NBS
PUBLICATIONS

NAT'L INST. OF STAND & TECH
A11106 229068

NBSIR 81-2276

A Compilation of Thermodynamic and Transport Properties of Aqueous Sulfuric Acid

Bert R. Staples and Theresa F. Wobbeking

August 1980

Issued June 1981

Prepared for:
Department of Energy
DOE Order No. EW 78-X-03-0509-A001.

QC
100
.U56
81-2276
1981
c.2

AUTHENTICATED
U.S. GOVERNMENT
INFORMATION
GPO

NATIONAL BUREAU
OF STANDARDS
LIBRARY

JUL 20 1981

Not acc - Circ
QC100
U56
no. 81-2276
1981
c.2

NBSIR 81-2276

A COMPILATION OF THERMODYNAMIC AND TRANSPORT PROPERTIES OF AQUEOUS SULFURIC ACID

Bert R. Staples and Theresa F. Wobbeking

August 1980

Issued June 1981

Prepared for:
Department of Energy
DOE Order No. EW 78-X-03-0509-A001.

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

A COMPILATION OF THERMODYNAMIC AND TRANSPORT PROPERTIES OF AQUEOUS SULFURIC ACID

Bert R. Staples

and

Theresa F. Wobbeking

Electrolyte Data Center
Chemical Thermodynamics Division
National Measurement Laboratory
National Bureau of Standards
Washington, DC 20234

ABSTRACT

A detailed compilation of sources of data for the thermodynamic and transport properties of aqueous sulfuric acid is presented. All ranges of temperature, concentration, and pressure are included.

Key Words: Activity coefficients; aqueous; compilation; conductivity; enthalpy; electrolytes; Gibbs energy; osmotic coefficients; solutions; sulfuric acid; thermodynamic properties; transport properties.

Appendix 1. Annotated Portion

Abel, E., J. Phys. Chem., 50, 260 (1946).
Represents vapor pressures of H_2SO_4 from 2.5 to over 90 mol/kg.

Bass, S. J., Gillespie, R. J., Oubridge, J. V., J. Chem. Soc., 837, (1960).
The authors have measured the osmotic coefficients of aqueous H_2SO_4 for compositions of 0.00 to 0.40m.

Burt, B. C., J. Chem. Soc., 85, 1339 (1904).
Reports the vapor pressure of sulfuric acid solutions for temperatures from 55 to 235C and for concentrations ranging from 24.92 to 95.94% H_2SO_4.

Collins, E. M., J. Phys. Chem., 37, 1191 (1933).
The vapor pressures for sulfuric acid solutions was obtained for temperatures from 24.87 to 135.61C and for concentrations ranging from 29.90 to 65.47% H_2SO_4.

Covington, A. K., Dobson, J. V., and Wynne-Jones, Trans. Far. Soc., 61, 2050 (1965).
Report data for the composition range of 0.007 to 0.1 mol/kg and 5 data sets for the cell Pt; H_2, H_2SO_4(m), $PbSO_4$, PbO_2; Pt, 13 data sets for the cell Pt; H_2, H_2SO_4(m), Hg_2SO_4, Hg; Pt and 7 points for the cell Pt; H_2, H_2SO_4(m), Ag_2SO_4; Ag.

Daudt, W., Z. Physik. Chem., 160, 255 (1923).
Measured vapor pressures at very low temperatures for compositions of 20-60 mol/kg H_2SO_4.

Deno, N. C. and Taft, R. W., Jr., J. Am. Chem. Soc., 76, 244 (1954).
Used the Hammett relation to calculate the activity of water in aqueous H_2SO_4 at molalities exceeding 30 mol/kg.

Duisman, J. A. and Giauque, W. F., J. Phys. Chem., 72, 562 (1968).
Used a variety of data sources to derive thermodynamic quantities for the lead storage cell and a set of emf values from third law considerations.

Edward, J. T. and Wang, I. C., Can. J. Chem. 43, 2867 (1965).
Measured the dissociation of the bisulphate ion over a concentration range of 0.010 to 0.30 OM at an temperature of 27.0+/-1.5C.

Feilchenfeld, H. and Fuchs, J., Israel J. Chem., 12, 899 (1974).
Measured the hydration of H_2SO_4 at 25C.

Flis, I. E., Mischenko, K. P., Pakhomova, N. Y., Russ. J. Inorg. Chem., 3, 1772 (1958).
The authors have measured the heat of neutralization of H_2SO_4 at 10, 25, 35 and 50C. The dissociation of the bisulphate ion was calculated at temperatures of 10, 25, 35, and 50C.

Gardner, W. L., Jekel, E. C. and Cobble, J. W., J. Phys. Chem. 73 (6), 2017 (1969).
The standard partial molal heat capacities of H_2SO_4 have been obtained by the integral heat method between 0 and 100C.

Gardner, W. L., Mitchell, R. E., and Cobble, J. W., J. Phys. Chem. 73 (6), 2021 (1969).
The authors used the third law method to calculate a set of activity coefficients as a function of temperature (0 to 55C) and concentration (0.1 to 4.0 mol/kg).

Glueckauf, E., and Kitt, G. P., Trans. Far. Soc. 52 , 1074 (1956).
Used a bithermal isopiestic method to determine osmotic coefficients between 20 and 65 mol/kg. These authors added a constant correction of 0.08 in the values of (m2-m1) to bring their results in agreement with others. The Clausius-Clapeyron relationship was used to construct a curve of osmotic coefficients at 25C.

Groenier, W. L., Partial dissertation, The University of Chicago (1933).
The heats of dilution of H_2SO_4 solutions at approximately 25C have been measured over a concentration range of about 0.003 to almost 4.0m.

Grollman, A. and Frazer, J. C. W., J. Am. Chem. Soc., 47, 712 (1925).
Determined the vapor pressures of aqueous sulfuric acid solutions at 25C. Thirteen values of the osmotic coefficient have been calculated from these data. The molalities range from 0.1 to 3 mol/kg.

Hamer, W. J., J. Am. Chem. Soc., 57, 9 (1935).
Determined the emf of the cell Pt; H_2, H_2SO_4 (m), $PbSO_4$; Pt for compositions of 0.005 to 7 mol/kg over a temperature range of 0-60C.

Hamer, W. J. Am. Chem. Soc., 57, 662 (1935).
Made measurements of the cell Hg; Hg_2SO_4, H_2SO_4 (m), Hg_2SO_4, Hg over an concentration range of 0.05 to 17.0 molal and at the temperatures of 0, 10, 15, 25, 35, 45, and 60C. The transference numbers of the hydogen ion of sulfuric acid were calculated over an concentration range of 0.05 to 17 molal and at temperatures of 0, 10, 15, 25, 35, 45, and 60C.

Harned, H. S. and Hamer, W. J., J. Am. Chem. Soc., 57, (1935).
Reported the emfs of the cell Pt; H_2, H_2SO_4 (m), Hg_2SO_4, Hg; Pt over a concentration range of 0.05 to 17.5 mol/kg at temperatures from 0 to 60C.

Hausrath, H., Ann. Phys. (Leipzig) 9, 522 (1902).
The freezing point method was used for 8 molalities in the dilute range from 0.0001 to 0.02 mol/kg.

Hepburn, J. R. I., Proc. Phys. Soc. London, 40, 249 (1928).
Determined the vapor pressures of H_2SO_4 solutions using a dew point method for 9 solutions from 7 to 12.5 mol/kg.

Hornung, E. W., and Giauque, W. F., J. Am. Chem. Soc., 77, 2744 (1955).
Performed a direct set of vapor pressure measurements on 3 solutions (14-28 mol/kg) as a function of temperature.

Jones, F. R., J. Appl. Chem. 1, S144 (1951).
An absorption method was employed by Jones to calculate the vapor pressure of H_2SO_4 at rounded molalities from 0.5 to 55 mol/kg.

Jones, H. C. and Getman, F. H., Am. Chem. J., 27, 433 (1902).
Have reported freezing point measurements for 9 concentrations (0.1 to 2.8 mol/kg).

Jones, H. C., Getman, F. H., Bassett, H. P. McMaster, L. and Uhler, H. S., Carnegie Institution of Washington, Publication No. 60, Washington, D.C. 1907.
Have reported freezing point measurements for 16 molalities between 0.1 and 6.4 mol/kg.

Jones, H. C., Z. Phys. Chem. (Leipzig) 12, 623 (1893).
Has reported freezing point measurements for 11 dilution solutions between 0.001 to 0.1 mol/kg.

Kerker, M., J. Am. Chem. Soc., 79, 3664 (1957).
Measured the quotient of activity coefficients of H_2SO_4 for compositions ranging from 0 to 1.80m at temperatures of 18, 25, and 50C. The dissociation of H_2SO_4 was measured at 18, 25, and 50C for concentrations of 0.0005 to 1.80m. The equivalent conductance of $HSO4^-$ was measured from 0.0 to 0.5m at temperatures of 18, 25, and 50C.

Kunzler, J. E. and Giauque, W. F., J. Am. Chem. Soc., 74, 5271 (1952).
Freezing point depressions were measured but all molalities were above 30 mol/kg.

Lange, E., Monheim, J. and Robinson, A. L., J. Am. Chem. Soc., 55, 4733 (1933).
Measured the heat of dilution of aqueous H_2SO_4 for concentrations of 0.00005 to 0.5m at an temperature of 25C.

Lilley, T. H. and Briggs, C. C., Electrochim Acta, 20, 257 (1975).
Empolyed earlier emf data (Shrawder and Cowperthwaithe, 1934) to calculate activity coefficients in the dilute region of 0.001 to 0.02 mol/kg.

Loomis, E. H., Ber Bunsenges. Phys. Chem., 26, 797 (1893).
Five freezing points were reported. The molalities for these points range between 0.01 to 0.2 mol/kg.

MacDougall, F. H. and Blumer, D. R., J. Am. Chem. Soc., 55, 2236 (1933).
The emf of the cell Pt; H_2, H_2SO_4 (m), $HgSO_4$, Hg; Pt was measured with varying additions of acetic acid. The authors also report measurements for 7 solutions where no acetic acid was added. These molalities varied from 0.05 to 2.2 mol/kg.

McHaffie, I. R., J. Chem. Soc., 112 (1927).
Determined vapor pressures for high molalities (above 20 mol/kg) using a vapor condensation method.

Morgan, J. J., Bender, D. A. and Capell, R. G., Chem. Met. Eng., 50, 122 (1943).
The authors measured the specific heats of H_2SO_4 at 80C.

Pickering, S. U., Ber. Dtsch. Chem. Ges., 25, 1099 (1892).
About 40 measurements of freezing points of H_2SO_4 solutions ranging from 0.001 to 0.4 mol/kg were made.

Pitzer, K. S., J. Phys. Chem., 80, 2863 (1976).
Has taken into account the dissociation of the HSO_4^- ion to describe some of the thermodynamic properties of sulfuric acid solutions.

Pitzer, K. S., Roy, R. N., and Silvester, L. F., J. Am. Chem. Soc., 99, 4930 (1977).
Calculated the cell potentials for H_2SO_4 at approximately 25C for compositions of 0.005 to 1.0 m. The activity and osmotic coefficients were determined for compositions of 0.1 to 6.0 m at approximately 25C.

Quist, A. S., Marshall, W. L., Jolley, H. R., J. Phys. Chem., 69, 2726 (1965).
The electrical conductances of dilute sulfuric acid solutions were measured at temperatures from 0 to 800 C and at pressures from 1 to 4000 bars. The first ionization constant of H_2SO_4 was calculated at densities below 0.8g/cm^3 and at temperatures between 400 and 800 C. The second ionization constant of H_2SO_4 was calculated at temperatures from 100 to 300 C and at densities up to 1.0g/cm^3.

Randall, M. and Cushman, O. E., J. Am. Chem. Soc., 40, 393 (1918).
Utilizing the cell Pt; H_2, H_2SO_4 (m), Hg_2SO_4, Hg; Pt, Randall and Cushman measured the free energy of dilution for 7 mole fractions corresponding to 0.005 to 8.2 mol/kg. The results were given only to the nearest 0.1mV.

Randall, M. and Scott, G. N., J. Am. Chem. Soc., 49, 647 (1927).
Have determine freezing points of 33 solutions from 0.001 to 0.1 mol/kg.

Randall, M. and Taylor, M. D., J. Phys. Chem., 45, 959 (1941).
Measured the heat capacity of aqueous H_2SO_4 for compositions of 0.05 to 2.4 m.

Rard, J. A. and Miller, D. G., Unpublished Data, (1977).
Have made available unpublished isopiestic data using KCl as a reference. The molalities range from 0.1 to 3 mol/kg. for 17 points.

Rard, J. A. and Spedding, F. H., J. Chem. Eng. Data, 22, 56 (1977).
Have carefully determined the isopiestic molalities of 60 solutions of H_2SO_4 using $CaCl_2$ is a reference. Their equilibration times of 4 days or more were generally double those by previous investigators. The molalities range from 3.8 to 13.3 mol/kg. and the measurements were taken at 25C.

Robinson, R. A., Trans. Faraday Soc., 35, 1229 (1939).
The activity coefficient of sulfuric acid has been determined by the isopiestic method at 25 C between 0.2 and 3 mol/kg. Robinson has used KCL as a reference to determine the isopiestic ratios of 53 solutions from 0.2 to 3 mol/kg.

Robinson, R. A., Trans R. Soc. N. Z., 75, 203 (1945).
Determined the isopiestic ratios of $H_2SO_4$4/NaCl at 25C.

Roth, W. A., and Knothe, W., Unpublished data given in Landolt-Bornstein Physikalisch-Chemische Tabellen, Auflage 6, Band II Teil 2, p. 862, A. Eucken, Editor, Springer-Verlag, Berlin (1960). Have determined freezing point depressions at 3 molalities below 0.1 mol/kg.

Scatchard, G., Hamer, W. J., and Wood, S. E., J. Am. Chem. Soc., 60, 3061 (1938).
Determined the isopiestic ratios of H_2SO_4 and both NaCl (32 points) and KCl (23 points), from 0.1 to 4.5 mol/kg.

Shankman, S. and Gordon, A. R., J. Am. Chem. Soc., 61, 2370 (1939).
The vapor pressure of sulfuric acid solutions at 25C has been measured by the static method for concentrations ranging from 2 to 23 molal.

Shrawder, J. Jr., and Cowperthwaite, I. A., J. Am. Chem. Soc., 56, 2340 (1934).
Have determine the activity coefficients of H_2SO_4 as a function of temperature for 5 dilute solutions (0.001 to 0.02 mol/kg). They employed the following cell Pb-Hg (2 phase), $PbSO_4$, H_2SO_4 (m), H_2, with an lead amalgam electrode.

Stokes, R. H., J. Am. Chem. Soc., 67, 1686 (1945).
The activities and partial molal heat contents of water in sulfuric acid solutions at 25C were computed over a concentration range of 0.01 to 17m directly from the electromotive forces of cells without transference.

Stokes, R. H. J. Am. Chem. Soc., 67, 1689 (1945).
Sodium hydroxide was used as a reference in the isopiestic determinations for 33 data sets of H_2SO_4 from 1.6 to 21.6 mol/kg at 25C.

Stokes, R. H., Trans. Far. Soc., 41, 637 (1945).
Measured the isopiestic molalities of H_2SO_4 and $CaCl_2$ at 25C. The 32 molalities of H_2SO_4 ranged from 4.3 to 15.4 mol/kg.

Stokes, R. H., Trans. Far. Soc., 44, 295 (1948).
The osmotic and activity coefficients of H_2SO_4 were measured at a temperature of 25C over a concentration range of 0.1 to 5.0m.

Trimble, H. M. and Ebert, P. F., J. Am. Chem. Soc., 55, 958 (1933).
Report emf measurements of the cell Pt; H_2, H_2SO_4 (m), Hg_2SO_4, Hg; Pt with ethylene glycol additions. The authors also reported measurements for 6 compositions from 0.005 to 1 mol/kg, for which there was no ethylene glycol added.

Turner, David J., J. Chem. Soc. Faraday Trans. I, 70, 1346 (1974).
The dissociation of the bisulphate ion was measured at 25C for a concentration range of 0.020 to 4.00m.

Vdovenko, V. M. Lazarev., L. N. and Khvorostin, Ya. S., Russian J. Inorganic Chem., 12, 610 (1967).
Dissociation constants of HSO_4^- at ionic strenghts of 0.50, 1.00, and 2.00 have been determined at temperatures of 20.0, 25.0 and 35C.

Vosburgh, W. C. and Craig, N., J. Am. Chem. Soc., 51, 2009 (1929).
Calculated and measured the potentials of the cell Pt; $PbSO_4$, PbO_2, H_2SO_4 (m)/ H_2SO_4 (m), Hg_2SO_4; Hg. The emfs of solutions from 0.05 to 3.5 mol/kg were measured at 25C.

Wilson, R. E., Ind. Eng. Chem., 13, 326, (1921).
Measured the vapor pressure of sulfuric acid solutions for temperatures from 0 to 75C and for concentrations ranging from 0.0 to 80% H_2SO_4. Wilson also reports the heats of dilution of H_2SO_4 for temperatures from 12.5 to 62.5% H_2SO_4.

Wirth, H. E., Electrochim. Acta, 16, 1345 (1971).
Presents a summary of emf measurements of H_2SO_4 solutions and uses the dissociation of the bisulfate ion to calculate activity coefficients.

Wu, Y. C. and Young, T. F., Enthalpies of Dilution of Agueous Electrolytes: Sulfuric Acid, Hydrochloric Acid, and Lithium Chloride (Paper is in press). Wu and Young conducted measurements of the enthalpies of dilution of aqueous H_2SO_4 at 25C for compositions of 0.00090 to 6.4 mol/kg.

Appendix 2. Bibliography

Abel, E., J. Phys. Chem., 50, 260 (1946).
"The Vapor Phase Above the System Sulfuric Acid-Water"

Adge, G., and Holtmann, H., Z. Anorg. Allg. Chem., 158, 317 (1926).
"Die Spezifischen Warmen der Systeme Schwefelsaure-Wasser, Eisenvitrol-Wasser, Schwefelsaure-Eisenvitrol-Wasser."

Adhikari, M., Ganguli, D. and Ghash, D., J. Ind. Chem. Soc., 46, 1131 (1960)
"Determination of the Second Dissocation Constant of H_2SO_4 from Measurements of E.M.F. Across Cation Exchange Membrane"

Ahrland, S. and Brandt, L., Acta Chem. Scand., 22, 1579 (1968).
"The Sulphate Complexes of Neptunyl (VI) and a Comparison of the Strength of Corresponding Uranium and Neptunian Complexes in Aqueous Solutions."

Akerlof, G.,J. Am. Chem. Soc., 48, 1160 (1926).
"Investigations of Sulfate Solutions. Experimental Methods and Results on Cells Without Liquid Junction"

Austin, J.M. and Mair, R.D., J. Phys. Chem., 66, 519 (1962).
"The Standard Enthalpy of Formation of Complex Sulfate Ions in Water. I. HSO_4^-, $LiSO_4^-$, $NaSO_4^-$"

Bailey, N., Carrington, A., Lott, K.A.K. and Symons, M.C.R., J. Chem Soc., 290, (1960).
"Structure and Reactivity of the Oxyanions of Transition Metals. Part VIII: Acidities and Spectra of Protonated Oxyanions"

Barnes, Trans, Roy. Soc. Canada, VI (3) 50.
Bass, S.J., Gillespie, R.J., Oubridge, J.V., J. Chem. Soc., 87 (1960).
"Solutions in Sulphuric Acid. Part XXVIII. Osmotic Coefficients of some Electrolyte Solutions."

Bayliss, N.S. and Watts, D.W., Australian J. Chem., 9, 319 (1956).
"The Spectra and Equilibria of Nitrosonium Ion, Nitroacidium Ion, and Nitrous Acid in Solutions of Sulphuric, Hydrochloric and Phosphoric Acid"

Beck, W.H., Dobson, J.V., and Wynne-Jones, W.F.K., Trans. Faraday Soc., 56, 1172 (1960).
"The Potentials of the Mercurous Sulphate/Mercury Electrode"

Beck, W.H., Singh, K.P., and Wynne-Jones, W.F.K., Trans. Faraday Soc., 55, 331(1959).
"The Behavior of the Lead Dioxide Electrode."

Becker, G. and Roth, W.A., Z. Phys. Chem., A169, 287 (1934).
Bestimming der Verbrennungswarme von Organischen Schwefekverbundungen."

Bedford, T.G., Proc. Royal Soc. London, 83A, 454 (1909).
"The Depression of Freezing Point in Very Dilute Aqueous Solutions."

Berkley, F.R.S., Hartley, E.G.J and Burton, C.V., Phil. Trans. Royal Soc. London, 218, 295 (1919).
"On Osmotic Pressures Derived from Vapour-Pressure Measurements: Aqueous Solutions of Cane Sugar and Methyl Glucoside."

Berthelot, Am. Chim. Phys., (4) 29, 328 (1873).
"Parallel Between Formation of Solid Salts Formed by Action of Picric Acid, Nitric Acid, Sulfuric Acid and Benzoic Acid."

Berthelot, Ann Chim. Phys., (4) 30, 433 (1873).
"On the Bisulfate Potassium Anhydrates and on the Heat of Solution of Sulfuric Acid Anhydrates."

Berthelot, Comptes Rendus, 78, 716 (1874).
"On the Crystalline Hydrates of Sulfuric Acid."

Berthelot, M., Ann. Chim. et Phys., (5) 4, 47 (1875).
"General Principles of Thermochemistry-Mixed Refrigerantes."

Berthelot, Ann. Chim. Phys., 4, 104 (1875).
"On the Heat of Combination as Carried to the Solid State. New Expressions of the Reactions."

Berthelot, M., Ann. Chim. Phys., (5) 4, 154 (1875).
"Solutions of Acids and Bases."

Berthelot, M., Ann. Chim. Phys., (5) 4, 445 (1875).
"Additional Remarks on the Amount of Heat Released by the Mixture of Water with Sulfuric Acid."

Berthelot, Ann. Chim. Phys., 13, 17 (1878).
"Some of the Fundamental Laws of Thermochemistry."

Berthelot, Ann. Chim. Phys., (5) 14, 443 (1878).
"On the Heat Release by the Reaction of Water with Sulfuric Acid in Great Excess."

Berthelot, Ann. Chim. Phys., (7) 13, 77 (1898).
"Annales de Chime et de Physique."

Bewley, D.K., Trans. Faraday Soc., 56, 1629 (1960).
"Heat of Reaction Between Ferrous Ammonium Sulphate and Hydrogen Peroxide in Aqueous Solution."

Bhattacharyya, S., Bhattacharyya, S.N., J. Chem. Eng. Data, 24, 93 (1979)
"Heat Capacity and Enthalpy of the Ternary System Ferrous Sulfate Heptahydrate, Sulfuric Acid, and Water."

Bichowskiy, F.R. J. Am. Chem. Soc., 44, 116 (1922).
"Equilibrium in the Reaction between Sulfur Dioxide and Water."

Biltz, W., Z. Phys. Chem. (Leipzig), 40, 185 (1902).
"On the Solution of Inorganic Salts in Water."

Binon, E., Russkue-Fiziko Khim. Obsh., Petr., 31, 171 (1899).
"Heat Capacities of Water Solutions of Sulfuric Acid."

Bobtelsky, M. and Lairsch, R.D., J. Chem. Soc., 3612 (1950).
"The Heat of Solution of Halides, Sulphuric Acid, Oxalic Acid, Sodium Hydroxide, and Urea in Ethyl Alcohol-Water Mixtures."

Bode, F., Z. Angew. Chem., 2, 244 (1889).
"Specific Heat of Sulfuric Acid."

Bose, E., Phys. Z., 6, 550 (1905).
"Observations on Julius Thomsen's Measurements of the Heat of Mixing of Acids."

Brand, J.C.D. and Rutherford, A., J. Chem. Soc., 3916 (1952).
"The Vapour Pressure of the System Sulphuric Acid-Disulphuric Acid."

Briggs, E., J. Soc. Chem. Ind., 22, 1275 (1903).
"The Vapour Pressures of Concentrated Solutions of Sulphuric Acid at High Temperatures."

Bright, N.F.H., Hutchison, H. and Smith, D., J. Soc. Chem. Ind., 65, 385 (1946)
"Vapour Pressure of Parathion and Related Compounds."

Bronsted, J.N., Z. Phys. Chem. (Leipzig), 68, 693 (1910).
"Studies on Chemical Affinity Between Mixing Affinity of Binary Systems. The Sulfuric Acid-Water System".

Broughton, D.B., Chem. and Met. Eng., 52, (4) 123 (1945).
"Sulphuric Acid and Oleum Enthalpy Chart."

Burt, B.C., J. Chem. Soc., 85, 1339 (1904).
"The Vapour Pressure of Sulphuric Acid Solutions and the Molecular Condition of Sulphuric Acid in Concentrated Solution."

Cabani, S. and Gianni, P., Anal. Chem., 44, 253 (1972).
"Analysis of Some Calorimetric Data Concerning the Formation of Bisulfate Ion in Aqueous Solution."

Cattaneo, C., Nuovo Cimento, 26, 50 (1889).

Collins, M., J. Phys. Chem., 37, 1191 (1933).
"The Partial Pressures of Water in Equilibrium with Aqueous Solutions of Sulfuric Acid."

Covington, A.K., Dobson, J.V. and Wynne-Jones, W.F.K., Trans. Far. Soc., 61, 2050 (1965).
"Stoichiometric Activity Coefficients of Sulphuric Acid and the Standard Potentials of the Lead Dioxide/Lead Sulphate and Mercury/Mercurous Sulphate Electrodes at 25°C."

Cowperthwaite, I.A., and Shrawder, J., J. Am. Chem. Soc., 56, 2345 (
"The Partial Molal Heat of Dilution of Sulphuric Acid from Electromotive Force Measurements"

Craig, D.N., and Vinal,G.W., J. Res. Nat. Bur. Stand., Sect. A24, 475 (1940).
"Thermodynamic Properties of Sulphuric Acid Solutions and Their Relation to the Electromotive Force and Heat of Reaction of the Lead Storage Battery."

Crockford, H.D. and Wideman, J. Phys. Chem., 50, 418 (1946).
"The Activity Coefficients of Sulphuric Acid in Aqueous Solution of Ethanol at 25°C."

Daudt. W., Z. Physik. Chem., 106, 255 (1923).
"Eine Differentialmethode Zur Messung Kleiner-Drucko Mittels der Warmeleitung."

Davis, C.W. Jones, H.W. and Monk, C.B., Trans. Far. Soc., 48, 921 (1952).
"E.M.F. Studies of Electrolytic Dissociation."

Deforcrand, R., Ann. Chim. Phys., (6) 3, 242 (1884).
"Sur les Sulfites et Bisulfites de Soude."

Dawson, H.M., Proc. Leeds Phil. Lit. Soc., 2, 359 (1933).
"The Ionisation of Sulphuric Acid."

Deno, N.C. and Taft, R.W. Jr., J. Am. Chem. Soc., 76, 244 (1954).

Denison, R.B. and Steele, B.O., Zeit. Fur Physikische Chemi., 57, 110 (1907).
"Uber Eine Methode Sur Gengauen Messung von Uberfuhrungzahlen."

Dieterici, C., Wied. Ann., 45, 207 (1892).

Dieterici, C., Ann. Phys., 286, 47 (1893).
"Uber die Dampfdrucke Wasseriger Losungen bei 0^{0}C."

Dieterici, C., Wied. Ann., 50, 47 (1893).
"Uber die Dampfdrucke Wasseriger Losungen bei 0^{0}C."

Dieterici, C., Ann. Phys., 298, 616 (1897).
"Uber die Dampfdrucke Verdunnter Wasseriger Losungen bei 0^{0}C."

Dieterici, C., Ann. Sec. Physik., 303, 859 (1899).
"Uber die Dampfdrucke Verdunnter Wasseriger Losungen bei 0^{0}C."

Dieterici, C., Wied. Ann., 67, 685 (1899).
"Uber die Dampfdrucke Verdunnter Wasseriger Losungen bei 0^{0}C."

Drucker, Von K., Z. Electrochem., 17, 398 (1911).
"Das Dissoziationsscheme Der Schwefelsaure und Beweglichkeit Des Hydrosulfations

Drucker, C., Z. Phys. Chem., 96, 381 (1920).
"Weiter Untersuchungen uber die Dissoziation Ternarer Elektrolyte."

Drucker, C., Ark. Kemi, Mineral., Geol., 11A, 1 (1934).

Duisman, J.A. and Giauque W.F., J. Phys. Chem., 72, 562 (1968).
"Thermodynamics of the Lead Storage Cell. The Heat Capacity and Entropy of Lead Dioxide from 15 to 318 K."

Edward, J.T. and Wang, I.C., Can. J. Chem. Soc., 77, 5501 (1955).
"Ultraviolet Study of the Ionization of Bisulfate Ion."

Eichler, E., and Rabideau, S., J. Am., Chem., 43, 2867 (1965).
"The Determination of the Bisulfate Dissociation Quotient from Potentiometric Measurements."

Evans, C.E. and Monk, C.B., Trans. Far. Soc., 67, 2652 (1971).
"E.M.F. Studies of Electrolytic Dissociation."

Favre, P.A., and Silbermann, T., Ann. Chim. Phys., (3) 37, 406 (1853).
"Recherches sur les Quantities de Chaleur Degages dans les Actions Chimiques et Moleculaire."

Feilchenfeld, H. and Fuchs, J., Israel J. Chem., 12, 899 (1974).
"Hydration Numbers of Some Acids and Bases."

Ferguson, A.L. and France, W.G., J. Am. Chem. Soc., 43, 2150 (1921).
"The Transference Numbers of Sulfuric Acid by the Concentrated Cell Method."

Flis, I.E., Z. Prik. Khim., 34, 1744 (1961).

Flis, I.E., Mishchenko, K.P., Pakhomova, N.V., Russ. J. Inorg. Chem., 3, 1772 (1958).
"The Thermochemistry of Dissociation of Sulphuric and Hypochlorous Acids in Aqueous Solutions."

Grable, Betz, and Marcon, J. Am. Chem. Soc., 72, 1445 (1950).
"Phase Equilibria of the System Sulfur Trioxide-Water."

Gardner, W.L., Jekel, E.C., and Cobble, J. W., J. Phys. Chem., 73, 2017 (1969).
"The Thermodynamic Properties of High-Temperature Aqueous Solutions. X. The Standard Partial Molal Heat Capacities of Sodium Sulfate and Sulphuric Acid/ from 0 to 100^{0}."

Gardner, W.L., Mitchell, R.E. and Cobble, J.W., J. Phys. Chem., 73, (1969).
"The Thermodynamic Properties of High-Temperature Aqueous Solutions. X. The Electrode Potentials of Sulphate Ion Electrodes from 0 to 100^{0}. Activity Coefficients and the Entropy of Aqueous Sulfuric Acid."

Gel'fmon, M.S., Zhur. Priklad Khim., 23, 913 (1950).

Giauque, W.F. Hornung, E.W. Kunzler, J. E. and Rubin, T.R. J. A.M. Chem. Soc., 82, 62 (1960).
"The Thermodynamic Properties of Aqueous Sulfuric Acid Solutions and Hydrates from 15 to 300 K."

Giauque, W.F. Kunzler, and Hornung, E.W. J. Am. Chem. Soc., 78, 5482 (1956).
"The Freezing Point Method of Determining Free Energies in a 2-Component System Forming Compounds. Concentrated Sulphuric Acid."

Gillespie, R.J., J. Chem. Soc., 2516 (1950).
"Cryoscopic Measurements in Sulphuric Acid. Part IV. Reactions of Ionised Sulphates in Sulphuric Oleum. Self-ionisation Equilibria in Sulphuric Acid, and Ionic Equilibria in Oleum. The Polysulphuric Acids."

Gillespie, J. Chem. Soc., 2537 (1950).
"Cryoscopic Measurements in Sulphuric Acid. Part VI."

Gillespie, R.J., J. Chem. Soc., 2542 (1950).
"Cryoscopic Measurements in Sulpuric Acid. Part VII. The Basicity of Nitro Compounds, Sulphonyl Compounds, and Sulphuryl Compounds in Sulphuric Acid."

Gillespie, R.J., and Graham, J. Chem. Soc., 2532 (1950).
"Cryoscopic Measurements in Sulphuric Acid. Part V. Ionisation of Nitric Acid in Sulphuric Oleum."

Gillespie, R.J., Hughes, and Ingold, J. Chem. Soc., 2473 (1950).
"Cryoscopic Measurements in Sulphuric Acid. Part 1. Principles and Methods. The Cryoscopic Constant and Some Other Constants of Sulphuric Acid."

Glueckauf, E. and Kitt, G.P., AEC C/R 1794, 13 (8 Nov 1955).
"Thermodynamic Data of Concentrated Sulphuric Acid Solutions."

Glueckauf, E. and Kitt, G.P., Trans. Faraday Soc., 52, 1074 (1956).
"Thermodynamic Data on Concentrated Sulphuric Acid Solutions."

Goldberg, R.N., Staples, B.R., Nuttall, R.L. and Arbuckle, R. "A Biliography of Sources of Experimental Data Leading to Activity or Osmotic Coefficients for Polyvalent Electrolytes in Aqueous Solution." Nat. Bur. Stand. (U.S.) Spec. Pub. 485, U.S. Gov'n. Printing Office, Washington, D.C., (1977).

Good, W.D., Lacina, Y.L., and McCullough, J. Am. Chem. Soc., 82, 558 960)
"Sulfuric Acid: Heat of Formation of Aqueous Solutions by Rotating-bomb Calorimetry."

Gopinath, C.R. An Rao, K.S.R., Curr. Sci., 42, 164 (1973).
"Calculation of High Frequency Dielectric Constant of Alkali Halide Crystals."

Graham, T., Philos. Mag., 22, 329 (1843).
"Experiments on the Heat Disengaged in Combinations."

Grau, R., and Roth, W.A., Landolt-Bornstein Physkalisch-Chemische Tabellam, Auf. 5, Erg. 2, P. 1550 (1931).

Greenewalt, C. H., Ind. End. Chem., 17, 522 (1925).
"Partial Pressure of Water Out of Aqueous Solutions of Sulfuric Acid."

Groenier, W.L., Thesis, Univ. Chicago, (1933).
"The Heats of Dilution of Sulphuric Acid Solutions."

Grollman, A. and Frazer, J.C.W., J. Am. Chem. Soc., 47, 712 (1925).
"The Vapor-Pressure Lowering of Aqueous Sulfuric Acid Solutions at 25 C."

Guggenheim, E.A., Stokes, R.H., Trans. Far. Soc., 54, 1646 (1958).
"Activity Coefficients of 2:1 and 1:2 Electrolytes in Aqueous Solution from Isopiestic Data."

Gunn, S.R.J., Physical Chem., 69,(9) 2902 (1965).
"Comparison Standards for Solution Calorimetry."

Guzzetta, F.H., Ph.d Thesis Ohio State University (1961).
"Crystal Fields Effects in Coordination Compounds: Calorimetric Studies of Some Hexacyano Metal Complexes."

Hacker, C., Ann. Phys., 39, 1342 (1912).

Hala, E., Coll. Czech. Chem. Communicatons, 28, 1780 (1963).
"Liquid-Vapour Equilibrium in Systems of Electrolytic Components. 1. Excess Free-Energy of Dilution and the Mean Rational Activity Coefficients of Ions."

Hamer, W. J., J. Am. Chem. Soc., 57, 9 (1935).
"The Potential of the Lead Dioxide-Lead Sulphate Electrode at Various Temperatures."

Hamer, W.J., J. Am. Chem. Soc., 57, 662 (1935).
"Temperature Variation in Transference Numbers of Concentrated Solutions of Sulfuric Acid as Determined by the Galvanic Cell Method."

Hammet, L.P., Deyrup, A.I., J. Am. Chem. Soc., 55, 1900 (1933).
"Some Properties of Electrolytes in the Solvent Sulfuric Acid."

Hantzsch, Berichte Der Bunsen Gesellschaft Fuer Phys, Chem., 58, 941 (1925).

Harned, H. S., and Hamer, W. J., J. Am. Chem. Soc., 57, 27 (1935).
"The Thermodynamics of Aqueous Sulfuric Acid Solutions from Electromotive Force Measurements."

Harned, H.S. and Sturgis, J. Am. Chem. Soc., 47, 945 (1925).
"The Free Energy of Sulfuric Acid in Aqueous Sulfate Solutions."

Hartung, E. J., Trans. Faraday Soc., 11, 64,(1915).
"A New Method for Determining the Specific Heats of Liquids."

Hausrath, H., Ann. Phys. (Leipzig), 9, 522 (1902).

Hayes, M.J. and Pepper, D.C., Trans. Far. Soc., 57, 432 (1961).
"The Solubility of H_2SO_4 in 1,2-Dichlorethane."

Hedwig, G.R. and Powell, H.K.J., J. Chem. Soc. Dalton, 798 (1973).
"A Reinvestigation of the Enthalpy Changes for the Interaction of the Sulphate Ion With Some Transition Metal Ions in Aqueous Solutions."

Helmholtz, R., Ann. Phys. (Leipzig), 27, 508 (1886).
"Heat of Formation of Oleums from Sulfur Trioxide and Water."

Hepburn, J. R. I., Proc. Roy. Soc. London, 40, 249 (1928).
"The Vapour Pressure of Waterr over Sulphuric Acid-Water Mixtures at 25 C., and Its Measurements by an Improved Dew-Point Apparatus."

Hogfeldt, E., Z. Physik. Chem., 35, 260 (1965).

Hornung, E. W. Brackett, T.E. and Giauque, W.F. J. Am. Chem. Soc., 78, 5747 (1956).
"The Low Temperature Heat Capacity and Entropy of Sulfuric acid Hemihexahydrate. Some Observations on Sulfuric Acid 'Octahydrate.'"

Hornung, E.W., and Giauque, W. F., J. Am. Chem. Soc., 77, 2744 (1955)
"The Vapour Pressure of Water over Aqueous Sulfuric Acid at 25°."

Hornung and Giauque, J. Am. Chem. Soc., 77, 2983 (1955).
Heat Capacities and Entropies of Sulfuric Acid Tri- and Tetrahydrates."

Hussian, F. and Haque, S.S., Pakistan J. Sci. Ind. Res., 6, 251 (1963).
"The Thermodynamics of Sulphuric Acid in Alcohols from Electromotive Force Measurements."

Hussian, F. and Rauf, A., Pakistan J. Sci, Ind. Res., 7 (3) 171 (1964).
"The Activity Coefficients of Sulphuric Acid in Acetone-Water Mixtures."

"Calorimetrically Determined Log K, ΔH, and ΔS Values for the Interaction of Sulphate Ion with H^+, Na^+, and K^+ in the Prescence of Tetra-n-alkyl-Ammonium Ions."

Johnson, W. H. and Sunner, S., Acta Chem. Scand., 17, 1917 (1963).
"The Heats of Solution and Oxidation of Sulfur Dioxide."

Jones, H.C. Z. Phys. Chem. (Leipzig), 12, 623 (1893).

Jones, F.R., J. Appl. Chem., 1, 5144 (1951).
"An Accurate Method for the Determination of Aqueous Vapour Pressure: The Equilibrium Humidities of Solutions of Sulphuric Acid."

Jones, H.C. and Getman, F.H. Am. Chem. J., 27, 433 (1902).
"The Lowering of the Freezing Point of Water Produced by Concentrated Solutions of Certain Electrolytes and the Conductivity of Such Solutions."

Jones, H.C. and Getman, F.H., Am. Chem. J., 31, 322 (1904).
"On the Nature of Concentrated Solutions of Electrolytes-Hydrates in Solution."

Jones, H.C. and Getman, Frederick, H., Physical Reviews, 18, 146 (1904).
"A Study of the Molecular Lowering of the Freezing Point of Water Produced by Concentrated solutions of Electrolytes."

Jones, H.C. Getman, F. H. Basset, H.P., McMaster, L. and Uhler, H.S. Carnegie Institution of Washington, Publication No. 60, Washington D.C. (1907).
"Hydrates in Aqueous Solutions."

Jones, H.C. and Pearce, J.N., Am. Chem. J., 38, 683 (1907).
"Dissociation as Measured by Freezing Point Lowering and by Conductivity Bearing on the Hydrate Theory. The Approxmate Composition of the Hydrates Formed by a Number of Electrolytes."

Kadyrov, R.K. Vzbek Khim. Zhur., 5, 44 (1961).

Kaimakov, E.A. and Varshauskaya, Russan Chemical Reviews (Uspekhi).

Khimi (Advances in Chemistry), 35, 89 (1966).
"Measurement of Transport Numbers in Aqueous Solutions of Electrolytes."

Kangro, W., Z. Physik. Chem., 32, 273 (1962).
"Konzentrierte Wassrige Losungen. II."

Karve, D.D., J. Indian Chem. Soc., 1-2, 247 (1924-25).
"Thermo-chemical Investigations on the Constitution of Acids in Solution."

Kenttamaa, J., Suomen Kemistilehti, 30B, 9 (1957).
"The Solubility of Silver Sulphate and the Dissociation of the Bisulphate Ion."

Kerker, M., J. Am. Chem. Soc., 79, 3664 (1957).
"The Ionization of Sulfuric Acid."

Kirkbride, B. J., and Wyatt, P.A.H., Trans. Faraday Soc., 54, 483 (1958).
"The Partial Molar Heat Contents of Solutes in Sulphuric Acid at 25^{0}C."

Klotz, I.M., and Eckert, C.F., J. Am. Chem. Soc., 64, 878 (1942).
"The Apparent Molal Volumes of Aqueous solutions of Sulfuric Acid at 25^{0}C."

Knietsch, R., Chem. Ber., 34, 4069 (1901).
Koskekallu, J. and Syrjapalo, Acta Chemica Scand., 19, 429 (1965).
"Association of Mineral Acids with Water in Dioxane-Water Mixtures."

Kunzler, J. E. and Giauque, W. F., J. Am. Chem. Soc., 74, 797 (1952)
"The Heat Capacity and Entropy of Sulfuric Acid Trihydrate Glass and Crystals from 15 to 300 K."

Kunzler, J. E., and Giauque, W. F., J. Am. Chem. Soc., 74, 3472 (1952).
"Aqueous Sulfuric Acid. Heat Capacity. Partial Specific Heat Content of Water at 25 and -20^0."

Kunzler, J. E. and Giauque, W.F., J. Am. Chem. Soc., 74, 5271 (1952)
"The Freezing Point Curves of Concentrated Aqueous Sulfuric Acid."

Land and Crockford, J. Am. Chem. Soc., 72 1895 (1950).
"The Activity Coefficients of Sulfuric Acid in Aqueous 2-Propanol Solutions at 25^0.

Lange, E., Monheim, J. and Robinson, A.L., J. Am. Chem. Soc., 55, 4733 (1933).
"The Heats of Dilution of Aqueous Solutions of Zinc, Cadmium and Copper Sulfates and Sulfuric Acid at 25^0."

Lauer, K. and Oda, R. Berichte Der Bunsun Gesellschaft Fuer Phys., 70B, 333 (1937).

Lauer, K. and Oda, R., Berichte Der Bunsun Gesellschaft Fuer Phys., 70B, 1707 (1937).
Lesplieau, Bul. Soc Chem., 11, 71 (1894).
Lewis, G.N. and Lacey, J. Am. Chem. Soc., 36, 804 (1914).
"The Potential of the Copper Electrode and the Activity of Bivalent Ions."

Lewis, G.N. and Linhart, G.A., J. Amer. Chem. Soc., 41, 1951 (1919).
"The Degree of Ionization of Very Dilute Electrolytes."

Lewis, G.N. and Randall, M.J. Am. Chem. Soc., 43, 1112 (1921).
"The Activity Coefficient of Strong Electrolytes."

Lilley, T. H. and Briggs, C.C., Electrochim Acta., 20, 257 (1975).
"Stoichiometric Activity Coefficients of Aqueous H_2SO_4 Solution
298.15 K."

Lindstrom, R.E. and Wirth, H.E., J. Phys. Chem., 73, 218 (1969).
"Estimation of the Bisulfate Ion Dissociation in Solutions of Sulfuric Acid and Sodium Bisulfate."

Lloyd, L. and Wyatt, P.A.H., J. Chem. Soc., 4262 (1957).

Loomis, E.H., Ber Bunsenges. Phys. Chem. 26, 797 (1893).

Loomis, E. H., Phys. Rev. 1, 274 (1894).
"On the Freezing Points of Dilute Solutions."

Loomis, E.H., Ann. Physik., 51, 500 (1894).
"Uber Ein Eracteres Verfahren bei des Bestimmung von Aefrierpunktserniedrigungen.

Luchenskii, G.P., Zhur. Fig. Khim., 30, 1207 (1956).

Luchinskii, G.P., Zhur. Fig. Khim., 33, 1275 (1959).

MacDougall, F.H. and Blumer, D.R., J. Am. Chem. Soc., 55, 2236 (1933).
"The Activity of Each Component in Aqueous Solutions of Sulfuric Acid and Acetic acid."

Magie, W. F., Phys. Rev., 35, 265 (1912).
"Heats of Dilution."

Maksimov, I.N., Russian J. Phys. Chem., 41, 27 (1967).
"Free Energy, Entropy, and Enthalpy of Ionic Equilibria in Aqueous Solution at High Temperatures."

Mansson, M. and Sunner, S. (Unpublised Paper Thermochemistry Lab Univ. of Lund, Sweden) 6. (1963).
"The Heat of Formation of Sulphuric Acid."

Marignac, M.C., Arch. Sci. Phys. Nat., 55, 113 (1876).
"Specific Heat of Saline Solutions."

Marignac, C., Ann. Chim. Phys., 8, 410 (1878).
"Sur les Chaleurs Specifiques des solutions Salines."

Marshall, W. L., Jones, E.Y., J. Phys. Chem., 70, 4028 (1966).
"Second Dissociation Constant of Sulfuric acid from 25 to 350^{0} Evaluated from Solubilities of Calcium Sulfate in Sulfuric Acid Solutions."

Mathias, E., Ann. Chim. Phys., (5)21, 90 (1890).

McBain, J.W., Washington Academy of Sciences, IX, 1-78 (1907)
(from University of Toronto Studies).
"The Experimental Data of the Quantitative Measurements of Electrolytic Migration."

McCurdy, J. and McKinley, C., Ind. Eng. Chem., 34, 1002 (1942).
"The System Nitric Acid-Sulfuric Acid-Water."

McHaffie, I. R., J. Chem. Soc., 112 (1927).
"The Vapour Pressure of Water over Sulphuric Acid-Water Mixture at 25^{0}."

Meyeren, W., Z. Phys. Chem., (Leipzig) A160, 272 (1932).
"Eine Einfache Methode zur Messung Kleiner Dampfdrucke."

Mochalova, I.A., Ponomareva, A.M. and Mashovets, V.P., J. Applied Chem., 48, 555 (1975).
"Phase Investigation of the Systems H_2SO_4-H_3PO_4-
and H_2SO_4-H_3PO_4-H_2O."

Morgen, R. A., Ind. Eng Chem., 34, 571 (1942).
"Heats of Solution of the System Sulfur Trioxide-Water."

Morgan, J.J., Bender, D.A., And Capell, R.G., Chem. Met. Eng., 50, 122 (1943).
"Specific Heats of Mixed Acids at Higher Temperatures."

Muller, J. A., Bull. Soc. Chim. France, 13, 1053 (1913).
Naude, S.M., Z. Physik. Chem. (Leipzig), 135, 209 (1928).
"Uber die Verdunnungswarme Schwach Konzentrierter Losungen."

Noyes, A.A. and Falk, K.G., J. Am. Chem. Soc., 32, 1017 (1910).
"The Properties of Salt Solutions in Relation to the Ionic Theory."

Papee, H.M. and Carmody, W.J. and Laidler, K.J., Can. J. Chem., 34, 1677 (1956).
"The Heat of Neutralization of Strong Acids and Bases in Highly Dilute Aqueous Solutions."

Pascal, P., and Garnier, M., Bull. Soc. Chim. France, 27, 8 (1920).

Paul, R.C. Ahleuvaliz, S.C. and Pahil, S.S., Indian J. Chem., 3 (7), 305 (1965)
"Thermochemical Studies in Dimethylformamide: Part II- Heats of Solutions and Neutralization of Protonic Acids."

Paul, R.C. Singh, S.C. Ahlewalia, and Pahil, S.S. Indian J. Chem., 2, 134 (1964).
"Thermochemical Studies of Acid-Base Neutralization Reactions in Acetic acid."

Pickering, Proc., Roy. Soc., 49, 18 (1890).
"The Nature of Solutions, as Elucidated by the Freezing Points of Sulphuric Acids Solutions."

Pickering, S.U., J. Chem. Soc., 57, 64 (1890).
"The Nature of Solutions, as Elucidated by a Study of the Density, Electric Conductivity, Heat Capacity, Heat of Dissolution and Expansion by Heat of Sulphuric Acid Solutions."

Pickering. S.V., J. Chem. Soc., 57, 331 (1890).
"Determinations of the Heat Capacity and Heat of Fusion of Some Substances to Test the Validity of Person's Absolute Zero."

Pickering, S. U., Proc. Roy. Soc. London, 49,11 (1891)

Pickering, S.U. Z. Phys.Chem. (Leipzig), 7, 378 (1891)
"Verhandungen Uber die Theorie der Losungen."

Pickering, S.U., Ber. Dtsch. Chem. Ges., 25, 1099 (1892).

Pitzer, K.S., J. Phys. Chem. 80, 2863 (1976).
"Thermodynamic Properties of Dilute Sulfuric Acid and the Potential of the Lead Sulfate-Lead Electrode."

Pitzer, K.S., Roy, R.N., and Silvester, L.F., J. Am. Chem. Soc., 99, 4930 (1977).
"Thermodynamics of Electrolytes. 7. Sulfuric Acid."

Platford, R.F., J. Chem. Eng. Data, 18, 215 (1973).
"Osmotic Coefficients of Aqueous Solutions of Seven Compounds at 0 C."

Porter, A. W., Trans. Faraday Soc., 13, 373 (1918).
"The Thermal Properties of Sulphuric Acid and Oleum."

Pretat, Mem. Poudres, 24, 119 (1930).

Quist, A.S., Marshall, W.L. and Jolley, H.R., J. Phys. Chem., 69, 2726 (1965).
"Electrical Conductances of Aqueous Solutions at High Temperatures and Pressure. II. The Conductances and Ionization Constants of Sulfuric Acid-Water Solutions from 0 to 800^0 and at Pressures up to 4000 Bars."

Radulescu, D., and Jula, O., Z. Phys. Chem. (Leipzig), B26, 390 (1934).

Randall, M. and Cushman, O.E., J. Am. Chem. Soc., 40, 393 (1918).
"The Free Energy of Dilution of Sulfuric Acid."

Randall, M. and Langford, C.T., J. Am. Chem. Soc., 49, 1455 (1927).
"The Activity Coefficient of Sulfuric Acid in Aqueous Solutions with Sodium Sulfate at 25^0."

Randall, M. and Scott, G.N., J. Am. Chem. Soc., 49, 647 (1927).
"The Freezing Point and Activity Coefficient of Aqueous Barium Nitrate, Sodium Sulfate and Sulfuric Acid."

Randall, M., and Taylor, M. D., J. Phys. Chem., 45, 959 (1941).
"Heat Capacity and Density of Aqueous Solutions of Potasssium Iodate, Potassium Acid Sulfate, Iodic Acid, and Sulfuric Acid at 25 C."

Rau, N. Rajeswara, Current Sci. (India), 11, 429 (1942).
"Effect of Temperature on the Dissociation of Strong Electrolytes by Raman Effect."

Rard, J. A., Habenschuss, A. and Speddng, F.H., J. Chem. Eng. Data, 21, 374 (1976).
"A Review of the Osmotic Coefficients of Aqueous H_2SO_4 at 25 C."

Rard, J. A. and Miller, D.G., Unpublished Data, 1 (1977).

Rard, J. A. and Spedding, F.H.J. Chem. Eng. Data, 22, 56 (1977).
"I. Isopiestic Determination of the Osmotic Coefficients of Aqueous $CaCl_2$ Solutions at 25^{0}C."

Readnour, J.M. and Cobble, J.W., Inorg. Chem., 8, 2174 (1969).
"Thermodynamics Properties for the Dissociation of Bisulfate Ion and the Partial Molal Heat Capacities of Bisulfuric Acid and Sodium Bisulfate over an Extended Temperature Range."

Regnault, H. V., Ann. Chem. Phys., (3) 15, 179 (1845).
Rhodes, F. H., and Nelson, C.C., Ind. Eng. Chem., 30, 648 (1938).
"Heats of Dilution of 'Mixed Acids'."

Richards, G.W. and Woolf, A.A., J. Chem. Soc., (A)470, (1968).
"Thermochemistry of Fluorine Compounds. Part I. Reaction Calorimetry in Fluorsulphuric Acid."

Robinson, R.A., Trans. Faraday Soc., 35, 1229 (1939).
"The Activity Coefficients of Sulphuric acid and Lanthanium Chloride in Aqueous solution at 25^0."

Robinson, R.A., Trans. R. Soc. N.Z., 75, 203 (1945).
"The Vapour Pressure of Solutions of Potassium Chloride and Sodium Chloride."

Roth, W.A., Grav, R. and Meichsner, A., Z. Anorg. Allgenor. Chem., 193, 1611 (1930).
"Beitrage zur Thermochemie des Schwefeis. III."

Roth, W.A. and Knothe, W., Unpublished data given in Landolt-Bornstein Physikalisch-Chemische Tabellen, Auflage 6, Band II Teil 2, p.862, A. Eucken, Editor, Springer-Verlag, Berlin (1960).

Roth, W.A. and Meichsner, A., Landolt-Bornstein Physikalisch-Chemische Tabellen, Auf. 5, Erg 2, 1550 (1931).

Rubin, T.R. and Giauque, W.F., J. Am. Chem. Soc., 74, 800 (1952).
"Heat Capacities and Entropies of Sulfuric acid and its Mono- and Di-hydrates from 15 to 300 K."

Rumelin, G., Z. Phys. Chem., (Leipzig) 58, 449 (1907).
"Uber die Verdunnungswarme Konzentrierrer Lonsungen."

Ryzhenko, B.N., Geokhimiya 1, 8 (1964).
"Determination of the Second Dissociation Constant of Sulfuric Acid and the Precipitation of Salts in the Reciprocal System Ca^{2+}, Ba^{2+}11SO_4^{2-} 2-, CO_3^{2-} under Hydrothermal Conditions."

San'ko, Yu. P., Inzh., Fiz. Zh., 27, 78 (1974).

Saunders, A., and Sawistowski, H., J. Appl. Chem. Biotechnol, 23, 111 (1973)
"Correlation of Activity Coefficients of Water in Solutions of Sulphuric Acid and Toluene Sulphonic Acid."

Scatchard, G., Hamer, W.J. and Wood, S.E., J. Am. Chem. Soc., 60, 3061 (1973) (1938).
"Isotonic Solutions. I. The Chemical Potential of Water in Aqueous Solutions of Sodium Chloride Potassium Chloride, Sulfuric Acid, Sucrose, Urea and Glycerol at 25^0."

Schlesigner, H., Phys. Z., 10, 210 (1909).

Schwabe, K. and Ferse, E., Ber. Bunsunges Physik Chem., 69(5), 383 (1965)
"Benichte Der Bunsen Gesellschaft Fur Physikalische Chemie."

Shankman, S. and Gordon, A.R., J. Am. Chem. Soc., 61, 2370 (1939).
"The Vapour Pressure of Aqueous Solutions of Sulfuric Acid."

Sharma, L. and Prasad, B., J. Ind. Chem. Soc., 47, 379 (1970).
"Standard E.M.F. of the Cell: Pt Q.H. H_2SO_4; H_2SO_4-H_2SO_4; Hg_2SO_4 Hg and the Standard Electrode Potential of Hg-Hg_2SO_4; SO_4^{2-} at 5^0, 15^0, 25^0, $+35^0$."

Sheffer, H., Janis, A.A. and Ferguson, J.B., Can. J. Res., B17, 336 (1939).
"The Activity of Water in Sulphuric Acid Solution at 25 C by the Isopiestic Method."

Shrawder, J., Jr., and Cowperthwaite, I.A., J. Am. Chem. Soc., 56, 2340 (1934).
"The Activity Coefficients of Sulfuric acid at Temperatures from 0 to 50^0."

Sinha, O.P. and Puri, O.P., Chem. Phys. Letters, 32, 495 (1975).
"Specific Heat Anomaly of Sulphuric Acid with Dilution."

Smith-Magowan, D. and Goldberg, R.N., "A Bibliography of Experimental Data Leading to Thermal Properties of Binary Aqueous Electrolyte Solutions," Nat. Bur. Stand. (U.S.) Spec. Pub. 537, U.S. Gov't. Printing Office, Washington D.C., (1979).

Smith, D.F. and Mayer, J.E., J. Am. Chem. Soc., 46, 75 (1924).
"The Free Energy of Aqueous Sulfuric Acid."

Socolik, A. S., Z. Ang. Chem., 158, 305 (1932).

Socolik, A., Zh. Obshchei Khim., 2, 311 (1932).
"Warmekapazitaten der Wasserigen Losungen von Schwefelsaure."

Sorel, E., J. Soc. Chem. Ind., 9, 175 (1890).
"The Manufacture of Sulphuric Acid."

Staples, B.R., "Activity and Osmotic Coefficients of Aqueous Sulfuric acid," J. Phys. Chem. Ref. Data, 10, xx (1981), in press.

Staples, B.R. and Nuttall, R.L., J. Phys. Chem. Ref. Data, 6, 385 (1977)
"Activity and Osmotic Coefficients of Aqueous $CaCl_2$ at 298.15 K".

Stokes, R.H., Trans. Fara. Soc., 41, 637 (1945).
"A Thermodynamic Study of Bivalent Metal Halides in Aqueous Solutions. Part XIII. Properties of Calcium Chloride Solutions up to High Concentrations at 25^0."

Stokes, R.H., J. Am. Chem. Soc., 67, 1689 (1945).
"The Derivation of Water Activities from Electromotive Force Data."

Stokes, R.H., J. Am. Chem. Soc., 69, 1291 (1947).
"The Measurement of Vapour Pressures of Aqueous Solutions by Bi-thermal Equilibrium Through the Vapor Phase."

Stokes, R.H., Trans. Far. Soc., 44, 295 (1948).
"A Thermodynamic Study of Bivalent Metal Halides in Aqueous Solutions. Part XVII. Revision of Data for all 2:1 and 1:2 Electrolytes at 25^0, and Discussion of Results."

Sundens, N., Svensk. Kem. Tidski, 66, 20 (1954).
"On the Complex Chemistry of the Indium Ion."

Suyorov, A.V., Dobootin, R. B., Godzlieu, S.M., Zhur. Neorg. Khim., 10, 1307 (1965).
"Dissociation Equilibrium in Sulphuric Acid Vapour."

Tartar, H.V., Newschwander, W.W. and Ness, A.T., J. Am. Chem. Soc., 63, 28 (1941).
"A Thermodynami Study of the System Zinc Sulfate-Sulfuric Acid-Water at 25^0."

Taylor, A.R. Leston, B.B. and Smith, D.F. U.S. Bureau Mines Rept. Invest., 6724 8pp (1966).
"Heats of Formation of Beryllium Sulfate and its Hydrates."

Thibaut, R., Z. Electrochem., 19, 8811 (1913).

Thomsen, J., J. Prakt. Chem., 17, 165 (1878).

Thomsen, J., Thermochemische Untersuchungen - Band I, J. A. Barth Verlag, Leipzig, (1883).

Thomsen, J.Thermochemische Untersuchungen - Band III, J. A. Barth Verlag, Leipzig, (1883).

Trimbie, H. M. and Ebert, D.F., J. Am. Chem. Soc., 55, 958 (1933).
"The Effect of Ethylene Glycol upon the Activity of Sulfuric Acid in Aqueous Solutions."

Tucker, T.S., and Callendar, H.L., Trans. Roy. Soc. London, A215, 319 (1915).
"Heats of Dilution of Concentrated Solutions."

Turner, D.J., J. Chem. Soc. Far. Trans.I, 70, 1346 (1974).
"Dissociation of the Bisulphate Ion at Moderate Concentrations."

Vdovenko, V.M., Lazarev, L.N. and Khvorostin, Ya. S., Russian J. Inorg. Chem., 12, 610 (1967).
"Determination of the Dissociation Constants of Hydrogen Sulphate Ions in Solutions at Different Ionic Strengths and Temperatures."

Von Herrmann, C., Ind. Eng. Chem., 33, 898 (1941).

Von Meyeren, Z. Phys, Chem. (Leipzig), A 160, 272 (1932)
"Eine Einfache Methode zur Messung Kleiner Dampfdrucker."

Vosburgh, W.C. and Craig, N., J. Am. Chem. Soc., 51, 2009 (1929).
"The Lead Dioxide-Lead Sulfate Electrode."

Vrevskii, M.S., J. Russ. Phys, Chem. Soc., 59, 69 (1927).

Vrevskii, M.S. and Nikolskii, J. Russ. Phys. Chem. Soc., 59, 77 (1927).

Wallace, R.M., J. Phys. Chem., 70, 3922 (1966).
"Determination of the Second Dissociation Constant of Sulfuric Acid by Donnan Membrane Equilibrium."

Wanders, A.C.M. and Zwietering, Th.N., J. Phys. Chem., 73, 2076 (1969).
"Calculation of delta ΔH and K Values from Thermometric Titration Curves."

Whitten, W.N. and Land, J.E., J. Am. Chem. Soc., 75, 2202 (1953).
"The Thermodynamics of Aqueous 2-Propanol-Sulfuric Acid Solutions from Electromotive Force Measurements."

Wilson, R.E., Ind. Eng. Chem., 13, 326 (1921).
"Humidity Control by Means of Sulfuric Acid Solutions, with Critical Compilation of Vapor Pressure Data."

Wirth, H.W., Electrochim. Acta., 16, 1345 (1971).
"Activity Coefficients in Sulphuric Acid and Sulphuric Acid-Sodium Sulphate Mixtures."

Wrewsky, M. S. Z. Physik, Chem., A 144, 244 (1929)
"Zietschrift Fur Physikalische Chemie."

Wu, Y.C., Thesis, Univ. of Chicago (1957).
"Part I. Thermal Effects of the Interaction Between Univalent Ions. Part II. Heat of Dilution of Sulfuric Acid in Aqueous Solution."

Wu, Y.C. and Hamer, W.J., Electochemical Data, Part XIV, Nat. Bur. Stand. (U.S.) Report 10052, U.S. Department of Commerce, Washington, D.C (1969).

Wu, Y.C. and Young, T.F., National Bureau Standards, Washington, D.C. 20234 and G.H. Jones Laboratory, Univ. Chicago, Chicago, Ill.
"Enthalpies of Dilution of Aqueous Electrolytes: Sulfuric Acid, Hydrochloric Acid and Lithium Chloride."

Wyatt, P.A.H., Trans. Far. Soc., 56, 490 (1960).
"The Constitution of 80-100% Aqueous Sulphuric Acid: A Case of Overlapping Equilibria."

Young, T.F. and Irish, D.E., Ann. Review Phys. Chem., 13, 435 (1962)
"Solutions of Electrolytes."

Yudin, J. D., Zhur. Fiz. Khim., 13, 1346 (1939).

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET** *(See instructions)*	1. PUBLICATION OR REPORT NO. NBSIR 81-2276	2. Performing Organ. Report No.	3. Publication Date August 1981

4. TITLE AND SUBTITLE

A BIBLIOGRAPHY OF THERMODYNAMIC AND TRANSPORT PROPERTIES OF AQUEOUS SULFURIC ACID.

5. AUTHOR(S)

Bert R. Staples, and Theresa F. Wobbeking

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

(DOE)EW-78-X-03-0509-A001

8. Type of Report & Period Covered

Interim,
Jan.-Sept., 1979

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Department of Energy
Energy Storage Division
Lawrence Livermore Laboratory, Berkely, CA

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A detailed compilation of sources of data for the thermodynamic and transport properties of aqueous sulfuric acid is presented. All ranges of temperature, concentration, and pressure are included.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Activity coefficients; aqueous; compilation; conductivity; entahlpy; electrolytes; Gibbs energy; osmotic coefficients; solutions; sulfuric acid; thermodynamic properties; transport properties.

13. AVAILABILITY

☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

26

15. Price

$6.50

USCOMM-DC 6043-P80