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PHYSICAL CHEMISTRY DIVISION

COMMISSION ON PHYSICOCHEMICAL MEASUREMENTS AND STANDARDS

PHYSICOCHEMICAL MEASUREMENTS: CATALOGUE OF REFERENCE MATERIALS FROM NATIONAL LABORATORIES

(REVISED 1976)

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During the past 50 yr scientific development and world trade have grown faster than at any previous time. Commerce depends upon agreements regarding commodities that are bought and sold. The buyer has certain specifications for his needs, and the seller must satisfy those specifications. The specifications are some sort of comparision with a standard acceptable to both buyer and seller. Without standards, the agreement between user and producer is much more difficult to achieve. Accepted standards have become part of the basic framework of commerce upon which further progress rests.

The machine age and automation are firmly grounded on standardized reference materials and at the XXIV IUPAC Conference in 1967 the Commission on Physicochemical Measurements and Standards decided to collect the information on the availability of reference materials certified for given properties that was published as the "Catalogue of Physicochemical Standard Substances."[1] For inclusion in this catalogue a standard substance was interpreted as one having a certified value of a physical property within a given accuracy that can be applied to the following types of measurements:

1. The calibration and standardization of a measuring mechanism.
2. The proof of measurement accuracy by a given method.
3. The transfer of measured quantities from one place to another.
4. The comparison of measurements made in different locations.

Revision of the catalogue was agreed at the XXVII Conference in 1973 and for the compilation of this new edition, inquiries were made from representatives of 31 nations known to have been active in the field of reference materials. The new title is a more exact description of the contents; it comprises materials available internationally that are issued or sponsored by a national laboratory and have certified physicochemical properties (chemical composition and engineering and technological properties have been excluded from consideration).

This revision contains reference materials for seven additional properties: magnetic susceptibility, relative humidity, specular spectral reflectance, surface area, surface tension, thermal emissivity, and thermal expansion. Some of the detail originally given has been omitted; e.g. reference materials for the realization of pH have been grouped and not repeated for each issuing laboratory, and only representative pH values have been given at one temperature, usually 20°C. The user is advised to obtain full information about each sample from the laboratory supplying it.

This Catalogue will be complementary to a series of IUPAC reports on "Recommended Reference Materials for the Realization of Physicochemical Properties" which are being prepared by the Commission through its Sub-Commission on Calibration and Test Materials. These reports, some of which have now been published,[2] are selective but are not restricted to certified reference materials only, as these are not available for all properties and conditions of importance. These reports will include recommendations on methods in addition to numerical values for the properties.

†*Chairman*: D. Ambrose (UK); *Vice-Chairman and Secretary*: J. P. Cali (USA); *Members*: E. Brunner (FRG), R. P. Graham (Canada), J. E. Lane (Australia), Y. Mashiko (Japan), T. Plebanski (Poland), J. Terrien (France); *Associate Members*: I. Brown (Australia), H. Feuerberg (FRG), A. Juhász (Hungary), H. Kienitz (FRG), G. Milazzo (Italy), W. M. Smit (Netherlands), L. A. K. Staveley (UK), D. R. Stull (USA); *National Representatives*: M. Matrka (Czechoslovakia), J. N. Mukherjee (India), M. Milone (Italy), A. Newton (UK).

‡The current version was compiled by J. P. Cali.

REFERENCES

[1] *Pure Appl. Chem.* **29**, 597 (1972).
[2] *Pure Appl. Chem.* **40**, 393 (1974); **48**, 241 (1976).

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Table 1. Reference materials certified with respect to a particular physical property†

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
		1. ACIDIMETRY		
99.99 ± 0.01	Potassium hydrogen phthalate (84 h)	99.99 ± 0.01	I	Also certified for ^{10}B and ^{11}B atom per cents.
99.98 ± 0.02	Benzoic acid (350)	99.98 ± 0.02		
100.00 ± 0.01	Boric acid	100.00 ± 0.01		
		2. CALORIMETRY	A. Heat capacity	
99.95	α-Aluminum oxide (720)	See Remarks	I	Enthalpy and heat capacity certified from 273 to 2250 K. Enthalpy accurate to ±0.1% heat capacity from ±0.01% at lowest temperature to ±0.3% at 1200 K. See certificate for full explanation of accuracy and precision.
99.99	Heptane	See Remarks	I	These materials are not certified as NBS Standard Reference Materials, but are held by the Calorimetry Conference, and are available to qualified users from E. J. Prosen at NBS. Heat capacity data are reported by Ginnings and Furukawa, *J. Am. Chem. Soc.* **75**, 522 (1953).
99.99	Benzoic acid	See Remarks		
99.99+	α-Aluminum oxide	See Remarks		
		B. Heat of transition and fusion		
99.99	Neopentane	(628.7 ± 0.3)cal·mol^{-1} at (140.49 ± 0.05) K (740.0 ± 0.3)cal·mol^{-1} at Trip. Pt 256.75 K	E	Purified by using a spinning band type distillation tower of 3 m height and an adsorption column packed with molecular sieve.
		C. Energy of combustion		
99.99	Benzoic acid	Certified for each batch	F	Purity derived from temperature/enthalpy curves.
	Benzoic acid	Certified for each batch	H	Value certified by NPL, but samples prepared, purified and sold by firms, e.g. BDH and Bureau of Analyzed Samples.

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
99.997	Benzoic acid (39i)	$(26.434 \pm 0.003)\text{kJ}\cdot\text{g}^{-1}$	I	Value certified when burned under, or corrected to the specific conditions described on the certificate.
99.993	2,2,4-Trimethyl-pentane (217b)	$47.713\,\text{kJ}\cdot\text{g}^{-1} \pm 0.02\%$	I	Value certified when burned under or corrected to the specific conditions described on the certificate.
		D. Solution calorimetry		
99.94	2-Amino-2-(hydroxy-methyl)-1,3-pro-panediol [Tris(hydroxy-methyl)amino-methane] (724a) (THAM or TRIS)	$245.76 \pm 0.26\,\text{J}\cdot\text{g}^{-1}$ (with HCl) $141.80 \pm 0.19\,\text{J}\cdot\text{g}^{-1}$ (with NaOH)	I	Certified as to purity and homogeneity. This compound is intended to serve as a uniform material for checking calorimeters in different laboratories. See certificate for exact conditions.
Natural Brazilian Quartz	α-Quartz	$-2362.2 \pm 1.1\,\text{J}\cdot\text{g}^{-1}$ at 353.15k in 24.4 wt% HF	I	See certificate for full details, also M. V. Kilday and E. J. Prosen, NBS Tech. Report 10 561 (1971).
		3. SPECTROPHOTOMETRY AND TRISTIMULUS COLORIMETRY		
Set of 10 plates of different colors for calibration of tristimulus colorimeters (ceramic tiles with a colored coating).			B	The plates are available with color specification according to any CIE observer (2° and 10°) standard illuminant, and geometry of illuminating and viewing.
Set of 12 ceramic tiles consisting of 3 neutral greys and 9 spectrally selective colors for testing different types of error in colorimetric instruments.			H	Spectral reflection calibrations 300 (10) 760 nm or 300 (5) 760 nm and colorimetric quantities x, y, $Y\%$, u, v under illuminants A, C and D65 for any of 3 geometries of illumination and view: 0°/45°, 0°/diffuse, 8°/total.
Orange-Red Glass (2101) Signal Yellow Glass (2102) Sextant Green Glass (2103) Cobalt Blue Glass (2104) Selective Neutral Glass (2105)			I	Spectrogram taken on each glass. For description of spectrophotometer-tristimulus integrator system see H. J. Keegan, J. C. Schleter and D. B. Judd, *J. Res. Nat. Bur. Stand.* **66A**, 203 (1962).
Two types of polished and unpolished black, bulk-dyed glasses for reflectometer (gloss) measurements			B	Reference: DIN: 67 530 ASTM: 523-67
	Glass Filter Set of three (930a)	Each filter individually certified for absorbance at 440, 465, 590, and 635 nm, with relative uncertainty of ±0.5%.	I	See certificate for full details; also R. Mavrodineanu, NBS Tech. Note 544 (1971).
	Set of three liquid absorbance filters	Each liquid filter certified for absorbance at 302, 395, 512, and 678 nm.	I	See R. W. Burke *et al.*, *J. Res. Nat. Bur. Stand.* **76A** (1972).
	Quartz Cuvette	Pathlength and parallelism certified to ±0.0005 nm.	I	
	Set of 16 enameled iron discs	Spectral reflectance values from 380 to 760 nm.	D	Tristimulus values and chromacity coordinates under illuminates A and C for geometries 45°/0° and 0°/45°.
	White reflection standard, durable, polished Russian MS-20 photometric Opal glass. Reflection value high over entire calibrated spectral range.		H	Same conditions as second item, above, in this category.
	Set of 6 neutral glass filters	Transmittance and absorbance certified at 9 wavelengths in region from 480 to 640 nm.	G	Uncertainty at 95% confidence level = ±0.3%T
	Set of 24 rotating two-sector discs	E.g. Disc No. 1, A = 1.39470 Disc No. 24, A = 0.01770	G	Uncertainty at 99% confidence level = 0.02%. Primary metrological standard.
	(White) reflection standard	Spectral radiance factor for the d/O-geometry in the wavelength region from 320 to 800 nm.	C	(From the spectral values, integrated values such as radiance factor or tristimulus values X, Y, Z may be calculated with sufficient accuracy.)
		Spectral radiance coefficient for the 45/O-geometry in the wavelength region from 390 to 800 nm.	C	Reference: DIN 5033 Blatt 9 The $BaSO_4$ powder is available from E. Merck, Darmstadt. A random sample of every batch is measured by the Physikalisch-Technische Bundesanstalt, Braunschweig. The values of the spectral radiance factor and spectral radiance coefficient are considered as representative for the whole batch.

†Units are given as reported by issuing laboratory.

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
		4. DENSITY (Confidence level 99%)		
99.95	Cyclohexane	(0.77854 ± 0.000005)g·cm^{-3} (20°C)	G	Temperature flotation method and pyknometric method. Density for these materials is given also at 10, 30, 40, 50 and 60°C.
Unknown	Kerosene(a)	(0.81016 ± 0.000005)g·cm^{-3} (20°C)		
Unknown	Kerosene(b)	(0.86188 ± 0.000005)g·cm^{-3} (20°C)		
97.5	Methylcyclohexane	(0.77037 ± 0.000005)g·cm^{-3} (20°C)		
>99.9	Toluene	(0.86668 ± 0.000005)g·cm^{-3} (20°C)		
99.5	2,2,4-Trimethyl-pentane	(0.69194 ± 0.000005)g·cm^{-3} (20°C)		
99.993 ±0.003	2,2,4-Trimethyl-pentane (217b)	(0.69183 ± 0.000002)g·cm^{-3}) (20°C)	I	Also certified for heat of combustion and refractive index and at 25 and 30°C.
99.72	*n*-Hexane	659.38 ± 0.07kg·m^{-3} (20°C)	G	Certified also at 25, 30, 35, 40, 45, and 50°C.
Unknown	*n*-Heptane	683.79 ± 0.03kg·m^{-3} (20°C)		
99.75	Isooctane	691.96 ± 0.07kg·m^{-3} (20°C)		
99.40	*n*-Octane	702.57 ± 0.03kg·m^{-3} (20°C)		
97.20	*n*-Nonane	717.68 ± 0.06kg·m^{-3} (20°C)		
99.80	Methylcyclohexane	769.58 ± 0.07kg·m^{-3} (20°C)		
99.98	Cyclohexane	778.58 ± 0.06kg·m^{-3} (20°C)		
99.74	Toluene	866.77 ± 0.04kg·m^{-3} (20°C)		
		5. DIELECTRIC CONSTANTS (relative permittivity)		
	Cyclohexane	2.025 ± 0.002(1.8 MHz, 20°C)	D	Purified with molecular sieve; spectroscopically pure.
	Carbon tetra-chloride	2.240 ± 0.002(1.8 MHz, 20°C)		
	Chlorobenzene	5.690 ± 0.002(1.8 MHz, 20°C)		
	Cyclohexane (1511)	2.02280 ± 0.00004(0.75–12 kHz) at 20°C	I	Certified also at 25 and 30°C.
	1,2-Dichloroethane	10.6493 ± 0.0008(0.75–12 kHz) at 20°C		
	Nitrobenzene	35.7037 ± 0.0010(0.75–12 kHz) at 20°C		
		6. DIFFERENTIAL THERMAL ANALYSIS*		
High-purity	Potassium nitrate (758)	Equilibrium value 127.7°C Extrapolated onset 128°C Peak 135°C	I	
High-purity	Indium(metal) 758)	Equilibrium value 157°C Extrapolated onset 154°C Peak 159°C		
High-purity	Tin(metal) (758)	Equilibrium value 231.9°C Extrapolated onset 230°C Peak 237°C		
Commercial grade	Potassium per-chlorate (758) (759)	Equilibrium value 299.5°C Extrapolated onset 299°C Peak 309°C		
Analysed reagent	Silver sulphate (758) (759)	Equilibrium value— Extrapolated onset 424°C Peak 433°C		
Natural quartz	Silica (759) (760)	Equilibrium value 573°C Extrapolated onset 571°C Peak 574°C		
Analysed reagent	Potassium sulphate (759) (760)	Equilibrium value 583°C Extrapolated onset 582°C Peak 588°C		

*Note: These reference materials are certified by the International Confederation for Thermal Analysis. They are issued through the National Bureau of Standards. They are for use in calibrating the temperature scale on differential thermal analysis and related thermoanalytical equipment under operating conditions, and are to be used only in the heating mode.

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
Analysed reagent	Potassium chromate (759) (760)	Equilibrium value 665°C Extrapolated onset 665°C Peak 673°C	I	
Analysed reagent	Barium carbonate (760)	Equilibrium value 810°C Extrapolated onset 808°C Peak 819°C		
Analysed reagent	Strontium carbonate (760)	Equilibrium value 925°C Extrapolated onset 928°C Peak 938°C		
		7. MAGNETIC SUSCEPTIBILITY		
>99.9	Aluminum (763)	0.604×10^{-6} cm^3·g^{-1} at 297K (uncertainty $< \pm 0.5\%$)	I	
>99.9	Platinum (764)	0.991×10^{-6} cm^3·g^{-1} at 297K		Same uncertainty as for Al
>99.9	Palladium (765)	5.26×10^{-6} cm^3·g^{-1} at 297K		
>99.9	Manganese fluoride	123.3×10^{-6} cm^3·g^{-1} at 297K		
99.99 wt% (tested for 18 elements)	Potassium chloride	at 25°C, specific conductivity is 146.6×10^{-6} S·cm^{-1} for 0.0745 g KCl in 1 kg H_2O solution	G	Specific conductivity certified at 0, 18 and 25°C for four different molalities ranging from 0.0745 to 71.1352 g KCl in 1 kg H_2O solution.
		8. MOLAR CONDUCTANCE		
Analytical reagent grade KCl	Potassium chloride	0.1 mol dm^{-3}(116.8 ± 0.1) S cm^{-1} (20°C) 0.01 mol dm^{-3}(127.7 ± 0.1) S cm^{-1} (20°C)	D	
		9. MOLECULAR WEIGHT OF POLYMERS		
	Polystyrene (narrow molecular weight distribution) (705)	M_N 170 900 ± 580	I	M_N = Number-average molecular weight (measured by osmotic pressure).
		M_W 179 300 ± 740		M_W = Weight-average molecular weight (measured by light scattering).
		M_Z 189 800 ± 2100		M_Z = Weight-average molecular weight (measured by sedimentation equilibrium).
	Polystyrene (broad molecular weight distribution) (706)	M_W 257 800 ± 930 M_Z 288 100 ± 9600	I	$M_Z:M_W:M_N = 1.12:1.07:1$ $M_Z:M_W:M_N = 2.9:2.2:1$
	Polyethylene (linear) whole polymer	M_Z = 138 000 ± 3700 M_W = 53 070 ± 620 M_N = 18 310 ± 360 $M_Z:M_W:M_N = 7.54:2.90:1$	I	Limiting viscosity number, melt flow rate and density are also certified. See *J. Res. Nat. Bur. Stand.* **76A**, No. 2 (1972).
	Polyethylene (branched) whole polymer	Limiting viscosity number = 0.8132 ± 0.0033 dl·g^{-1} at 130°C in 1-chloronaphthalene melt index = 1.19 ± 0.010 g/10 min density = 0.9312 ± 0.0006 g·cm^{-3}	I	Limiting viscosity number given also for 1,2,4 trichlorobenzene and decalin.
	Polypropylene (narrow molecular weight distribution)	Certified for each batch for M_N and M_W	H	Batches available in the range 10,000 < M_W < 33,000 and $M_W:M_N \approx 1.5$
	Polypropylene (broad molecular weight distribution)	Certified for molecular weight distribution	H	Molecular weight distribution determined by gel permeation chromatography in the range 9,000–400,000
	Polystyrene (broad molecular weight distribution)	Certified for molecular weight distribution	H	In the range 10,000–1,500,000
	Poly(vinylchloride) (narrow molecular weight distribution)	Certified for each batch for M_N and polydispersity	H	Polydispersity = M_W/M_N as determined by gel permeation chromatography. Batches available in the range 30,000 < M_N < 180,000 and $M_W M_N \approx 1.5$
	Polypropylene (narrow molecular weight distribution)	Each batch certified for M_W and M_N	H	Batches available in the range M_W = 10,000–350,000 (measured by light scattering). M_N measured by osmometry.

†Units are given as reported by issuing laboratory.

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
		10. MÖSSBAUER DIFFERENTIAL CHEMICAL SHIFT		
Single crystals grown from solution of ACS grade salt	Sodium pentacyanonitrosylferrate(iii) dihydrate (725) (Sodium nitro prusside)	(0.0000 ± 0.0002)cm/s at 25°C	I	Average value of electric quadrupole splitting (0.1726 ± 0.0002)cm/s.
	Iron Foil (1541)	Six peak positions certified with respect to SRM 725, above.	I	See NBS Spec. Publ. 260-13 (1972).
		11. pH		
(Note: pH reference materials are certified by D, G, H, and I. pH values, for each material listed, are given only at 20°C for the material whose pH has the smallest uncertainty quoted. Purities range from 99.5 to >99.9 mol%. Readers should contact the specific supplier for detailed information, and the definition of the pH scale employed.)				
	Potassium tetroxalate	1.675 ± 0.005 at 20°C	D,G,I	
	Potassium hydrogen tartrate	3.557 ± 0.005 at 25°C	D,G,I	
	Potassium hydrogen phthalate	4.003 ± 0.005 at 20°C	D,G,H,I	H certifies, but samples are prepared and distributed by commercial firms, e.g. BDH
	Potassium dihydrogen phosphate *plus* disodium hydrogen phosphate	6.878 ± 0.005 at 20°C 7.426 ± 0.005 at 20°C	D,G,I D,G,I	0.025 mol kg^{-1} of KH_2PO_4 plus 0.025 mol kg^{-1} Na_2HPO_4 0.008695 mol kg^{-1} KH_2PO_4 plus 0.03043 mol kg^{-1} Na_2HPO_4.
	Sodium tetraborate decahydrate	9.225 ± 0.005 at 20°C	D,G,I	
	Sodium hydrogen carbonate *plus* sodium carbonate	10.064 ± 0.005 at 20°C	D,I	0.025 mol kg^{-1} of solution for both $NaHCO_3$ plus Na_2CO_3
	Calcium hydroxide	12.63 ± 0.1 at 20°C	G	
	Note for Source G: whenever possible pH value is being standardized vs platinum hydrogen electrode.			
		12. pD		
	Potassium dihydrogen phosphate (2186-I) *plus* disodium hydrogen phosphate (2186-II)	7.449 ± 0.01 (20°C)	I	Purities meet ACS Specifications. 0.025 mol kg^{-1} KH_2PO_4 + 0.025 mol kg^{-1} Na_2HPO_4.
	Sodium hydrogen carbonate (2191) *plus* sodium carbonate (2192)	10.794 ± 0.01 (20°C)		Purities meet ACS Specifications. 0.025 mol kg^{-1} $NaHCO_3$ + 0.025 mol kg^{-1} Na_2CO_3.
		13. POLARIMETRY–SACCHARIMETRY		
	Sucrose	α[546.1 nm, 20°C] = 78.35 ± 0.01°	G	At ICOMSA definition of 100°S refers to 26 g per 100 cm^3 of solution.
	Sucrose (17a)	α(546.1 nm, 20°C) = 78.342°	I	Concentration 26 g/100 cm^3. Moisture less than 0.01%, reducing substances less than 0.02%.
	D-Glucose (41a)	α(589.25 nm, 20°C) = 66.529° α(D, 20°C) = 52.7°	I	Concentration 26 g/100 cm^3. α(546.1 nm, 20°C) = 62.032°. Ash less than 0.01%, moisture less than 0.1%.
	Quartz plates	Degree of optical rotation ±0.001°	C	Quartz plates with certified values of optical rotation are used as standards for the calibration of saccharimeters in the spectral range from 540 to 590 nm. Specifications for quartz plates are given in OIML-Recommendations No. 14. Users have to send plates to PTB for certification. See: K. Zander, W. Seiler, R. Bünnagel, Präzisionsmessungen der Rotationsdispersion wässriger Saccheroselösungen von 18°C bis 30°C als Basis für die Internationale Zuckerskala. *Zucker*, 27, S. 642–647 (1974).

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
		14. REDUCTOMETRY–OXIDIMETRY		
	Arsenic trioxide (83c)	99.99 ± 0.02		
	Potassium dichromate (1361c)	99.98 ± 0.02	I	Purity meets ACS Specifications.
	Sodium oxalate (40 g)	99.95 ± 0.02		
		15. REFRACTIVE INDEX		
99.95	2,2,4-Trimethyl-pentane	$1.39139 \pm 0.00003 n_D$ (20°C)	G	95% confidence level.
99.993 ± 0.002	2,2,4-Trimethyl-pentane (217b)	at 589.25 nm and 20°C n = 1.39147	I	Certified for 7 wavelengths and at 20, 25, and 30°C. Uncertainty of all values less than 0.00002.
Unknown	Methylsilicon oil	$1.40444 \pm 0.00003 n_D$ (20°C)	G	Viscosity 152 cP density: 969.0 kg·m^{-3}
Unknown	Methylcyclohexane	$1.42431 \pm 0.00003 n_D$ (20°C)		
94.1	Cyclohexane	$1.42622 \pm 0.00003 n_D$ (20°C)	G	All at 95% confidence level.
99.75	Toluene	$1.49675 \pm 0.00003 n_D$ (20°C)		
97.8	1-Bromonaphthalene	$1.6580 \pm 0.0002 n_D$ (20°C)		
98.9	Chlorobenzene	$1.52452 \pm 0.00003 n_D$ (20°C)		
99.4	o-Nitrotoluene	$1.54643 \pm 0.00003 n_D$ (20°C)	G	95% confidence level.
99.95	Trimethylpentane	$1.39139 \pm 0.00003 n_D$ (20°C)		
	Glass (1820)	At hydrogen C line (656.28 nm), e.g. n = 1.48532 ± 0.00001	I	n given for 13 different spectral source wavelengths
	Optical glass "Crown"	$1.51840 \pm 0.00002 n_D$ (20°C)		
	Optical glass "Dense Barium Flint"	$1.62292 \pm 0.00001 n_D$ (20°C)	G	
	Optical glass "Dense Barium Flint"	$1.65145 \pm 0.00001 n_D$ (20°C)		
		16. RELATIVE HUMIDITY		
Analytical Reagent Grade used for all Relative Humidity Reference Materials	Lithium chloride Monohydrate	RH = 12.6 ± 1% at 20°C	G	All RH data at 99% confidence level
	Magnesium chloride Hexahydrate	RH = 33.6 ± 1.2% at 20°C	G	$RH\% = p/p_w \cdot 100$ Instructions given for all RH reference materials.
	Magnesium nitrate Hexahydrate	RH = 56.2 ± 2.2% at 20°C	G	
	Sodium chloride	RH = 76.2 ± 1.7% at 20°C		
	Ammonium sulfate	RH = 81.3 ± 1% at 20°C	G	Data also certified at 25 and 30°C.
	Potassium nitrate	RH = 95.0 ± 1.7% at 20°C		
	Potassium sulfate	RH = 98.9 ± 1.3% at 20°C		
		17. SPECULAR SPECTRAL REFLECTANCE		
	Aluminum on glass (2001-04)	Certified for near-normal (9°) specular reflectance	I	At wavelengths from 0.2537 to 30 μm and band widths from 1.0–1800 nm. Precision is σ_m of six replicate measurements.
	Gold on glass (2005-08)	Same as above	I	Same. See reference NBS Spec. Publ. 260-38 (1972).
		18. SURFACE AREA		
High-purity (full analysis available)	Carbon black	11.1 ± 0.8 m^{2}g^{-1}	H	Graphitized at 2700°C. For all four of these reference materials, specific surface areas are nitrogen BET values and were
	Carbon black	71.3 ± 2.7 m^{2}g^{-1}	H	calculated from adsorption isotherm data from 13 laboratories.
	Non-porous silica	165.8 ± 2.1 m^{2}g^{-1}	H	Materials produced by plasma process.
	Silica gel	286.2 ± 3.5 m^{2}g^{-1}	H	Micronized meso-porous material.
		19. SURFACE TENSION		
	Sulfuric acid and ethanol	25.9 to 56.2 ± 0.16 mN·m^{-1}	D	Density from (0.90–1.84) × 10^3 kg·m^{-3}
99	*n*-Hexane	(18.42 ± 0.02) mN/m at 20°C	C	mN/m (MilliNewton per Meter) = dyn/cm; Surface tension liquid–air Measuring principle: Modified Wilhelmy-plate procedure.
99.9	*n*-Heptane	(20.23 ± 0.02) mN/m at 20°C		
99	*n*-Octane	(21.64 ± 0.02) mN/m at 20°C		

† Units are given as reported by issuing laboratory

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
		20. THERMAL CONDUCTIVITY ($W \cdot m^{-1} \cdot K^{-1}$)		
99.98	Platinum	$(70.25 + 0.0075t) \pm 0.5\%$	C	$0°C < t < 100°C$
99.0	Propyl alcohol	$(0.1575 - 0.000230t) \pm 0.5\%$	C	$10°C < t < 40°C$—0.05
99.8	Isopropyl alcohol	$(0.1395 - 0.000202t) \pm 0.5\%$	C	$10°C < t < 40°C$—0.1
99.5	Butyl alcohol	$(0.1534 - 0.000211t) \pm 0.5\%$	C	$10°C < t < 55°C$—0.1 } Water (mass%)
99.8	see Butyl alcohol	$(0.1400 - 0.000203t) \pm 0.5\%$	C	$10°C < t < 55°C$—0.05
99.2	Isobutyl alcohol	$(0.1353 - 0.000166t) \pm 0.5\%$	C	$10°C < t < 55°C$—0.05
99.9+	Electrolytic iron (734)	λ certified from 6 to 280K	I	See J. G. Hust *et al.*, *J. Res. Nat. Bur. Stand.* **74A**, 673 (1970).
	Austenitic stainless steel (735)	λ certified from 5 to 280K	I	Same reference as above.
		21. THERMAL EMISSIVITY ϵ (Dimensionless)		
	Platinum—13% Rhodium alloy (1402-09)	Certified for ϵ at 800, 1100, 1400 and 1600K and wavelengths from 1 to 36 μm.	I	See W. N. Harrison *et al.*, Report AD426846 National Technical Information Service (1963).
	Oxidized kanthal (1420–28)	Certified for ϵ at 800, 1100, and 1300K from 1 to 15 μm.	I	Same reference as above.
	Oxidized inconel (1440-47)	Same as above.	I	Same reference as above.
		22. THERMAL EXPANSION (Expansivity, (α), K^{-1})		
	Borosilicate glass (731)	Certified for expansion and expansivity from 80 to 680K.	I	See NBS Spec. Publ. 303 (1968)
99.99 at%	Copper	Certified for expansion and expansivity from 20 to 800K.	I	See T. A. Hahn, *J. Appl. Phys.* **41**, 5096 (1970).
99.8	Fused silica	Certified for expansion and expansivity from 80 to 1000K.	I	
		23. THERMOMETRIC FIXED POINTS		
	Water triple point cell	Triple point 273.16K[a]	H	International Practical Temperature Scale (1968)
9 99.999	Aluminum metal	Freezing point (660°C)[b]	C	
	Aluminum (44e)	Freezing point $(660.3 \pm 0.2°C)$[b]	I	International Temperature Scale (1968).
99.9+	Aluminum oxide (742)	Melting point $(2053 \pm 5°C)$[b]	I	IPTS-68, Pyrometric standard
	Benzene–water	Freezing point certified for each batch	H	Used in STPTC Test Method RLB 24-67 and British Standard BS-135
99.99	Benzoic acid	Freezing point (122°C)[b]	F	Purity derived from temperature/enthalpy curves.
99.99	Benzophenone	Freezing point (48°C)[b]	F	
99.99	Dimethyl terephthalate	Freezing point (142°C)[b]	F	
99.99	Biphenyl	Freezing point (70°C)[b]	F	
99.999	Cadmium metal	Freezing point (321°C)[b]	C	
99.999	Copper (45d)	Freezing point $(1084.8 \pm 0.5°C)$[b]	I	International Temperature Scale (1968).
99.998	Gold metal	Freezing point (1064.43°C)[a]	C	
	Lead (49e)	Freezing point $(327.493 \pm 0.005°C)$[b]	I	International Temperature Scale (1968).
99.99	Naphthalene	Freezing point (80°C)[b]	F	Purity derived from temperature/enthalpy curves.
99.996	Neopentane	Transition point (−132°C)[b]	E	Purified by using a spinning band type distillation tower of 3 m height and an adsorption column packed with molecular sieve.
		Triple point (−16°C)[b]	E	
99.99	Phenanthrene	Freezing point (100°C)[b]	F	Purity derived from temperature/enthalpy curves.
99.994	Silver metal	Freezing point (961.93°C)[a]	C	Thermodynamic temperatures.
>99.9	Silver–copper eutectic	Freezing point (779°C)[b]	C	Thermodynamic temperatures.
99.99	1,2,4,5-Tetrachlorobenzene	Freezing point (140°C)[b]	F	Purity derived from temperature/enthalpy curves.
99.99	Sodium	Freezing point (97°C)[b]	F	Purity derived from temperature/enthalpy curves.
99.999	Sulphur	Boiling point (444°C)[b]	C	Thermodynamic temperatures.
99.999+	Tin (741)	Freezing point $(231.9681 \pm 0.0007°C)$[a]	I	Primary fixed point on IPTS-68
99.999	Tin metal	Freezing point (231°C)[b]	C	Thermodynamic temperatures.
	Tin (42f)	Freezing point $(231.940 \pm 0.005°C)$[b]	I	International Temperature Scale (1968).

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
99.999	Zinc metal	Freezing point (419.58°C)[a]	C	Thermodynamic temperatures.
99.9999	Zinc (740)	Freezing point (419.58°C)[a]	I	Fixed point on International Practical Temperature Scale of 1968.
	Superconductive thermometric fixed point device (767)	Cadmium—0.515 ± 0.0025K Zinc—0.844 ± 0.0015K Aluminum—1.1746 ± 0.002K Indium—3.416 ± 0.0015K Lead—7.201 ± 0.0025K	I	Use of this device and discussion of how prepared and certified, see NBS Spec. Publ. 260-44 (1972).
99.9+	4-Nitrotoluene	Melting temperature 53°C[b]		
99.9+	Naphthalene	Melting temperature 81°C[b]		
99.9+	Benzil	Melting temperature 96°C[b]		
99.9+	Acetanilide	Melting temperature 115°C[b]		
99.9+	Benzoic acid	Melting temperature 123°C[b]	H	Certificates accompanying each sample state the meniscus and liquefaction (melting) temperature of the compound measured in glass capillary tubes, under controlled conditions of temperature rise. The freezing temperatures of the samples have also been measured.
99.9+	Diphenylacetic acid	Melting temperature 147°C[b]		
99.9+	Anisic acid	Melting temperature 184°C[b]		
99.8	2-Chloroanthraquinone	Melting temperature 211°C[b]		
99.9+	Carbazole	Melting temperature 247°C[b]		
99.9+	Anthraquinone	Melting temperature 286°C[b]		

Note: Temperature of the primary fixed points for calibration on the International Practical Temperature Scale of 1968 (IPTS-68) are indicated by the superscript a. Secondary reference points carry a nominal temperature value for general information only, and are indicated by the superscript b. The temperature certified by the standardizing laboratory appears only on the certificate provided with the sample.

24. VAPOUR PRESSURE

99.9968	Neopentane	35.793 ± 0.017 kN m^{-2} (256.750K)	E	Purified by using a spinning band type distillation tower of 3 m height and an adsorption column packed with molecular sieve.
99.999+	Gold (745)	Certified for vapor pressure over range 1300–2100K. At 1338K (M.P.), $P = 2.56 \times 10^{-8}$ atm	I	1 atm = 101,325 N·m^{-2} See NBS Spec. Publ. 260-19 (1970) for full discussion of data and uncertainties.
99.999+	Cadmium (746)	Certified for vapor pressure over range 350–594K. At 594K (M.P.), $P = 1.51 \times 10^{-4}$ atm	I	See NBS Spec. Publ. 260-21 (1971) for full discussion of data and uncertainties.
99.999+	Silver (748)	Certified for vapor pressure over range 800–1600K at 1235K (M.P.), $P = 3.71 \times 10^{-6}$ atm		
99.94 ± 0.03	Naphthalene	0.23–1.38Pa, ±5% (263.61–278.22K) 2.41–489Pa, ±2% (283.14–343.06K)	H	Vapour pressures measured over a range of temperature using a diaphragm gauge.
99.92 ± 0.02	Hexamethylbenzene	0.28–14.39Pa, ±10% (303.10–343.02K)	H	

25. VISCOSITY

A. Liquids

	AS 2.5 oil	1.8(0.03%)* at 310.9K	
	AS 7.5 oil	6.0(0.03%)* at 310.9K	
	AS 25 oil	20(0.04%)* at 310.9K	A Newtonian liquid**. In centipoise = cP = mN·s·m^{-2}.
	AS 75 oil	65(0.05%)* at 310.9K	
	AS 200 oil	180(0.08%)* at 310.9K	
	AS 600 oil	550(0.2%)* at 310.9K	

Note for Source A: *Nominal standard error of the dynamic viscosity.
**These liquids also certified as to nominal density and kinematic viscosity.

	Mineral oil	1–1000 (20°C)0.2%	
	Polymer solutions	2000–200000 (20°C)0.5%	F Newtonian liquids. In centipoise (as above) except last; confidence level >95%.
	Polymer solutions	2000–200000 (20°C)1%	
	Polymer solution	2000–20000 (20°C)2% (poise)	
	Series of 11 mineral oils	Certified for actual batches available, in centipoise. Range over all oils is from 5.896 ± 0.1% to 1298 ± 0.2% at 20°C	Uncertainties at >95% confidence level. G Certified also at 50 and 80°C. cP = mN·s·m^{-2}

†Units are given as reported by issuing laboratory.

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
	Silicone oil	245,000 ± 1.5% at 20°C	G	Values via rotating cylinder viscometer
	Silicone oil	317,000 ± 2.0% at 20°C		and by 'Visco wage' viscobalance.

Note for Source G: All values are given for materials actually in stock. Determined by the use of long (400 mm) capillary tube suspended level Ubbelohde viscometers.

	Type JS 2.5–2000 (series of 10 liquids)	Certified for viscosity in centipoise and kinematic viscosity in centistokes. Range for viscosity at 20°C from 2 to 1800.	E	
	Type 60H	60,000 cSt at 20°C	E	
	Type 200H	200,000 cSt at 20°C	E	
	Mineral oil	1–1000 cP ±0.1% at 20°C		Newtonian liquid. Certified also for
	Mineral oil	10^3–10^4 cP ±0.5% at 20°C	D	density and kinematic viscosity.
	Polyisobutenes	10^4–10^5 cP ±1.5% at 20°C		Newtonian liquid. Rotating cylinder
	Silicone oil	10^5–3×10^5 cP ±1.5% at 20°C	D	viscometer method used.
	Series of 11 Mineral oils	Certified for viscosity in centipoise at 20°C. Range from 1.503 ± 0.1% to 1729 ± 0.2%.	G	Certified also for kinematic viscosity and density. Data also for 50 and 80°C.
	Series of 7 Polyisobutylenes	Certified for viscosity in centipoise at 20°C. Range from 4170 ± 1.3% to 589×10^3 ± 1.0%.	G	Data also at 50, 80, and 100°C.

Oil	Viscosity at 20°C dyn. in cP	kin. in cSt
1 B	0.97	1.25
2 A	2.12	2.64
5 B	4.59	5.83
10 A	8.5	10.2
10 B	12.9	15.2
10 D*	14.7	16.7
10 C	18.3	21.2
20 C	21.2	24.9
20 E*	45.5	49.6
50 C	88	100
100 A	117	134
100 D*	131	149
100 C	157	177
200 A	223	254
200 C	237	265
200 D*	338	381
500 B	430	458
500 F	650	730
500 E*	875	970
2000 C	1790	1990
2000 E	2850	3280
2000 A	4100	4700
10,000 C	8500	9700
10,000 D	13,500	15,200
20,000 C	26,600	30,000

C — cP: Centipoise; c St: Centistokes; Amounts available: 100 ml, 200 ml, 500 ml. Oils marked by * indicate amounts of 1000 ml are also available.

25. VISCOSITY

B. Glasses

Soda-lime silica glass (710)

SiO_2	70.5%
Na_2O	8.7%
K_2O	7.7%
CaO	11.6%
Sb_2O_3	1.1%
SO_3	0.2%
R_2O_3	0.2%

$$\log_{10}\eta = -1.626 + \frac{4236.118}{t - 266}$$

$\sigma = 0.020$

(t in °C)

I — Softening point (avg.) 724°C
Annealing point (avg.) 546°C
Strain point (avg.) 504°C

Table 1 (Contd.)

Purity (mol %)	Chemical name (Identification No.)	Certified value† and accuracy	Source	Remarks
	Lead–silica glass (711) SiO_2 46.0% PbO 45.32% K_2O 5.62% Na_2O 2.50% R_2O_3 0.56%	$\log_{10}\eta = -1.621 + \frac{4254.649}{t - 1521}$ $\sigma = \pm 0.035$ (t in °C)	I	Softening point (avg.) 602°C Annealing point (avg.) 432°C Strain point (avg.) 392°C
	Borosilicate glass (717) SiO_2 70% B_2O_3 17% K_2O 8% Na_2O 1% Al_2O_3 3% Li_2O 1%	$\log_{10}\eta = -1.546 + \frac{4775.14}{t - 198.3}$ $\sigma = 0.029$ (t in °C)	I	Softening point (avg.) 720°C Annealing point (avg.) 516°C Strain point (avg.) 471°C
	(Glasses from 2 melts are available. Nominal composition is $SiO_2 = 72.2\%$; $Al_2O_3 = 1.0\%$; CaO = 6.6%; MgO = 4.2%; $Na_2O = 15.1\%$ (plus others). Viscosity is certified on basis of Vogel equation; mean deviations (in K) from the equation are given together with constants of the Corr.-Function. Full details are found in G. Meerlender, Viskositäts-Temperaturverhalten des Standardglases I der DGG, *Glastechnische Berichte* **47**, 1–3 (1974).		C	

†Units are given as reported by issuing laboratory

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