5.14 \times 10^{-5}(t - 25)^2 \quad (8)$$

$$\text{For DIPSO (0.04 mol} \cdot \text{kg}^{-1}\text{)+NaDIPSO (0.04 mol} \cdot \text{kg}^{-1}\text{)} \\ \text{p}a_{\text{H}}=7.453 - 1.8420 \times 10^{-2}(t - 25)+5.00 \times 10^{-5}(t - 25)^2 \quad (9)$$

$$\text{For DIPSO (0.06 mol} \cdot \text{kg}^{-1}\text{)+NaDIPSO (0.06 mol} \cdot \text{kg}^{-1}\text{)} \\ \text{p}a_{\text{H}}=7.461 - 1.8530 \times 10^{-2}(t - 25)+5.62 \times 10^{-5}(t - 25)^2 \quad (10)$$

$$\text{For DIPSO (0.08 mol} \cdot \text{kg}^{-1}\text{)+NaDIPSO (0.08 mol} \cdot \text{kg}^{-1}\text{)} \\ \text{p}a_{\text{H}}=7.465 - 1.8480 \times 10^{-2}(t - 25)+5.03 \times 10^{-5}(t - 25)^2 \quad (11)$$

$$\text{For DIPSO (0.08 mol} \cdot \text{kg}^{-1}\text{)+NaDIPSO (0.08 mol} \cdot \text{kg}^{-1}\text{)+NaCl (0.08 mol} \cdot \text{kg}^{-1}\text{)} \\ \text{p}a_{\text{H}}=7.475 - 1.8848 \times 10^{-2}(t - 25)+5.12 \times 10^{-5}(t - 25)^2 \quad (12)$$

$$\text{For DIPSO (0.06 mol} \cdot \text{kg}^{-1}\text{)+NaDIPSO (0.06 mol} \cdot \text{kg}^{-1}\text{)+NaCl (0.10 mol} \cdot \text{kg}^{-1}\text{)} \\ \text{p}a_{\text{H}}=7.483 - 1.8411 \times 10^{-2}(t - 25)+4.37 \times 10^{-5}(t - 25)^2 \quad (13)$$

$$\text{For DIPSO (0.04 mol} \cdot \text{kg}^{-1}\text{)+NaDIPSO (0.04 mol} \cdot \text{kg}^{-1}\text{)+NaCl (0.12 mol} \cdot \text{kg}^{-1}\text{)} \\ \text{p}a_{\text{H}}=7.490 - 1.8765 \times 10^{-2}(t - 25)+5.21 \times 10^{-5}(t - 25)^2 \quad (14)$$

$$\text{For DIPSO (0.02 mol} \cdot \text{kg}^{-1}\text{)+NaDIPSO (0.02 mol} \cdot \text{kg}^{-1}\text{)+NaCl (0.14 mol} \cdot \text{kg}^{-1}\text{)} \\ \text{p}a_{\text{H}}=7.496 - 1.8768 \times 10^{-2}(t - 25)+4.54 \times 10^{-5}(t - 25)^2 \quad (15)$$

where t is the temperature in °C. The standard deviations of regression for Eqs. (8–15) are: 0.0008, 0.0012, 0.0019, 0.0014, 0.0007, 0.0009, 0.0005, and 0.0007, respectively.

The values of pH at 25 and 37°C were also determined from cells with liquid-junction (cells B and C). The flowing junction cell was donated to the author's laboratory by the National Institute of Standards and Technology (NIST/NBS). The emf values of the cells (B) and (C) at 25 and 37°, are given in Table 7. Also, the values of the liquid junction potential E_j shown in Table 8 were obtained by using Eq. (1). Finally, the values of pH listed in Table 9 were obtained by using Eq. (2) and Eq. (3). The error in pH values can be attributed to the assumptions in the convention used for single-ion-activity coefficient calculation, as well as an error in liquid junction measurement. However, the excellent agreement between the calculated pH values and the values obtained from E_j corrections are within ± 0.002 pH units. The overall uncertainty for the pH values was estimated by combining the systematic

uncertainties due to (i) assumption for the calculation of the single-ion-activity coefficient (± 0.003 pH unit), (ii) extrapolation to $p(a_{H^+Cl})^\circ$ by plotting to $m_{Cl} = 0$, (iii) liquid junction potential measurement, and (iv) error in the experimental emf measurement (± 0.03 mV). It is evident from table 9 that the pH range lies in the physiological region, for all four buffer solutions of DIPSO. These are recommended as pH buffer standards in the range of biophysiological application.

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Table 1

Electromotive force of Cell A: Pt(s); H₂ (g, 1 atm) | DIPSO (*m*₁), NaDIPSO (*m*₂), NaCl (*m*₃) | AgCl(s), Ag(s)

<i>m</i> ₁ ^a	<i>m</i> ₂ ^a	<i>m</i> ₃ ^a	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C	45°C	50°C	55°C
0.02	0.02	0.005	0.79429	0.79596	0.79760	0.79897	0.80024	0.80137	0.80224	0.80264	0.80309	0.80394	0.80428	0.80471
0.02	0.02	0.010	0.77974	0.78120	0.78247	0.78333	0.78457	0.78527	0.78582	0.78609	0.78633	0.78678	0.78687	0.78706
0.02	0.02	0.015	0.77197	0.77319	0.77423	0.77489	0.77605	0.77649	0.77683	0.77701	0.77715	0.77729	0.77719	0.77724
0.02	0.02	0.020	0.76700	0.76814	0.76902	0.76972	0.77062	0.77112	0.77106	0.77115	0.77129	0.77137	0.77118	0.77111
0.04	0.04	0.005	0.79859	0.80016	0.80174	0.80295	0.80440	0.80533	0.80627	0.80655	0.80695	0.80760	0.80789	0.80831
0.04	0.04	0.010	0.78255	0.78325	0.78469	0.78563	0.78666	0.78732	0.78801	0.78814	0.78834	0.78873	0.78870	0.78881
0.04	0.04	0.015	0.77299	0.77369	0.77473	0.77547	0.77641	0.77687	0.77732	0.77742	0.77754	0.77772	0.77753	0.77747
0.04	0.04	0.020	0.76661	0.76683	0.76789	0.76850	0.76933	0.76966	0.77002	0.77008	0.77015	0.77024	0.76995	0.76979
0.06	0.06	0.005	0.79968	0.80133	0.80281	0.80418	0.80560	0.80623	0.80733	0.80765	0.80784	0.80862	0.80913	0.80966
0.06	0.06	0.010	0.78308	0.78457	0.78573	0.78674	0.78794	0.78817	0.78896	0.78919	0.78923	0.78969	0.78983	0.79009
0.06	0.06	0.015	0.77352	0.77480	0.77583	0.77665	0.77760	0.77776	0.77842	0.77846	0.77845	0.77870	0.77874	0.77862
0.06	0.06	0.020	0.76671	0.76770	0.76857	0.76931	0.77018	0.77014	0.77059	0.77068	0.77053	0.77072	0.77061	0.77059
0.08	0.08	0.005	0.80037	0.80214	0.80375	0.80500	0.80641	0.80735	0.80841	0.80852	0.80887	0.80954	0.80998	0.81051
0.08	0.08	0.010	0.78396	0.78541	0.78674	0.78768	0.78876	0.78940	0.79014	0.79014	0.79034	0.79072	0.79090	0.79113
0.08	0.08	0.015	0.77446	0.77573	0.77684	0.77762	0.77850	0.77895	0.77951	0.77948	0.77958	0.77979	0.77981	0.77990
0.08	0.08	0.020	0.76767	0.76881	0.76982	0.77044	0.77117	0.77152	0.77190	0.77184	0.77189	0.77198	0.77190	0.77186

^aUnits of *m*, mol·kg⁻¹

Table 2

Emf of the Cell A (in volts): Pt(s); H₂ (g, 1 atm) | DIPSO (*m*₁), NaDIPSO (*m*₂), NaCl (*m*₃) | AgCl(s), Ag(s)

<i>m</i> ₁ ^a	<i>m</i> ₂ ^a	<i>m</i> ₃ ^a	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C	45°C	50°C	55°C
0.08	0.08	0.08	0.73604	0.73665	0.73696	0.73726	0.73701	0.73688	0.73629	0.73611	0.73583	0.73520	0.73446	0.73351
0.06	0.06	0.10	0.73057	0.73127	0.73147	0.73151	0.73186	0.73156	0.73140	0.73102	0.73067	0.72972	0.72910	0.72812
0.04	0.04	0.12	0.72706	0.72756	0.72782	0.72775	0.72742	0.72711	0.72659	0.72631	0.72598	0.72513	0.72429	0.72321
0.02	0.02	0.14	0.72354	0.72402	0.72431	0.72420	0.72402	0.72352	0.72281	0.72242	0.72196	0.72111	0.72010	0.71896

^aUnits of *m*, mol·kg^{−1}

Table 3

$p(a_{\text{H}\gamma\text{Cl}})^\circ$ of (DIPSO + NaDIPSO) buffer solutions from 5 to 55°C, computed using Eq. (5)^a

$t(^{\circ}\text{C})$	0.02 <i>m</i> DIPSO + 0.02 <i>m</i> NaDIPSO <i>I</i> = 0.02 <i>m</i>	0.04 <i>m</i> DIPSO + 0.04 <i>m</i> NaDIPSO <i>I</i> = 0.04 <i>m</i>	0.06 <i>m</i> DIPSO + 0.06 <i>m</i> NaDIPSO <i>I</i> = 0.06 <i>m</i>	0.08 <i>m</i> DIPSO + 0.08 <i>m</i> NaDIPSO <i>I</i> = 0.08 <i>m</i>
5	7.813	7.920	7.944	7.955
10	7.712	7.817	7.842	7.853
15	7.618	7.720	7.741	7.755
20	7.523	7.622	7.645	7.657
25	7.433	7.533	7.556	7.568
30	7.346	7.441	7.459	7.476
35	7.262	7.355	7.375	7.391
37	7.230	7.320	7.341	7.353
40	7.180	7.268	7.286	7.300
45	7.105	7.187	7.207	7.219
50	7.024	7.105	7.128	7.139
55	6.948	7.028	7.052	7.063

^aUnits of *m*, mol·kg⁻¹

Table 4

$p(a_{\text{H}^+}\gamma_{\text{Cl}})$ of (DIPSO + NaDIPSO) buffer solutions from 5 to 55°C, computed using Eq. (4)^a

$t(^{\circ}\text{C})$	0.08 <i>m</i> DIPSO + 0.08 <i>m</i> NaDIPSO +0.08 <i>m</i> NaCl <i>I</i> = 0.16 <i>m</i>	0.06 <i>m</i> DIPSO + 0.06 <i>m</i> NaDIPSO +0.10 <i>m</i> NaCl <i>I</i> = 0.16 <i>m</i>	0.04 <i>m</i> DIPSO + 0.04 <i>m</i> NaDIPSO +0.12 <i>m</i> NaCl <i>I</i> = 0.16 <i>m</i>	0.02 <i>m</i> DIPSO + 0.02 <i>m</i> NaDIPSO +0.14 <i>m</i> NaCl <i>I</i> = 0.16 <i>m</i>
5	7.997	7.995	8.010	8.014
10	7.895	7.896	7.909	7.913
15	7.794	7.795	7.810	7.816
20	7.699	7.697	7.712	7.718
25	7.601	7.611	7.615	7.625
30	7.511	7.519	7.524	7.532
35	7.417	7.434	7.435	7.440
37	7.383	7.397	7.400	7.403
40	7.332	7.345	7.349	7.351
45	7.248	7.258	7.265	7.268
50	7.168	7.181	7.185	7.187
55	7.087	7.101	7.105	7.107

^aUnits of *m*, mol·kg⁻¹

Table 5Values of $\text{p}a_{\text{H}}$ of equimolal (DIPSO + NaDIPSO) buffer solutions from 5 to 55°C, computed using Eqs. (4–6)^a

$t(^{\circ}\text{C})$	0.02 <i>m</i> DIPSO + 0.02 <i>m</i> NaDIPSO <i>I</i> = 0.02 <i>m</i>	0.04 <i>m</i> DIPSO + 0.04 <i>m</i> NaDIPSO <i>I</i> = 0.04 <i>m</i>	0.06 <i>m</i> DIPSO + 0.06 <i>m</i> NaDIPSO <i>I</i> = 0.06 <i>m</i>	0.08 <i>m</i> DIPSO + 0.08 <i>m</i> NaDIPSO <i>I</i> = 0.08 <i>m</i>
5	7.755	7.843	7.854	7.855
10	7.654	7.740	7.752	7.753
15	7.559	7.642	7.651	7.655
20	7.464	7.544	7.555	7.557
25	7.374	7.454	7.465	7.467
30	7.286	7.362	7.367	7.374
35	7.201	7.275	7.282	7.288
37	7.170	7.240	7.248	7.250
40	7.119	7.188	7.193	7.197
45	7.043	7.106	7.113	7.115
50	6.962	7.023	7.033	7.034
55	6.886	6.945	6.956	6.957

^aUnits of m , $\text{mol}\cdot\text{kg}^{-1}$

Table 6

Values of pq_H for DIPSO (m_1) + NaDIPSO (m_2) + NaCl (m_3) buffer solutions from 5 to 55°C, computed using Eqs. (4–6)^a

m_1^a	m_2^a	m_3^a	5°C	10°C	15°C	20°C	25°C	30°C	35°C	37°C	40°C	45°C	50°C	55°C
0.08	0.08	0.08	7.872	7.770	7.669	7.574	7.475	7.384	7.290	7.255	7.203	7.119	7.038	6.956
0.06	0.06	0.10	7.869	7.771	7.669	7.572	7.485	7.392	7.306	7.269	7.217	7.129	7.051	6.970
0.04	0.04	0.12	7.885	7.784	7.685	7.587	7.489	7.397	7.307	7.272	7.221	7.136	7.055	6.974
0.02	0.02	0.14	7.888	7.788	7.690	7.593	7.498	7.405	7.312	7.275	7.223	7.139	7.057	6.976

^aUnits of m , mol·kg^{−1}

Table 7

Emf of Cell B for DIPSO buffer

m_1	m_2	m_3	E/V	
			25°C	37°C
0.08	0.08	0.00	0.68535	0.68255
0.08	0.08	0.08	0.68415	0.68061
0.06	0.06	0.10	0.68484	0.68157
0.04	0.04	0.12	0.68497	0.68166
Emf of Cell C ^a				
Cell C			E/V	
0.008695 <i>m</i> KH ₂ PO ₄			25°C	37°C
+ 0.03043 <i>m</i> Na ₂ HPO ₄			0.68275	0.69147

^aPublished data [7,19], for physiological phosphate buffer solutions

Table 8

Values of the liquid junction potentials for DIPSO buffer at 25 and 37°C

System	E_j^a/mV	
	25°C	37°C
Physiological phosphate (0.008695 <i>m</i> KH ₂ PO ₄ + 0.03043 <i>m</i> NaCl)	2.6	2.9
0.08 <i>m</i> DIPSO + 0.08 <i>m</i> NaDIPSO + 0.00 <i>m</i> NaCl	2.2	2.5
0.08 <i>m</i> DIPSO + 0.08 <i>m</i> NaDIPSO + 0.08 <i>m</i> NaCl	0.5	0.7
0.06 <i>m</i> DIPSO + 0.06 <i>m</i> NaDIPSO + 0.10 <i>m</i> NaCl	0.6	0.8
0.04 <i>m</i> DIPSO + 0.04 <i>m</i> NaDIPSO + 0.12 <i>m</i> NaCl	0.5	0.7

^a $E_j = E + E_{SCE}^\circ - k \text{ pH}$ from Eq. (1), E is the emf from Table 5, k = Nernst slope with values 0.059156 at 25°C, and 0.061538 at 37°C; the pH of the primary reference standard phosphate buffer is 7.415 and 7.395 at 25°C and 37°C;

E_{SCE}° = electrode potential of the saturated calomel electrode = -0.2415 V and -0.2335 V at 25 and 37°C [14,15], respectively; units of m , $\text{mol}\cdot\text{kg}^{-1}$

Table 9

Values of pH at 25 and 37°C for DIPSO buffer solutions

Cell B			25°C		37°C	
m_1	m_2	m_3	Ionic strength, I	Without ^a E_j corr	With ^b E_j corr	Calc ^c
0.08	0.08	0.00	0.08	7.459	7.466	7.467
0.08	0.08	0.08	0.16	7.439	7.474	7.475
0.06	0.06	0.10	0.16	7.450	7.484	7.485
0.04	0.04	0.12	0.16	7.453	7.488	7.489
						7.250
						7.254
						7.268
						7.271
						7.272

^a $pH = 7.415 + [E - 0.68275]/(0.059156)$ at 25°C, and $pH = 7.395 + [E - 0.69144]/(0.061538)$ at 37°C; the emf values (Table 7) are 0.68275 volt and 0.69144 volt at 25 and 37°C for the physiological phosphate buffer standard solution; units of m , $mol \cdot kg^{-1}$

^b Values obtained from Eq. (2) and E_j^0 data of Table 8

^c Obtained from Table 5 and Table 6