**Registry No.** HCl, 7647-01-0; NaCl, 7647-14-5.

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**Supplementary Material Available:** The original, unsmoothed experimental data incorporated in Table IA, 3 pages. Ordering information is given on any current masthead page.

# Densities and Refractive Indices of Aqueous Zinc Nitrate Solutions

**Surender K. Jain,* Anil K. Jain,† Ajay K. Gupta, and Vijay V. Singh**

*Hindu College, University of Delhi, Delhi 110007, India*

**Densities and refractive indices of aqueous zinc nitrate solutions (0.01–21.6 *m*) have been measured as a function of temperature over the range 20–60 °C. Thermal expansivity ($\alpha$) for the system shows a maximum near a concentration of 10 *m*, which corresponds to a water:salt mole ratio (*R*) of 6, and tends to attain a limiting value at higher salt concentrations. From the density measurements, apparent molal volumes ($\phi$) and partial molal volumes of zinc nitrate ($\bar{V}_2$) and water ($\bar{V}_1$) have been calculated. The refractive indices at all compositions vary linearly with temperature and have negative temperature coefficients. An increase in the salt content increases the refractive index of the system, leading to a limiting value beyond ≈15 *m*, which corresponds to *R* = 4. The molar refractions have been calculated by using the Lorentz and Lorenz equation and are found to depend upon temperature. The expansivity estimated from the temperature coefficient of the refractive index and the differential forms of the Gladstone–Dale and Lorentz–Lorenz equations agrees well with that estimated from the density data.**

## Introduction

Continuing our work concerning the measurement of refractive index in molten hydrates and concentrated electrolytic solutions (*1–4*), we present some results for aqueous zinc nitrate solutions over an extended range of temperature and concentration.

## Experimental Section

Zinc nitrate hexahydrate (AR) was used in the present study. The solutions were prepared by weighing the hexahydrate and then making up the solutions with distilled water. Melts with lower water content were prepared by removing calculated amounts of water from weighed quantities of the hydrate melts by continuous evacuation at ≈50 °C. All the solutions or melts were transparent.

† Present address: Department of Textile Technology, Indian Institute of Technology, Delhi.

The densities were measured with a modified manometric densitometer as described earlier (*5*). The refractive indices were measured on an Abbé-type refractometer. The experimental technique and the precision of measurement were essentially similar to those described earlier (*4*).

## Results and Discussion

The mole fraction ($X$) is not a convenient unit for describing the composition of solutions such as those studied here because of the variation in its magnitude by a factor of about $10^6$ over the composition range studied in the present work. Therefore, for the present study the compositions are expressed in terms of molality ($m$) and water-to-salt mole ratio ($R$).

The densities ($\rho$) for 0.01–21.6 *m* aqueous solutions of zinc nitrate presented in Table I show a quadratic temperature dependence and have been fitted to eq 1. The coefficients $A$, $B$, and $C$ are presented in Table II. The composition dependence of density across the entire concentration range at 60 °C is shown in Figure 1. The data of Jain and Tamamushi (*2*) for $Zn(NO_3)_2 \cdot xH_2O$ where $2 \leq x \leq 6$ have been included for a facile comparison. The agreement between the two independent studies is better than ±0.5%. The expansivity ($\alpha$) determined from eq 2 passes through a maximum at a concentration of approximately 10 *m* (Figure 1), which corresponds to a water-to-salt mole ratio of six, and tends to acquire a limiting value at higher salt concentrations. The expansivity values are presented in Table II.

$$\rho(\text{g cm}^{-3}) = A + Bt + Ct^2 \quad (1)$$

$$\alpha_t = -\frac{1}{\rho_t}\left[\left(\frac{d\rho}{dT}\right)\right]_t \quad (2)$$

The apparent molal volumes of zinc nitrate ($\phi$) were calculated (*6*, *7*) from each individual density value using eq 3, where

$$\phi = \frac{1}{d}\left[M_2 - \frac{1000(d - d_1)}{md_1}\right] \quad (3)$$

$d$ is the density of the solution, $M_2$ is the molar mass of zinc

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**Table I. Experimental Density and Refractive Index Data for Zinc Nitrate + $H_2O$ Systems[a]**

| $m$, mol kg$^{-1}$ | $t$, °C | $\rho$, g cm$^{-3}$ | $n$ | $m$, mol kg$^{-1}$ | $t$, °C | $\rho$, g cm$^{-3}$ | $n$ | $m$, mol kg$^{-1}$ | $t$, °C | $\rho$, g cm$^{-3}$ | $n$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00746 | 23.0 | 0.9983 | 1.3339 | 1.02 | 25.3 | | 1.3592 | | 37.3 | 1.7863 | 1.4562 |
| | 30.5 | 0.9963 | 1.3322 | | 32.7 | 1.1422 | 1.3575 | | 45.0 | 1.7778 | 1.4543 |
| | 38.0 | 0.9938 | 1.3316 | | 40.2 | 1.1384 | 1.3560 | | 53.0 | 1.7688 | 1.4522 |
| | 48.4 | 0.9889 | 1.3296 | | 48.3 | 1.1339 | 1.3548 | | 61.0 | 1.7597 | 1.4500 |
| | 56.1 | 0.9844 | 1.3286 | | 55.7 | 1.1296 | 1.3532 | | 69.6 | 1.7498 | 1.4480 |
| | 63.3 | 0.9794 | 1.3276 | | 63.5 | 1.1247 | 1.3518 | 9.48 | 31.5 | 1.8458 | |
| | 69.6 | 0.9726 | 1.3259 | | 71.4 | 1.1196 | 1.3508 | | 39.5 | 1.8365 | 1.4618 |
| 0.0492 | 23.0 | 1.0052 | 1.3351 | 2.08 | 22.5 | 1.2839 | 1.3830 | | 47.4 | 1.8277 | 1.4599 |
| | 30.3 | 1.0032 | 1.3342 | | 30.6 | 1.2788 | 1.3808 | | 55.3 | 1.8185 | 1.4579 |
| | 38.5 | 1.0001 | 1.3329 | | 38.1 | 1.2741 | 1.3790 | | 63.3 | 1.8088 | 1.4559 |
| | 48.5 | 0.9957 | 1.3319 | | 45.9 | 1.2690 | 1.3779 | | 71.6 | 1.7993 | 1.4538 |
| | 56.7 | 0.9908 | 1.3299 | | 53.8 | 1.2635 | 1.3760 | 9.75 | 40.5 | 1.8439 | 1.4634 |
| | 63.3 | 0.9859 | 1.3289 | | 62.0 | 1.2576 | 1.3742 | | 48.4 | 1.8349 | 1.4612 |
| | 69.5 | 0.9816 | 1.3279 | | 70.5 | 1.2513 | 1.3730 | | 57.1 | 1.8246 | 1.4589 |
| 0.125 | 23.0 | 1.0137 | 1.3372 | 4.07 | 23.7 | 1.4945 | 1.4159 | | 65.2 | 1.8151 | 1.4566 |
| | 30.3 | 1.0115 | 1.3361 | | 31.5 | 1.4880 | 1.4140 | | 73.0 | 1.8057 | 1.4542 |
| | 38.7 | 1.0084 | 1.3351 | | 39.5 | 1.4814 | 1.4134 | 11.9 | 28.8 | | 1.4758 |
| | 47.8 | 1.0042 | 1.3341 | | 47.8 | 1.4745 | 1.4108 | | 31.2 | 1.9361 | 1.4740 |
| | 56.1 | 0.9992 | 1.3331 | | 55.9 | 1.4676 | 1.4092 | | 39.2 | 1.9267 | 1.4720 |
| | 63.3 | 0.9946 | 1.3312 | | 64.1 | 1.4606 | 1.4068 | | 47.3 | 1.9175 | 1.4700 |
| | 69.5 | 0.9913 | 1.3302 | | 72.0 | 1.4533 | 1.4048 | | 55.1 | 1.9081 | 1.4679 |
| 0.271 | 22.6 | 1.0387 | 1.3432 | 5.19 | 24.5 | 1.5878 | 1.4303 | | 63.0 | 1.8986 | 1.4658 |
| | 31.9 | 1.0356 | 1.3414 | | 31.5 | 1.5819 | 1.4289 | | 71.0 | 1.8887 | 1.4638 |
| | 40.3 | 1.0323 | 1.3398 | | 39.0 | 1.5749 | 1.4272 | 15.5 | 33.7 | 2.0355 | 1.4848 |
| | 48.5 | 1.0285 | 1.3375 | | 46.6 | 1.5681 | 1.4256 | | 39.8 | 2.0276 | 1.4830 |
| | 56.3 | 1.0238 | 1.3368 | | 54.6 | 1.5609 | 1.4237 | | 47.5 | 2.0183 | 1.4810 |
| | 64.2 | 1.0188 | 1.3348 | | 63.0 | 1.5528 | 1.4230 | | 55.2 | 2.0095 | 1.4790 |
| | 71.8 | 1.0139 | 1.3331 | | 71.6 | 1.5444 | 1.4197 | | 63.5 | 1.9997 | 1.4770 |
| 0.389 | 23.4 | 1.0565 | 1.3452 | 6.23 | 23.3 | 1.6694 | 1.4418 | | 71.3 | 1.9905 | 1.4749 |
| | 32.0 | 1.0533 | 1.3422 | | 31.5 | 1.6614 | 1.4400 | 21.6 | 26.0 | 2.1336 | 1.4948 |
| | 40.3 | 1.0498 | 1.3412 | | 39.7 | 1.6529 | 1.4380 | | 29.5 | 2.1295 | 1.4940 |
| | 48.1 | 1.0464 | 1.3402 | | 47.6 | 1.6452 | 1.4364 | | 33.2 | 2.1253 | 1.4930 |
| | 56.5 | 1.0421 | 1.3398 | | 55.2 | 1.6377 | 1.4346 | | 37.0 | 2.1207 | 1.4920 |
| | 64.4 | 1.0373 | 1.3373 | | 63.2 | 1.6296 | 1.4327 | | 40.8 | 2.1162 | 1.4910 |
| | 71.8 | 1.0329 | 1.3361 | | 71.6 | 1.6210 | 1.4306 | | 45.0 | 2.1115 | 1.4900 |
| 0.944 | 24.3 | 1.1350 | 1.3577 | 7.29 | 23.9 | 1.7383 | 1.4512 | | 48.8 | 2.1071 | 1.4890 |
| | 32.0 | 1.1313 | 1.3564 | | 31.6 | 1.7304 | 1.4498 | | 52.8 | 2.1023 | 1.4880 |
| | 40.0 | 1.1270 | 1.3548 | | 39.3 | 1.7223 | 1.4476 | | 56.2 | 2.0983 | 1.4870 |
| | 48.5 | 1.1222 | 1.3532 | | 47.5 | 1.7136 | 1.4457 | | 60.6 | 2.0933 | 1.4860 |
| | 56.6 | 1.1164 | 1.3519 | | 55.3 | 1.7055 | 1.4439 | | 64.7 | 2.0886 | 1.4851 |
| | 64.5 | 1.1111 | 1.3509 | | 63.4 | 1.6966 | 1.4417 | | 68.6 | 2.0843 | 1.4841 |
| | 72.0 | 1.1061 | 1.3499 | | 70.8 | 1.6886 | 1.4398 | | 73.0 | 2.0793 | 1.4830 |
| | | | | 8.38 | 24.5 | 1.8014 | 1.4582 | | 77.0 | 2.0750 | 1.4820 |
| | | | | | 30.7 | 1.7936 | 1.4577 | | | | |

[a] Uncertainties: densities, ±0.0005; refractive indices, ±0.0002.

**Table II. Temperature-Density Equations and Calculated Expansivity Values ($\alpha$) for Aqueous Solutions of Zinc Nitrate**

| $m$, mol kg$^{-1}$ | $N^a$ | $\rho/(\text{g cm}^{-3}) = A + Bt + Ct^2$ | | | | |
|---|---|---|---|---|---|---|
| | | $A$ | $-10^4B$ | $-10^5C$ | $10^3$SE[b] | $10^4\alpha$, deg$^{-1}$ |
| 0.00746 | 7 | 0.9969 | −0.2462 | 0.844 | 0.46 | 7.81 |
| 0.0492 | 7 | 1.0071 | −0.0552 | 0.610 | 0.18 | 6.85 |
| 0.125 | 7 | 1.0184 | 0.1037 | 0.419 | 0.34 | 6.08 |
| 0.271 | 7 | 1.0429 | 0.0808 | 0.453 | 0.17 | 6.38 |
| 0.389 | 7 | 1.0626 | 0.1910 | 0.311 | 0.10 | 5.42 |
| 0.944 | 7 | 1.1450 | 0.3386 | 0.284 | 0.24 | 6.10 |
| 1.02 | 6 | 1.1569 | 0.3849 | 0.191 | 0.06 | 5.45 |
| 2.08 | 7 | 1.2966 | 0.5287 | 0.161 | 0.06 | 5.73 |
| 4.07 | 7 | 1.5128 | 0.7545 | 0.097 | 0.10 | 5.95 |
| 5.19 | 7 | 1.6083 | 0.8068 | 0.119 | 0.11 | 6.10 |
| 6.23 | 7 | 1.6926 | 0.9898 | 0.011 | 0.13 | 6.14 |
| 7.29 | 7 | 1.7626 | 0.9990 | 0.066 | 0.08 | 6.34 |
| 8.38 | 7 | 1.8291 | 1.1493 | −0.016 | 0.25 | 6.42 |
| 9.48 | 6 | 1.8821 | 1.1440 | 0.017 | 0.18 | 6.42 |
| 9.75 | 5 | 1.8920 | 1.1877 | −0.010 | 0.15 | 6.46 |
| 11.9 | 6 | 1.9709 | 1.0864 | 0.100 | 0.10 | 6.34 |
| 15.5 | 6 | 2.0800 | 1.3871 | −0.189 | 0.20 | 5.79 |
| 21.6 | 14 | 2.1639 | 1.1747 | −0.020 | 0.15 | 5.49 |

[a] Data points. [b] SE = standard error = $[\sum(\rho_{\text{exptl}} - \rho_{\text{calcd}})^2/(N-1)]^{1/2}$.

nitrate, $m$ is the molality, and $d_1$ is the density of water at the studied temperature. The $\phi$ values were plotted against $m^{1/2}$

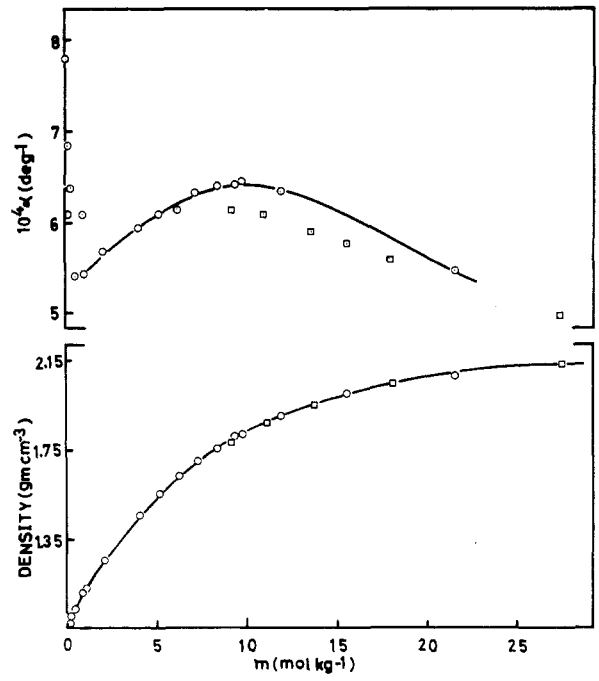


**Figure 1.** Density ($\rho$) and expansivity ($\alpha$) vs. molality ($m$) at 60 °C for $Zn(NO_3)_2$ + $H_2O$ system: O, present study; □, Jain & Tamamushi (*2*).

**Table III. Apparent Molal Volume-Molality Equations for $Zn(NO_3)_2$ + $H_2O$ Systems**

| t, °C | molality range, mol kg$^{-1}$ | N[a] | $\phi/(cm^3\ mol^{-1}) = \phi^0 + am^{1/2} + bm + cm^{3/2}$ $\phi^0$ | $a$ | $b$ | $-c$ | SE[b] |
|---|---|---|---|---|---|---|---|
| 20 | 0.39–21.6 | 13 | 31.22 | 4.484 | 1.457 | 0.198 | 0.19 |
| 30 | 0.39–21.6 | 13 | 34.11 | 2.830 | 1.884 | 0.237 | 0.18 |
| 40 | 0.39–21.6 | 13 | 35.83 | 2.117 | 2.043 | 0.251 | 0.18 |
| 50 | 0.39–21.6 | 13 | 36.99 | 1.691 | 2.153 | 0.262 | 0.18 |
| 60 | 0.39–21.6 | 13 | 37.93 | 1.252 | 2.305 | 0.281 | 0.18 |
| 70 | 0.39–21.6 | 13 | 38.98 | 0.435 | 2.627 | 0.319 | 0.20 |

[a] Data points. [b] SE = standard error = $[\sum(\phi_{exptl} - \phi_{calcd})^2/(N-1)]^{1/2}$.

(Figure 2). The data (Table III) could be adequately fitted to a third-degree polynomial, viz., eq 4.

$$\phi = \phi^0 + am^{1/2} + bm + cm^{3/2} \quad (4)$$

The partial molal volumes of zinc nitrate ($\bar{V}_2$) and water ($\bar{V}_1$) were calculated (6, 7) by using eq 5 and 6. $\bar{V}_2$ and $\bar{V}_1$ are

$$\bar{V}_2 = \phi^0 + {}^3/_2 am^{1/2} + 2bm + {}^5/_2 cm^{3/2} \quad (5)$$

$$\bar{V}_1 = (18.016/d_1) - 0.018016[{}^1/_2 am^{3/2} + bm^2 + {}^3/_2 cm^{5/2}] \quad (6)$$

shown as functions of $m^{1/2}$ in Figure 2. The partial molal volumes vary systematically with composition and tend to reach limiting values at higher salt content. Unlike calcium nitrate solutions (*4*), no maxima and minima were observed in plots of $\bar{V}_i$ vs. $m^{1/2}$ for the solutions of zinc nitrate. Values of the apparent molal volume at infinite dilution ($\phi^0$) are lower for zinc nitrate than for calcium nitrate, apparently reflecting the difference in the ionic radii of the two cations. The partial molal volume of water ($\bar{V}_1$) in zinc nitrate solutions at higher salt concentrations is about 8–10% lower than that observed in the calcium nitrate–water system. This indirectly suggests that water molecules in the coordination sphere of $Zn^{2+}$ are more closely packed than they are in the coordination sphere of $Ca^{2+}$, probably due to more covalent character in $Zn^{2+}$–$H_2O$ bonding.

The refractive index ($n$) data presented in Table I show a linear variation with temperature for all the aqueous solutions. The $n$–$t$ equations are presented in Table IV. The composition dependence of refractive index at a typical temperature, 60 °C, is shown in Figure 3.

Molar refraction, introduced by Lorentz (*8*) and Lorenz (*9*), is one of the best parameters that characterizes the polarization

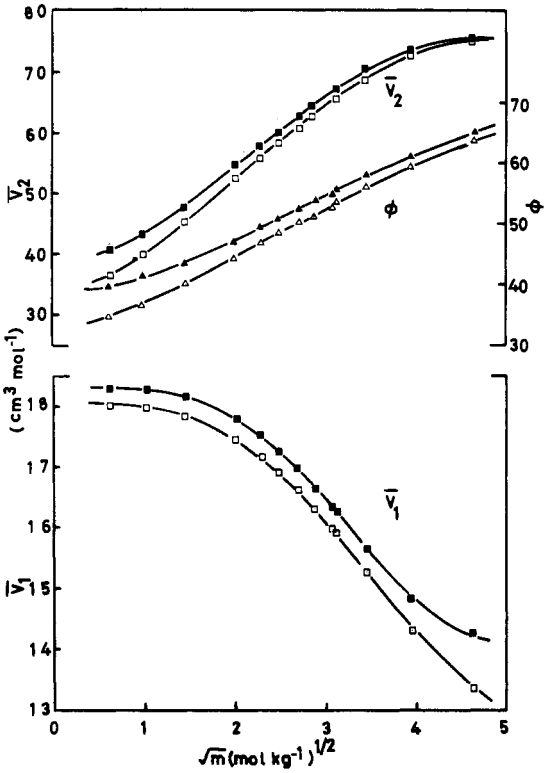


**Figure 2.** Apparent molal volume ($\phi$) and the partial molal volumes of zinc nitrate ($\bar{V}_2$) and water ($\bar{V}_1$) shown as a function of molality$^{1/2}$ ($m^{1/2}$ at 60 °C (▲, ■) and 20 °C (△, □).

phenomenon. The molar refraction of the solute was obtained at 20, 40, and 60 °C (Table IV) from eq 7 in which $\phi$ is the

$$R_{LL} = \frac{n^2 - 1}{n^2 + 2}\phi \quad (7)$$

apparent molal volume of zinc nitrate. The $R_{LL}$–molality isotherm at 60 °C is shown in Figure 3. The $R_{LL}$ values show a slight variation (≈3%) over the range 20–60 °C. The magnitude of the derivative $(\partial R_{LL}/\partial T)_{p,\lambda}$ for the systems investigated here varies from $2.8 \times 10^{-2}$ for dilute solutions to $0.42 \times 10^{-2}$ for the most concentrated solution. When this is compared with the corresponding value of $1 \times 10^{-3}$ for molten $KNO_3$–$NaNO_3$ mixtures (*10*), one gets the feeling that at such a high salt concentration the zinc nitrate–water system develops a molten salt character. As a first approximation, if the temperature

**Table IV. Refractive Index-Temperature Equations and Molar Polarizations for $Zn(NO_3)_2$ + $H_2O$ Systems**

| m, mol kg$^{-1}$ | N[b] | temp range, °C | $n = a - bt$, °C $a$ | $10^3 b$ | $10^3$SE[a] | $R_{LL}$, cm$^3$ mol$^{-1}$ 20 °C | 40 °C | 60 °C | $10^4\alpha_{LL}$, deg$^{-1}$ | $10^4\alpha_{GD}$, deg$^{-1}$ | $\alpha/\alpha_{GD}$ | $10^2(\partial R/\partial T)_{p,\lambda}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00746 | 7 | 23–70 | 1.3375 | 0.162 | 0.31 | | | | 4.49 | 4.93 | 1.58 | |
| 0.0492 | 7 | 23–69 | 1.3389 | 0.157 | 0.29 | | | | 4.33 | 4.77 | 1.44 | |
| 0.125 | 7 | 23–69 | 1.3407 | 0.146 | 0.38 | | | | 4.01 | 4.41 | 1.38 | |
| 0.271 | 7 | 23–72 | 1.3478 | 0.204 | 0.30 | | | | 5.50 | 6.07 | 1.05 | |
| 0.389 | 7 | 23–72 | 1.3485 | 0.170 | 0.68 | 7.35 | 7.97 | 8.24 | 4.56 | 5.04 | 1.07 | 2.22 |
| 0.944 | 7 | 24–72 | 1.3616 | 0.166 | 0.25 | | | | 4.26 | 4.72 | 1.29 | |
| 1.02 | 7 | 25–71 | 1.3636 | 0.183 | 0.23 | 8.16 | 8.74 | 8.98 | 4.67 | 5.19 | 1.05 | 2.05 |
| 2.08 | 7 | 22–70 | 1.3873 | 0.207 | 0.32 | 9.33 | 9.75 | 9.96 | 4.94 | 5.53 | 1.04 | 1.57 |
| 4.07 | 7 | 24–72 | 1.4217 | 0.229 | 0.49 | 11.19 | 11.50 | 11.68 | 4.96 | 5.63 | 1.06 | 1.22 |
| 5.19 | 7 | 24–72 | 1.4356 | 0.214 | 0.48 | 12.17 | 12.45 | 12.63 | 4.44 | 5.07 | 1.20 | 1.15 |
| 6.23 | 7 | 23–72 | 1.4472 | 0.231 | 0.11 | 12.82 | 13.11 | 13.28 | 4.64 | 5.32 | 1.15 | 1.15 |
| 7.29 | 7 | 24–71 | 1.4573 | 0.245 | 0.18 | 13.52 | 13.77 | 13.93 | 4.82 | 5.55 | 1.14 | 1.02 |
| 8.39 | 7 | 24–70 | 1.4647 | 0.238 | 0.41 | 14.08 | 14.36 | 14.53 | 4.57 | 5.28 | 1.22 | 1.12 |
| 9.48 | 5 | 39–72 | 1.4717 | 0.250 | 0.03 | 14.68 | 14.92 | 15.07 | 4.72 | 5.47 | 1.17 | 0.97 |
| 9.75 | 5 | 40–73 | 1.4749 | 0.281 | 0.11 | 14.92 | 15.15 | 15.29 | 5.30 | 6.15 | 1.05 | 0.92 |
| 11.9 | 7 | 29–71 | 1.4829 | 0.271 | 0.40 | 15.88 | 16.05 | 16.16 | 5.00 | 5.82 | 1.09 | 0.70 |
| 15.5 | 6 | 34–71 | 1.4934 | 0.260 | 0.10 | 17.04 | 17.22 | 17.31 | 4.66 | 5.45 | 1.06 | 0.67 |
| 21.6 | 14 | 26–77 | 1.5013 | 0.251 | 0.07 | 18.63 | 18.74 | 18.80 | 4.40 | 5.17 | 1.06 | 0.42 |

[a] SE = standard error = $[\sum(n_{exptl} - n_{calcd})^2/(N-1)]^{1/2}$. [b] Data points.

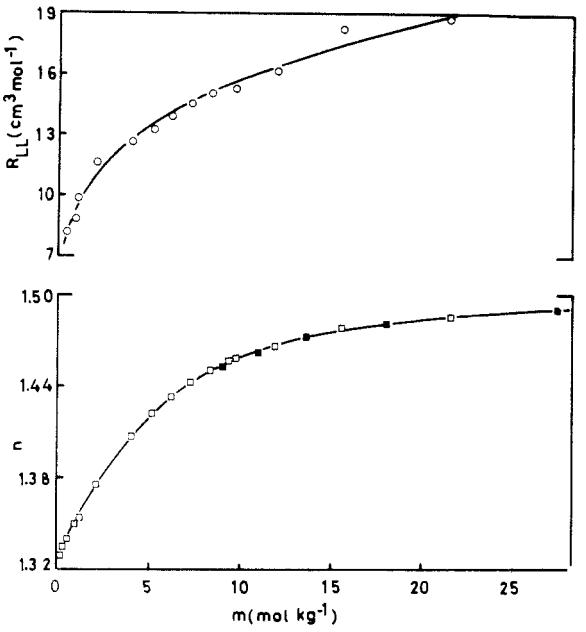


**Figure 3.** Refractive index ($n$) and molar refraction ($R_{LL}$) shown as a function of molality at 60 °C.

dependence of $R_{LL}$ is ignored, the expansivities may be calculated from the temperature coefficient of the refractive index and the differential forms of the Gladstone–Dale and the Lorenz–Lorentz equations (eq 8 and 9). The computed values of

$$\alpha_{GD} = [1/(1 - n)]\, dn/dT \quad (8)$$

$$\alpha_{LL} = [6n/(1 - n^2)(2 + n^2)]\, dn/dT \quad (9)$$

$\alpha_{GD}$ and $\alpha_{LL}$ for the zinc nitrate–water system are included in Table IV; note that $\alpha_{LL}$ is always smaller than $\alpha_{GD}$. The ratio $\alpha/\alpha_{GD}$ decreases with decreasing water content and the value at higher salt content is very similar to that shown by the ionic systems.

**Registry No.** $Zn(NO_3)_2$, 7779-88-6.

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# Electrical Resistivities of Iridium, Palladium, Rhodium, and Tungsten at Temperatures between 295 and 1100 K

**E. Yolanda García and Daniel G. Löffler***

*Institute of Materials Science and Technology (INTEMA), Universidad Nacional de Mar del Plata—CONICET, Juan B. Justo 4302, 7600 Mar del Plata, Argentina*

**The electrical resistivities of Ir, Pd, Rh, and W are measured at temperatures varying between 295 and 1100 K. A polynomial expression is found to fit our results and other authors' data with deviations smaller than 1% over the whole range of temperatures investigated.**

While the electrical resistivities of the platinum group metals and W at low temperatures have been measured several times in the past (*1*), data in the high temperature range (above 300 K) for Ir, Pd, and Rh are not very abundant and results by different authors are not in good agreement (*2*, *3*). Moreover, much experimental work has been published in the form of small-scale graphs without inclusion of actual figures. The purpose of the present work is to present new resistivity vs. temperature data for the above-mentioned metals and correlate them with algebraic equations.

In order to establish the relationship between resistance and temperature, metal samples in the form of thin wires were inserted into a quartz cell similar to the one described by Rye and Hansen (*4*) and placed in a temperature-controlled furnace. Resistance measurements were made, after the temperature had stabilized to ±1 K, using the ohmmeter function of a five-digit digital voltmeter. The temperature within the cell was measured with a chromel–alumel thermocouple located next to the metal sample. A four-wire technique was used to eliminate errors caused by test lead resistances. The accuracy of the voltmeter, which had been calibrated by the manufacturer just before the experiments, was ±0.6% or better in the range of

**Table I. Details of Specimens**

| quoted purity, % | elctrical resistivity at 295 K, μΩ cm | ref |
|---|---|---|
| | Iridium | |
| 99.9 | 9.01 | present work |
| 99.95 | 4.65[a] | 5 |
| 99.98 | 5.01 | 6 |
| | Palladium | |
| 99.9 | 10.56 | present work |
| 99.99 | 10.01[a] | 5 |
| 99.99 | 10.6 | 6 |
| 99.98 | 10.71[a] | 7 |
| | Rhodium | |
| 99.9 | 4.73 | present work |
| 99.93 | 4.42[a] | 5 |
| 99.99 | 4.78 | 6 |
| | Tungsten | |
| 99.98 | 5.64 | present work |
| 99.98 | 5.33 | 6 |
| | 5.6 | 8 |

[a] Adjusted to 295 K from published values.

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