Thermal Conductivities and Electrical Resistivities of the Platinum Metals

By R. W. Powell, D.Sc., Ph.D., F.Inst.P., R. P. Tye
and Margaret J. Woodman

Basic Physics Division, National Physical Laboratory, Teddington

New values are presented and discussed for the thermal conductivities and electrical resistivities of ruthenium, osmium, rhodium, iridium, palladium and platinum over the approximate temperature range 80° to 500°K.

It became apparent during a recent revision by one of the authors of the thermal conductivity section of Kaye & Laby's well-known book of tables of physical constants that the values hitherto quoted for the thermal conductivity of some metals, and in particular of rhodium and iridium, were clearly in error.

When the previously reported data were examined it was found that the values of the Lorenz number (thermal conductivity multiplied by electrical resistivity divided by the absolute temperature) gave unusually low values for these metals, and investigations were put in hand to make new determinations of thermal conductivity and electrical resistivity. The new values found for iridium and rhodium have already been reported (1) and it may be noted that at room temperature the value of thermal conductivity for iridium is greater than the value previously quoted by a factor of about 2.5 and that for rhodium by about 1.7.

Of the four metals of the platinum group yet to be considered, no thermal conductivity values appear to have been measured at normal temperatures or higher for osmium and ruthenium, those for palladium in the range 0° to 100°C (2, 3, 4) show differences of up to 27 per cent, and, whereas most available values for platinum show closer agreement in this temperature range (2, 4, 5, 6, 7), differences of about 30 per cent occur between the fewer measurements made at 1000°C (8, 9, 10).

The thermal conductivities of osmium and ruthenium have been measured by White and Woods (11), but only below 150°K. These workers note that extrapolation of their thermal data suggest a thermal conductivity at room temperature of about 0.9 ± 0.1 W $cm^{-1}deg^{-1}$ for osmium and about 1.1 ± 0.1 W $cm^{-1}deg^{-1}$ for ruthenium. They at the same time make a plea for accurate determinations of the thermal conductivity at 300° or 400°K to be made.

Specimen Details

The specimens studied in this work were all supplied by Johnson, Matthey & Co., Limited, in the form of small rods having the dimensions given in Table I. This table also contains values of the density and such details as were supplied regarding chemical impurities and the method of preparation.

Experimental Methods and Results

The experimental methods used have been similar to those described previously (1, 12). An electrical resistivity determination was first made at room temperature with the samples resting on knife edges at a fixed distance apart and serving as potential con-

Table I

Details of Specimens

Metal	Length cm	Dia. cm	Impurities per cent										Density g/ml	Other Information
			Au	Ag	Cu	Fe	Ni	Pd	Rh	Ir	Ru	Pt		
Ruthenium	2.5	0.660			.001	.01	.001	.0005	.03			.002	12.36	Argon-arc melted and ground
Osmium	2.7	0.489		.0001	.0002	.0005			.002		.03		22.45	,, ,,
Rhodium	5.0	0.348		.002 to .005		.005		.001 to .003		.03 to .1			12.44	
Iridium ..	5.0	0.318						.001	.02 to .05		.002 to .005		22.43	
Palladium	6.1	0.636	.0005	<.0001	.0001	.0005			.005			.0002	12.02	
Platinum ..	6.1	0.635			.0001	.0001		<.0001					21.51	Annealed at ~1000°C

tacts. The resistivity obtained by comparing this potential drop with that across a standard resistance was later used to give the effective shape factor, ratio of area to length, when thermocouples fixed to the rods served to measure the temperature and also as potential leads.

Determinations of electrical resistivity were made in this way to high temperatures and down to liquid nitrogen temperatures. For resistivity measurements at liquid helium temperatures a comparison method was used in which the potential drops operated in opposition through a galvanometer, and the currents in the standard resistance and the specimen circuits were adjusted to give no deflection.

The electrical resistivity values obtained at the liquid helium, ρ_0, and ice temperatures, ρ_{273}, and the ratio of these two resistivities, ρ_0/ρ_{273}, are given in Table II. This table includes some of the results of other workers. The residual resistance ratio given in the last column can frequently be taken as an indication of the state of purity of the sample, the ratio becoming lower as the purity is increased or the state of strain decreased. Only for iridium and platinum is this ratio lowest in the samples used for the present work.

Curves showing the variation of electrical resistivity with temperature for each metal over the range so far studied are given in the lower portion of Fig. 1.

The upper portion of this figure reproduces on an enlarged scale the mean curves for the lower range of temperatures investigated. For palladium and platinum, however, the

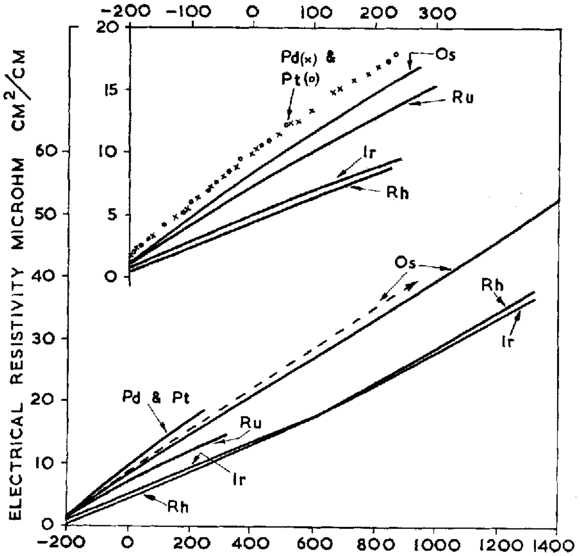


Fig. 1 Variation of electrical resistivity of the platinum metals with temperature

Table II

Electrical Resistivity, microhm cm²/cm, measured at Liquid Helium, ρ_0 and Ice Temperatures, ρ_{273}

Metal	Observer	Specimen Details	Electrical Resistivity		
			ρ_{273}	ρ_0	$10^3\rho_0/\rho_{273}$
Ruthenium	Present work	As received	7.13	0.566	79.4
	Meissner & Voigt (15)	—	—	—	8.3
	Justi (16)	99.99%: sintered 2200°C	7.157	0.501	70
	Hulm & Goodman (17)		—	—	60
	White & Woods (11)	Arc-melted Ru2	7.9*	0.235	30*
		„ „ Ru3	6.8*	0.02	3*
Osmium	Present work	As received	8.532	0.272	32
		After heating to 1540°C	8.12	0.244	30
	Hulm & Goodman (17)		—	—	40
	White & Woods (11)	Arc-melted Os2	8.5*	0.0996	11.7*
		„ „ Os3	8.5*	0.0873	10.3*
Rhodium	Present work	After heating to 1336°C	4.33	0.024	5.5
	Meissner & Voigt (15)	—	—	—	3.0
	White & Woods (18)	J.M., annealed 1300°C	4.4*	0.0084	1.9*
	Kemp *et al* (19)	Sample No. 1 of Grüneisen & Goens (20)	4.63*	0.0155	3.3*
Iridium	Present work	After heating to 1310°C	4.71	0.055	11.7
	Meissner & Voigt (15)	—	—	—	47.7
	White & Woods (18)	J.M., annealed 1300°C	4.75*	0.1034	21.8*
Palladium	Present work	As received	9.93	0.144	14.5
	Meissner & Voigt (15)	—	—	—	35.3
	Kemp *et al* (21)	Annealed at 450°C	9.9*	0.0182	1.8*
	MacDonald *et al* (22)	Prepared by J.M., 0.031% impurity	—	—	14.3*
Platinum	Present work	As received	9.85	0.013	1.3
	Meissner & Voigt (15)	—	—	—	1.6
	White & Woods (18)	Annealed 1050°C	9.6*	0.0125	1.3*
	MacDonald *et al* (22)	Prepared by J.M.	—	—	4.3*

* Adjusted to 273°K, from published value

curves are still too close to be shown separately and for these metals some of the experimental points are shown.

For the thermal conductivity measurements, four versions of the longitudinal heat flow method have been used. Over the approximate temperature range of 50° to 250°C the following variants of the guarded comparative heat-flow method have been used, but all with water cooling at the lower end, so providing an additional absolute measure of the heat out-flow from the specimen:

Moderate Temperature Method I:

The test specimen was joined to the top of a rod of Armco iron of known thermal conductivity, water cooled at its base. Measurements of the heat out-flow from the test specimen were obtained in terms of the gradient of temperature in the iron and by the water-flow calorimeter. This method was used for iridium and rhodium.

Moderate Temperature Method II:

In this variant, the rod of Armco iron was uppermost and the water-flow calorimeter attached to the lower end of the test specimen. Hence, the heat in-flow to the test specimen was measured in terms of the temperature gradient established in the iron and the heat out-flow by means of the water-flow calorimeter. This method was used for iridium, rhodium, palladium and platinum.

Moderate Temperature Method III:

For the two shortest specimens it was necessary to join on another rod on which the heating unit could be wound. A rod of Armco iron was used for this purpose, of sufficient length to enable a measurement of the heat in-flow to be made in terms of the gradient of temperature established in a portion of this rod. The heat out-flow was derived both from the gradient in another Armco iron rod attached to the lower end of the specimen and by the water-flow calorimeter at the base of this iron rod. This method was used for osmium and ruthenium.

All joints were made by means of shrunk fits into small steel collars. The interspace between the composite central rod and the guard tube was packed with a thermal insulating powder having a thermal conductivity of about 0.00033 J cm/cm^2 sec deg C. After corrections had been made for any imperfectly matched conditions the various heat-flow measurements usually agreed to within some 2 per cent.

Low Temperature Method

Determinations were made with the specimen attached to the base of an internally polished metal container which could be continuously evacuated through a thin-walled cupro-nickel tube. The container was immersed in turn in boiling water, melting ice, crushed solid carbon dioxide, liquid oxygen or liquid nitrogen during an experiment. A heating coil was wound on the top of the specimen and was covered with a wrapping of aluminium foil. The energy supplied to this heater was measured, corrected for lead conduction, and used to determine the heat flow in the working section of the rod. Corrections for radiation transfer were derived from a second series of experiments made at comparable mean temperatures but with the specimen freely suspended in the enclosure.

Of the present group of metals, this method has been used only for iridium and rhodium. It should be noted, however, that the method has also been applied to Armco iron (13) and to rhenium (14) and has yielded values in good accord with those of other workers.

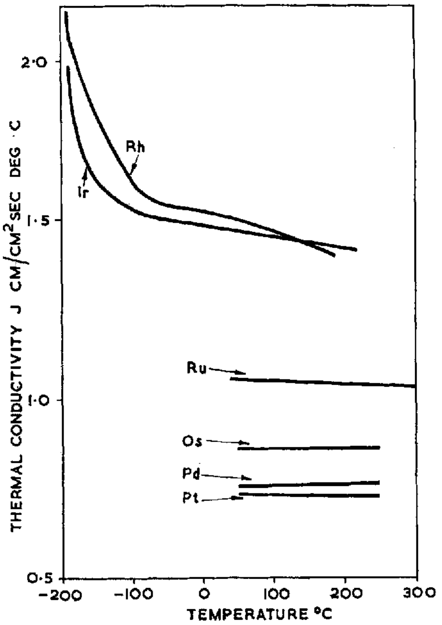


Fig. 2 Variation of thermal conductivity with temperature

Fig. 2 depicts the variation of thermal conductivity with temperature by means of smooth curves or straight lines that have been drawn through similar sets of experimental points for each metal.

The curves for iridium and rhodium differ a little from the results previously published by the authors (1), particularly at the lowest temperatures. This is due to use of a revised calibration for the nickel-chromium and Constantan thermocouples used.

The values of the pairs of metals belonging to the same sub-groups, ruthenium and osmium, rhodium and iridum and palladium and platinum, tend to come together.

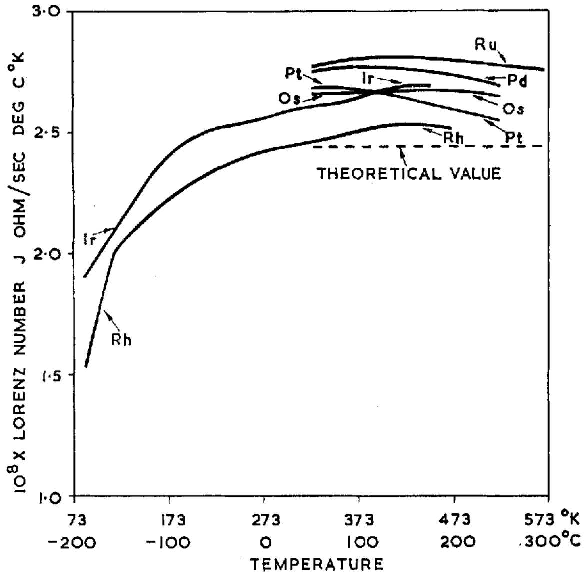


Fig. 3 Variation of the Lorenz number with temperature

Above normal temperature, the thermal conductivities of each metal are relatively constant. The values for ruthenium agree well with the predicted value of White and Woods (11) mentioned earlier, while that for osmium lies at the lower limit of the range of values which they gave.

Curves showing the dependence of the Lorenz number on temperature are reproduced in Fig. 3. It is of interest to note that over the range from 323° to 500°K the Lorenz numbers of the metals of the platinum group exceed the theoretical value by amounts ranging only from 0 to 15 per cent. It would seem that by using a value of 2.6×10^{-8} J ohm/sec deg C °K it should be possible to calculate their thermal conductivities at higher temperatures from the electrical resistivity values, and to achieve an accuracy of well within 10 per cent. This order of accuracy is good when compared with the wide differences between available data, as indicated in the introduction. This conclusion raises doubts regarding the reliability of published values in the higher temperature range for the thermal conductivity of platinum (8, 10) and the Lorenz number of platinum (23) and palladium (24). For instance, the data of Holm and Störmer give Lorenz numbers which increase from 2.6×10^{-8} at about 100°C to 3.0×10^{-8} at about 1000°C, while Hopkins (23) and Hopkins and Griffiths (24) obtain values of rather above 3×10^{-8} for platinum and palladium between 1000°C and their melting points.

As the temperature is reduced towards and below the characteristic temperature, θ, the relaxation times associated with electric and thermal electronic transport are no longer comparable, hence the observed decrease towards lower values for the Lorenz number that commences in the range 300° to 400°K. At temperatures exceeding θ, where the theoretical value of the Lorenz number should hold, any excess above the theoretical value can be attributed to augmentation of the thermal conductivity by phonon or lattice conduction.

Derived values for this lattice component have the numerically highest values of about 0.13 J cm/cm² sec deg C for the samples of iridium and ruthenium. In general the lattice component shows a small decrease with increase in temperature and supports the doubts already expressed regarding the high temperature data for platinum and palladium.

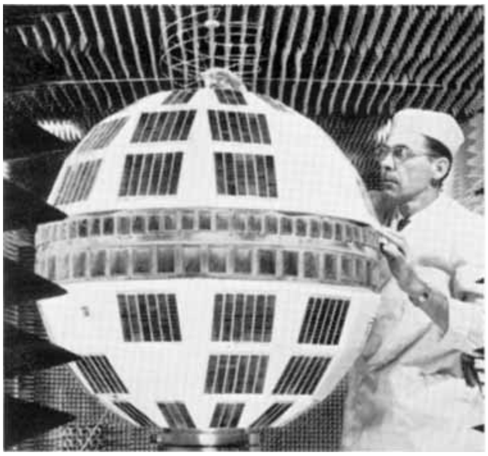
Acknowledgments

The authors are indebted to Mr. H. E. Bennett of Johnson, Matthey & Co., Limited who arranged for the loan of the various samples. Mrs. J. A. Weston made the electrical resisitivity measurements at liquid helium temperature. The work has formed part of the research programme of the Basic Physics Division of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory.

References

1 R. W. Powell and R. P. Tye, *Proc. 9th International Congress of Refrigeration*, 1955, **1**, 2149
2 T. Barrett and R. M. Winter, *Proc. Phys. Soc.*, 1914, **26**, 347; *Ann. Physik*, 1925, **77**, 1
3 E. Sedström, 1924, Dissertation, Stockholm
4 W. Jaeger and H. Diesselhorst, *Abh. d. Phys. Tech. Reichsanstalt*, 1900, **3**, 269
5 J. H. Gray, 1895, *Phil. Trans. (A)*, **186**, 165
6 W. Meissner, *Ann. Physik*, 1915, **47**, 1001
7 W. G. Kannuluik and E. H. Carmen, *Australian J. Sci. Res.*, 1951, **4**, 303
8 R. Holm and R. Störmer, *Wiss. Veroffentl Siemens-Konzern*, 1930, 312
9 K. S. Krishnan and C. S. Jain, *Brit. J. App. Phys.*, 1954, **5**, 426
10 K. H. Bode, "Progress in International Research on Thermodynamic and Transport Properties", A.S.M.E., 1962, 481
11 G. K. White and S. B. Woods, *Canadian J. of Physics*, 1958, **36**, 875
12 R. W. Powell and R. P. Tye, *The Engineer*, 1960, **209**, 729
13 R. W. Powell, M. J. Hickman, R. P. Tye and Miss M. J. Woodman, "Progress in International Research on Thermodynamic and Transport Properties", A.S.M.E., 1962, 466
14 R. W. Powell, R. P. Tye and Miss M. J. Woodman. In course of publication.
15 W. Meissner and B. Voigt, *Ann. Physik*, 1930, **7**, 892
16 E. Justi, *Z.f.Naturforsch.*, 1949, **4a**, 472
17 J. K. Hulm and B. B. Goodman, *Phys. Rev.*, 1957, **106**, 659
18 G. K. White and S. B. Woods, *Canadian J. of Phys.*, 1957, **35**, 248
19 W. R. G. Kemp, P. G. Klemens and R. J. Tainsh, *Annalen der Physik*, 1959, **5**, 35
20 E. Grüneisen and E. Goens, *Z. Phys.*, 1927, **44**, 615
21 W. R. G. Kemp, P. G. Klemens, A. K. Sreedhar and G. K. White, *Phil. Mag.*, 1955, **46**, 811
22 D. K. C. MacDonald, W. B. Pearson and I. M. Templeton, *Proc. Roy. Soc., A.*, 1962, **266**, 161
23 M. R. Hopkins, *Phys. Zeit.*, 1957, **147**, 148
24 M. R. Hopkins and R. L. Griffiths, *Phys. Zeit.*, 1958, **150**, 325

PLATINUM IN TELSTAR SATELLITE



In July this year the experimental Telstar communications satellite, designed and constructed by the Bell Telephone Laboratories, was successfully launched at Cape Canaveral. Roughly spherical in shape, with a faceted surface, the satellite is 34½ inches in diameter and weighs about 170 pounds.

This satellite carries equipment not only for broadband microwave communications in space but also for obtaining and transmitting information on its own performance and on the nature of the space environment. Power for its electronic circuits is supplied by rechargeable nickel-cadmium cells which are charged by 3,600 solar cells mounted on 60 of the 72 facets of the satellite shell. Each solar cell is mounted on a ceramic base and is covered by a transparent wafer of synthetic sapphire held in place by a framework of platinum.

The materials for the solar cell assemblies have been selected because of their durability in the space environment and their similar properties of expansion and contraction with changes of temperature. It is expected that the bonded assemblies will remain intact for many years, thus enabling the satellite to carry out its programme of investigation.