

TABLE 8.7 Proton Transfer Reactions of Inorganic Materials in Water at 25°C

Substance	Formula or remarks	pK_1	pK_2
Aluminic acid	H_3AlO_3	11.2	
Aluminum ion (aquo)	Al^{3+} (aquo)	4.98(4)	
Americium(III) ion	Am^{3+} (aquo) $\mu = 0.1$	5.92	
Ammonium ion	NH_4^+	9.246(2)	
Ammonium- d_3	ND_3H^+	9.757	
Antimonic acid	$HSb(OH)_6 = Sb(OH)_6^- + H^+ \mu = 0.5$	2.55	
Antimony(III) ion	$SbO^+ + H_2O = Sb(OH)_3 + H^+ \mu = 1.0$	1.42	
Barium ion	pK_b of $Ba(OH)^+ \mu = 0.1$	0.64	
Berkelium(III) ion	pK for hydrolysis of $Bk^{3+} \mu = 0.1$	5.66	
Beryllium(II) ion	Be^{2+} (aquo) = $BeOH^+ + H^+ \mu = 1.0$	6.5	
Bismuth(III) ion	$Bi^{3+} = BiOH^{2+} + H^+ \mu = 3.0$	1.58	
Boric acid, tetra-	$H_2B_4O_7$	4	9
Bromine	$Br_2 + H_2O = HBrO + H^+ + Br^-$	7.92	
Cadmium ion	Cd^{2+} (aquo) hydrolysis	9.2(1)	
Calcium ion	Ca^{2+} (aquo) hydrolysis	12.67(3)	
Californium(III) ion	Cf^{3+} (aquo) hydrolysis $\mu = 0.1$	5.62	
Carbon dioxide	CO_2 (aquo)	6.352(1)	10.329
	CO_2 in D_2O	6.77	10.93
Cerium(III) ion	Ce^{3+} (aquo) hydrolysis	ca. 9.3	
Cerium(IV) ion	Hydrolysis to $Ce(OH)^{3+}$ and $Ce(OH)_2^+$	-1.15	0.82
Chromium(III) ion	Cr^{3+} (aquo) hydrolysis	3.95	
Cobalt(II) ion	Co^{2+} (aquo) hydrolysis	8.9	
Cobalt(III) ion	Co^{3+} (aquo) hydrolysis $m = 1$	1.75	
Copper(II) ion	Cu^{2+} (aquo) hydrolysis	7.34	
Curium(III) ion	Cm^{3+} (aquo) hydrolysis $m = 0.1$	6.00(5)	
Deuterium oxide	D_2O (molal scale)	14.956(1)	
Dysprosium(III) ion	Dy^{3+} (aquo) hydrolysis	8.10	
Erbium(III) ion	Er^{3+} (aquo) hydrolysis $\mu = 3$	9.0	
Europium(III) ion	Eu^{3+} (aquo) hydrolysis	8.03	
Fermium(III) ion	Fm^{3+} hydrolysis $\mu = 0.1$	3.8	
Gadolinium(III) ion	Gd^{3+} hydrolysis	8.27	
Gallium(III) ion	Ga^{3+} (successive values for hydrolysis)	2.92	3.77
		pK_3 4.75	
Gold(III) hydroxide	H_3AuO_3	<11.7	13.36
Hafnium(IV) ion	Hf^{4+} hydrolysis $\mu = 1$	-0.12	0.23
Hexaminotriphosphazene	$N_3P_3(NH_2)_6$	<3.2	7.68(3)
Holmium(III) ion	Ho^{3+} hydrolysis $\mu = 0.3$	8.04	

TABLE 8.7 Proton Transfer Reactions of Inorganic Materials in Water at 25°C (*Continued*)

Substance	Formula or remarks	pK ₁	pK ₂
Hydrazinium(2+) ion	$^+H_3N-NH_3^+$	0.27	7.94(3)
Hydrogen amidodisulfonate	$HNSO(OH)_2$	pK ₃ 8.50	
Hydrogen amidophosphate	$H_2NPO(OH)_2$ (26°C)	2.739	8.102
Hydrogen arsenate	H_3AsO_4	2.223	6.760
Hydrogen- <i>d</i> ₃ arsenate	D_3AsO_4	2.596	
Hydrogen arsenite	$HAsO_2$	9.28(10)	
Hydrogen azide	HN_3	4.62	
Hydrogen- <i>d</i> azide	DN_3 (in D ₂ O)	5.115	
Hydrogen borate (3-)	H_3BO_3	9.236	
Hydrogen bromate	$HBrO_3$ (in formamide)	1.02	
Hydrogen bromide	HBr	-8.72(15)	
Hydrogen chlorate	$HClO_3$ (theoretical prediction)	-2.7	
Hydrogen chloride	HCl	-6.2(1)	
Hydrogen- <i>d</i> chloride	DCl (in dimethylformamide)	3.58	
Hydrogen chlorite	$HClO_2$	1.94	
Hydrogen chromate	H_2CrO_4	0.74	6.488
Hydrogen cyanate	$HOCN$	3.46	
Hydrogen cyanide	HCN	9.21	
Hydrogen- <i>d</i> cyanide	DCN (in D ₂ O) $\mu = 0.11$	8.97	
Hydrogen diamidophosphate	$(NH_2)PO(OH)$ (30°C)	1.279(+1)	4.889
Hydrogen diamidothiophosphate	$(NH_2)PO(SH)$ (20°C)	2.0(+1)	4.3
Hydrogen diimidotriphosphate	$(HO)_2PO(NH)PO(OH)(NH)PO(OH)_2$ $\mu = 0.1$	~ 1	~ 2
		pK ₃ 3.03	pK ₄ 6.61
		pK ₅ 9.84	
Hydrogen diphosphate	$H_4P_2O_7$	0.91	2.10
		pK ₃ 6.70	pK ₄ 9.35
		-12	-8
Hydrogen disulfate	$H_2S_2O_7$ (theoretical prediction)	-3.4	-0.2
Hydrogen dithionate	$H_2S_2O_6$	0.35	2.45
Hydrogen dithionite	$H_2S_2O_4$	3.20(4)	
Hydrogen fluoride	H_2F_2	9.01	12.30
Hydrogen germanate	H_2GeO_4		1.92
Hydrogen hexafluorosilicate	H_2SiF_6		2.50
Hydrogen hydrosulfite	$H_2S_2O_4$	0.35	
Hydrogen hypobromite	$HBrO$	8.55	
Hydrogen hypochlorite	$HClO$	7.537	
Hydrogen hypoiodite	HIO	10.5(5)	
Hydrogen hyponitrite	$H_2N_2O_2$	7.21	11.45(10)
Hydrogen iodate	HIO_3	0.804	

Source: J. J. Christensen, L. D. Hansen, and R. M. Izatt, *Handbook of Proton Ionization Heats and Related Thermodynamic Quantities*, Wiley-Interscience, New York, 1976; D. D. Perrin, *Ionisation Constants of Inorganic Acids and Bases in Aqueous Solution*, 2d ed., Pergamon Press, 1982.

TABLE 8.7 Proton Transfer Reactions of Inorganic Materials in Water at 25°C (*Continued*)

Substance	Formula or remarks	p <i>K</i> ₁	p <i>K</i> ₂
Hydrogen- <i>d</i> iodate	DIO ₃ (in D ₂ O)	1.15	
Hydrogen iodide	HI	−8.56	
Hydrogen manganate(VI)	H ₂ MnO ₄ (35°C) $\mu = 0.1$		10.15
Hydrogen nitrate	HNO ₃	−1.37(7)	
Hydrogen nitrite	HNO ₂	3.14(1)	
Hydrogen perchlorate	HClO ₄	−1.6	
Hydrogen periodate	HIO ₄	1.64	
Hydrogen peroxide	H ₂ O ₂	11.64(2)	
Hydrogen peroxophosphate	H ₃ PO ₅ $\mu = 0.2$	1.1	5.5
		p <i>K</i> ₃ 12.8	
Hydrogen peroxosulfate	H ₂ SO ₅	1.0	9.86
Hydrogen perrhenate	HReO ₄	−1.25	
Hydrogen pertechnetate	HTcO ₄	0.3	
Hydrogen perthiocarbonate	H ₂ CS ₄	3.54	7.24
Hydrogen perxenate	H ₄ XeO ₆	p <i>K</i> ₃ 10.5	
Hydrogen phosphate(3−)	H ₃ PO ₄	2.148(20)	7.198(10)
		p <i>K</i> ₃ 12.32(6)	
Hydrogen- <i>d</i> ₂ phosphate	D ₂ PO ₄ (in D ₂ O)	7.780	
Hydrogen phosphinate	H ₂ PHO ₂	1.23	
Hydrogen phosphonate	H ₂ PHO ₃	1.43	6.68(14)
Hydrogen selenate	H ₂ SeO ₄		1.66
Hydrogen selenide	H ₂ Se $\mu = 0.03$	3.89	11.0
Hydrogen selenite	H ₂ SeO ₃	2.62	8.30(15)
Hydrogen silicate(4−)	H ₄ SiO ₄	9.60(10)	11.8(1)
Hydrogen sulfamate	H ₂ NSO ₃ H	0.99	
Hydrogen sulfate	H ₂ SO ₄		1.99(1)
Hydrogen sulfide	H ₂ S	6.97	12.90
Hydrogen sulfite	SO ₂ + H ₂ O = HSO ₃ [−] = H ⁺	1.89	7.205
Hydrogen tellurate	H ₆ TeO ₆	7.65(5)	11.00(5)
Hydrogen telluride	H ₂ Te (18°C)	2.64	11–12
Hydrogen tellurite	H ₂ TeO ₃ (20°C)	6.27	8.43
Hydrogen tetrafluoroborate	BF ₄ [−]	0.5	
Hydrogen tetracyanonickelate	H ₂ Ni(CN) ₄	4.69	6.59
Hydrogen tetraperoxo chromate	H ₃ CrO ₈ (30°C) $\mu = 3$	7.16	
Hydrogen tetrapolyphosphate	H ₄ P ₄ O ₁₃ $\mu = 0.034$	1.99	2.64
		p <i>K</i> ₃ 6.62	p <i>K</i> ₄ 8.2

TABLE 8.7 Proton Transfer Reactions of Inorganic Materials in Water at 25°C (*Continued*)

Substance	Formula or remarks	p <i>K</i> ₁	p <i>K</i> ₂
Hydrogen tetrathiosphosphate	H ₃ PS ₄	1.5	3.5
Hydrogen thiocyanate	HSCN $\mu = 3$	p <i>K</i> ₃ 6.6 -1.8	
Hydrogen thiophosphate	H ₃ PO ₃ S	1.788	5.427
Hydrogen thiosulfate	H ₂ S ₂ O ₃	p <i>K</i> ₃ 10.08 0.6	1.74
Hydrogen tripolyphosphate	H ₃ P ₃ O ₉	~1 p <i>K</i> ₃ 2.00(10) p <i>K</i> ₂ 5.83(7) p <i>K</i> ₃ 8.51(6)	1.7
Hydrogen triselenocarbonate	H ₂ CSe ₃	1.16	7.70
Hydrogen trithiocarbonate	H ₂ CS ₃ (20°C)	2.68	8.18
Hydrogen tungstate	H ₂ WO ₄	2.20	3.70
Hydrogen vanadate(-1)	HVO ₃	3.80	
Hydrogen vanadate(3-)	H ₃ VO ₄	3.78	7.78(4)
Hydroxylamine- <i>N,N</i> -disulfonic acid	HON(SO ₃ H) ₂ $\mu = 1.6$	p <i>K</i> ₃ 11.85	
Hydroxylamine <i>O</i> -sulfonate	⁺ H ₃ NOSO ₃ ⁻ $\mu = 1$	1.48	
Imidodiphosphoric acid	(HO) ₂ PO(NH)PO(OH) ₂ $\mu = 0.2$	~2 p <i>K</i> ₃ 7.08	2.85 p <i>K</i> ₄ 9.72
Indium(III) ion	In ³⁺ hydrolysis	3.54	4.28
Iridium(III) ion	Ir ³⁺ hydrolysis $\mu = 1$	4.37	5.20
Iron(II) ion	Fe ²⁺ hydrolysis $\mu = 1$	6.8	
Iron(III) ion	Fe ³⁺ hydrolysis	2.19	
Lanthanum(III) ion	La ³⁺ hydrolysis	9.06	
Lead(II) ion	Pb ²⁺ hydrolysis $\mu = 0.3$	7.8	
Lead(IV) ion	Pb ⁴⁺ hydrolysis	1.8	3.2
Lithium(I) ion	Li ⁺	13.8	
Lutetium(III) ion	Lu ³⁺ hydrolysis	7.94	
Magnesium(II) ion	Mg ²⁺ hydrolysis	11.41	
Manganese(II) ion	Mn ²⁺ hydrolysis	10.59	
Manganese(III) ion	Mn ³⁺ hydrolysis	0.4	
Mercury(I) ion	Hg ₂ ²⁺ hydrolysis $\mu = 0.5$	5.0	
Mercury(II) ion	Hg ²⁺ hydrolysis $\mu = 0.5$	3.70	2.65
Neodymium(III) ion	Nd ³⁺ hydrolysis $\mu = 3$	9.0(5)	
Neptunium(III) ion	Np ³⁺ hydrolysis $\mu = 0.3$	7.43	
Neptunium(IV) ion	Np ⁴⁺ hydrolysis $\mu = 2$	2.30	
Neptunium(V) ion	NpO ₂ ⁺ hydrolysis	8.90(2)	
Nickel(II) ion	Ni ²⁺ hydrolysis	9.86	
Osmium tetroxide	OsO ₄ hydrolysis $\mu = 1$	12.1	
Palladium(II) ion	Pd ²⁺ (stepwise p <i>K</i> _b values)	13.0	12.8
Pentacyanoaquoferate(II) ion	Fe(CN) ₅ (H ₂ O) ³⁻ $\mu = 0.1$	2.63	

TABLE 8.7 Proton Transfer Reactions of Inorganic Materials in Water at 25°C (*Continued*)

Substance	Formula or remarks	pK ₁	pK ₂
Plutonium(III) ion	Pu ³⁺ hydrolysis $\mu = 0.07$	7.2(2)	
Plutonium(IV) ion	Pu ⁴⁺ hydrolysis $\mu = 2$	1.26	
Plutonium(V) ion	PuO ₂ ⁺ hydrolysis $\mu = 0.003$	9.7	
Plutonium(VI) ion	PuO ₂ ²⁺ hydrolysis	3.33	4.05
Polonium(IV) ion	Po ⁴⁺ hydrolysis	0.48	2.74
		pK ₃ 5.58	
Praseodymium(III) ion	Pr ³⁺ hydrolysis $\mu = 0.3$	8.55	
Protoactinium(IV) ion	Pa ⁴⁺ hydrolysis $\mu = 3$	0.14	0.38
Protoactinium(V) ion	Pa ⁵⁺ hydrolysis $\mu = 3$	1.05	
Scandium(III) ion	Sc ³⁺ hydrolysis $\mu = 0.05$	4.58(3)	
Silver(I) ion	Ag ⁺ hydrolysis	> 11.1	
Sodium ion	Na ⁺ (aquo)	14.67(10)	
Strontium ion	Sr ²⁺ (aquo)	13.18	
Terbium(III) ion	Tb ³⁺ hydrolysis $\mu = 0.3$	8.16	
Thallium(I) ion	Tl ⁺	13.36(15)	
Thallium(III) ion	Tl ³⁺ hydrolysis $\mu = 3$	1.14	
Thorium(IV) ion	Th ⁴⁺ hydrolysis $\mu = 0.5$	3.89	4.20
Tin(II) ion	Sn ²⁺ hydrolysis $\mu = 3$	3.81(10)	
Titanium(III)	Ti ³⁺ hydrolysis $\mu = 3$	2.55	
Titanium(IV)	TiO ²⁺ + H ₂ O = TiO(OH) ⁺ + H	1.3	
Tritium oxide	pK _w for T ₂ O = T ⁺ + OH ⁻	15.21	
Uranium(IV) ion	U ⁴⁺ hydrolysis	0.68	
Uranyl(VI) ion	UO ₂ ²⁺ $\mu = 0.035$	5.82	
Vanadium(II) ion	V ²⁺ hydrolysis	6.85	
Vanadium(III) ion	V ³⁺ hydrolysis	2.92	3.5
Vanadyl(IV) ion	VO ²⁺ hydrolysis	6.86(10)	
Vanadyl(V) ion	VO ₂ ⁺ (20°C) $\mu = 0.1$	1.83	
Xenon trioxide	XeO ₃ + H ₂ O = HXeO ₄ ⁻ + H ⁺	10.5	
Ytterbium(III) ion	Yb ³⁺ hydrolysis	7.99(6)	
Yttrium(III) ion	Y ³⁺ hydrolysis $\mu = 0.3$	8.34	
Zinc ion	Zn ²⁺ hydrolysis	8.96	
Zirconium(IV) ion	Zr ⁴⁺ hydrolysis $\mu = 1$	-0.32	0.06
		pK ₃ 0.35	