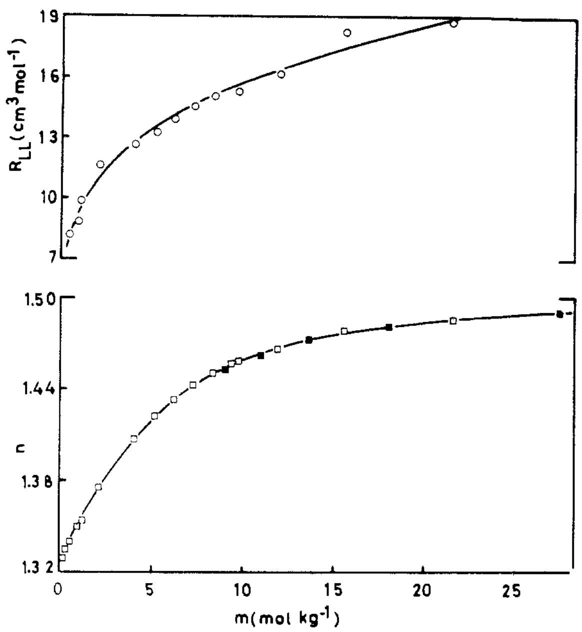

Figure 3. Refractive index (n) and molar refraction (R_{LL}) shown as a function of molality at 60 °C.

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

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

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

α_{GD} and α_{LL} for the zinc nitrate-water system are included in Table IV; note that α_{LL} is always smaller than α_{GD}. The ratio α/α_{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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Received for review August 8, 1984. Accepted December 28, 1984. We thank the UGC, New Delhi, for the financial assistance given for this project.

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

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.

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

0021-9568/85/1730-0304$01.50/0

Table II. Resistance Ratio R_T/R_{295} vs. Temperature for Ir, Pd, Rh, and W

	iridium			palladium		rhodium			tungsten			
T, K	this work	ref 2	ref 3	this work	ref 7	this work	ref 2	ref 3	this work	ref 2	ref 8	ref 3
100		0.420	0.225				0.276	0.187		0.176		0.192
150		0.568	0.434				0.458	0.400		0.389		0.394
200		0.717	0.635				0.651	0.615		0.602		0.604
250		0.868	0.828		0.925[a]		0.832	0.816		0.811		0.8106
295	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0
350	1.15	1.16	1.33[a]	1.20	1.27[a]	1.21	1.20	1.29[a]	1.23	1.23		1.37[a]
400	1.29	1.32		1.39		1.43	1.39		1.42	1.44	1.44	
450	1.44	1.47		1.59	1.58[a]	1.63	1.58		1.63	1.65		
500	1.56	1.61		1.73		1.81	1.76		1.84	1.87	1.87	
550	1.69	1.76	2.11[a]	1.86	1.89[a]	2.03	1.95	2.13[a]	2.06	2.08		2.32[a]
600	1.84	1.91		2.01		2.21	2.14		2.31	2.29	2.36	
650	1.98	2.06		2.15	2.18[a]	2.43	2.33		2.55	2.50		
700	2.12	2.21		2.29		2.61	2.51		2.78	2.73	2.87	
750	2.25			2.43	2.45[a]	2.83			3.02			
800	2.39			2.55		3.01			3.27		3.39	
850	2.53			2.68	2.69[a]	3.23			3.53			
900	2.69			2.80		3.45			3.80		3.92	
950	2.83			2.92	2.91[a]	3.64			4.10			4.5[a]
1000	2.96			3.03		3.85			4.40		4.45	
1050	3.09			3.14	3.13[a]				4.61			
1100	3.23			3.25					4.94		4.99	

[a] Actual temperature = T + 23 K.

Table III. Coefficients for Eq 1

	iridium		palladium		rhodium		tungsten	
coeff	present work	ref 2	present work	ref 7	present work	ref 2	present work	ref 2[a]
a_0	0.1756	0.1210	−0.09819	−0.08578	−1.967	−0.1065	−0.09031	−0.23
10^3a_1, K^{-1}	2.779	2.983	+4.088	+3.951	4.035	3.742	3.328	4.18
10^7a_2, K^{-2}			−9.545	−8.853			11.15	

[a] Tungsten data from ref 2 for temperatures between 620 and 1200 K.

resistance measured. Pressure within the cell was kept in the low 10^{-2} Pa range by pumping with an oil-sealed mechanical vacuum pump.

The specimens studied in this work were all supplied by Alfa Products (Danvers, MA) in the form of 0.0127-cm-diameter wires, which were cut to 8.7-cm lengths. Quoted purity and room-temperature electrical resistivity of the samples are given in Table I. All samples were heated in the cell for about 1 h at 1000 K; after this initial treatment no variation in room-temperature resistivities was observed with cycling to high temperatures.

Experimental values of relative resistivities normalized to unity at 295 K are shown in Table II along with other authors' data. Only results reported in tabular form have been selected. Each set of data in Table II can be fitted with a polynomial expression

$$R/R_{295} = a_0 + a_1T + a_2T^2 \qquad (1)$$

A least-squares analysis of the data points at temperatures above 295 K yields the values for the coefficients shown in Table III. In all cases, the resistivity ratios calculated by using eq 1 deviate from measured values reported in Table II less than 1%. Extrapolation of our data using eq 1 to temperatures down to 100 K results in good agreement with values reported by Mimeault and Hansen (2) and by White and Woods (6) for Rh and W, and by Conybeare (7) and by White and Woods (6) for Pd. Our extrapolated resistivity ratios for Ir agree with Mimeault and Hansen's data but not with the results of White and Woods.

It should be noted that the electrical resistivity of iridium measured by us at 295 K is about twice the value reported by Powell et al. (5). Annealing for several hours at 1300 K reduced the resistivity of the fresh wire at room temperature from 9.46 to 9.01 $\mu\Omega$ cm, but this value could not be further reduced. X-ray energy-dispersive analysis of the Ir wires showed no impurities.

Acknowledgment

We are indebted to Mr. H. T. Asencio, who built the quartz cell.

Registry No. Ir, 7439-88-5; Pd, 7440-05-3; Rh, 7440-16-6; W, 7440-33-7.

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Received for review June 14, 1984. Revised manuscript received November 13, 1984. Accepted November 29, 1984.