CEE 680 8 March 2018

FIRST EXAM

Closed book, one page of notes allowed.

Answer any 4 of the following 5 questions. Please state any additional assumptions you made, and show all work.

Miscellaneous Information:

R = 1.987 cal/mole°K = 8.314 J/mole°K Absolute zero = -273.15°C 1 joule = 0.239 calories 10°F = the new 30°F

- 1. (25%) Use the graphical solution to determine the pH and complete solution composition for 1 liter of pure water to which you've added 10⁻² moles of Phenol. Graph paper is attached to this exam for this purpose.
- 2. (25%) Determine the pH and solution composition of a mixture of 10⁻² moles of Phenol plus 10⁻³ moles of Disodium o-Phthalate [Na₂C₆H₄(COO⁻)₂] in 1 liter of water. Please use a graphical solution for this one too.
- 3. (25%) Determine the complete solution composition of:
 - a. a solution of 10⁻² moles of Sodium Hypochlorite (NaOCl) in 1 Liter of water
 - b. a solution of 10⁻² moles of the conjugate acid [i.e., Hypochlorous Acid (HOCl)] in 1 Liter of water.

But this time use an algebraic solution. You can ignore ionic strength effects (i.e., assume infinite dilution). Remember to make simplifying assumptions

4. (25%) Repeat problem #3a, but this time add 0.1 M of NaCl as well as the 10⁻² moles of NaOCl to your liter of water. Also this time, do not ignore ionic strength effects.

, ,	True/False. Mark each one of the following statements with either a "T" or an rhichever is most accurate
a	The pH of pure water in equilibrium with atmospheric CO ₂ is below 6
b	Equilibrium constants can be calculated from the ratio of the forward and backward rate constants
c	The pKa of an acid is always equal to the pKb of its conjugate base
d	pH = 7 at the end-point of a titration
e	Nitric acid always completely donates its proton to the solvent it is dissolve in, regardless of the nature of that solvent
f	The principle of electroneutrality is always observed in aqueous solutions
g	Non-carbonate hardness is equal to the magnesium concentration minus the sulfate concentration
h	Increases in ionic strength have no effect on species with zero charge.
i	Hypochlorite is a very strong base in water
i.	The value of α_0 plus α_1 must always equal 1 for any monoprotic acid system.

Selected Acidity Constants (Aqueous Solution, 25°C, I = 0)

Perchloric acid HClO ₄ = H ⁺ + ClO ₄ * -7 STRONG Hydrochloric acid HCl = H ⁺ + Cl - -3 -4 -4 -6 -4	NAME	FORMULA	pKa
Hydrochloric acid HCI = H ⁺ + Cl ⁻ -3 (&2) ACIDS Sulfuric acid H ₂ SO ₄ = H ⁺ + HSO ₄ -3 (&2) ACIDS Nitric acid HNO ₃ = H ⁺ + HO ₃ -0 Hydronium ion H ₃ O ⁺ = H ⁺ + H ₂ O 0 Trichloroacetic acid CCl ₃ COOH = H ⁺ + CCl ₃ COO ⁺ 0.70 Iodic acid HIO ₃ = H ⁺ + IO ₃ 0.8 Bisulfate ion HSO ₄ = H ⁺ + SO ₄ 2 2 Phosphoric acid H ₃ O ₄ = H ⁺ + H ₂ PO ₄ 2.15 (&7.2,12.3) o-Phthalic acid C ₆ H ₄ (COOH) ₂ = H ⁺ + C ₆ H ₄ (COOH) ₂ COO 2.89 (&5.51) Citric acid C ₃ H ₅ O(COOH) ₃ = H ⁺ + C ₃ H ₅ O(COOH) ₂ COO 3.14 (&4.77,6.4) Hydrofluoric acid HF = H ⁺ + F 3.2 Aspartic acid C ₂ H ₆ N(COOH) ₂ = H ⁺ + C ₂ H ₆ N(COOH) ₂ COO 3.86 (&9.82) m-Hydroxybenzoic acid C ₂ H ₆ N(COOH) ₂ = H ⁺ + C ₆ H ₄ (OH)COO 4.06 (&9.92) P-Hydroxybenzoic acid C ₆ H ₄ (OH)COOH = H ⁺ + C ₆ H ₄ (OH)COO 4.48 (&9.32) Nitrous acid HNO ₂ = H ⁺ + NO ₂ 4.5 Acetic acid CH ₃ COOH = H ⁺ + C ₄ H ₅ COO 4.87 o-Phthalate C ₆ H ₄ (COH)COO = H ⁺ + C ₆ H ₄ (COO+) ₂ 5.51 Carbonic acid H ₂ CO ₃ = H ⁺ + HCO ₃ 6.35 (&10.33) Hydrogen sulfide H ₂ S = H ⁺ + HS 7.02 (&13.9) Hydrogen phosphate H ₂ PO ₄ = H ⁺ + HPO ₄ 7.2 Hypochlorous acid HOC = H ⁺ + COI 7.5 Boric acid HOC = H ⁺ + COI 7.5 Boric acid HOC = H ⁺ + COI 9.3 P-Hydroxybenzoic acid C ₆ H ₄ (OH)COO = H ⁺ + C ₆ H ₄ (OCOO 9.32 Phenol C ₆ H ₅ OH = H ⁺ + C ₆ H ₅ O 9.9 P-Hydroxybenzoic acid C ₆ H ₄ (OH)COO = H ⁺ + C ₆ H ₄ (O)COO 9.92 Phenol C ₆ H ₅ OH = H ⁺ + C ₆ H ₅ O 9.9 P-Hydroxybenzoic acid HCO ₃ = H ⁺ + CO ₃ 10.33 Monohydrogen HPO ₄ = H ⁺ + S ² 13.9 Water H ₂ O = H ⁺ + OH 14.00 Ammonia NH ₃ = H ⁺ + NH ₂ 23	Perchloric acid	$HClO_4 = H^+ + ClO_4^-$	
Sulfuric acid H2SO4=H+ HSO4* -3 (&2) ACIDS Nitric acid HNO3 = H+ NO3* -0 Hydronium ion H3O* = H* + H2O 0 Trichloroacetic acid CCl3COOH = H* + CCl3COO* 0.70 Iodic acid H103 = H* + H03* 0.8 Bisulfate ion H8O4* = H* + SO4*2 2 Phosphoric acid H3PO4 = H* + H2PO4* 2.15 (&7.2,12.3) o-Phthalic acid C6H4(COOH)2 = H* + C6H4(COOH)COO* 2.89 (&5.51) Citric acid C3H50(COOH)3= H* + C3H50(COOH)2COO* 3.14 (&4.77.64) Hydrofluoric acid HF = H* + F* 3.2 Aspartic acid C2H6N(COOH)2 = H* + C2H6N(COOH)2COO* 3.86 (&9.82) M-Hydroxybenzoic acid C6H4(OH)COOH = H* + C2H6N(COOH)COO* 4.06 (&9.92) p-Hydroxybenzoic acid C6H4(OH)COOH = H* + C6H4(OH)COO* 4.48 (&9.32) Nitrous acid HNO2 = H* + NO2* 4.5 Acetic acid CH3COOH = H* + CH3COO* 4.75 Propionic acid C2H5COOH = H* + C2H5COO* 4.87 o-Phthalate C6H4(COOH)COO* = H* + C6H4(COO+)2 5.51 Carbonic acid	Hydrochloric acid	-	
Nitric acid HNO3 = H ⁺ + NO3 ⁻ -0 Hydronium ion H30 ⁺ = H ⁺ + H2O 0 Trichloroacetic acid CCl3COOH = H ⁺ + CCl3COO ⁻ 0.70 Iodic acid HIO3 = H ⁺ + IO3 ⁻ 0.8 Bisulfate ion HSO4 ⁻ = H ⁺ + SO4 ⁻² 2 Phosphoric acid H3PO4 = H ⁺ + H2PO4 ⁺ 2.15 (&7.2,12.3) o-Phthalic acid C6H4(COOH)2 = H ⁺ + C6H4(COOH)COO ⁻ 2.89 (&5.51) Citric acid U3H50(COOH)3 = H ⁺ + C3H50(COOH)2COO ⁻ 3.14 (&4.77,6.4) Hydrofluoric acid HF = H ⁺ + F ⁻ 3.2 Aspartic acid C2H6N(COOH)2 = H ⁺ + C2H6N(COOH)COO ⁻ 3.86 (&9.82) m-Hydroxybenzoic acid C6H4(OH)COOH = H ⁺ + C6H4(OH)COO ⁻ 4.06 (&9.92) p-Hydroxybenzoic acid HNO2 = H ⁺ + NO2 ⁻ 4.5 Acetic acid CH3COOH = H ⁺ + C4H3COO ⁻ 4.75 Propionic acid C2H5COOH = H ⁺ + C2H5COO ⁻ 4.75 Propionic acid C2H5COOH = H ⁺ + C4H4(OO) ⁻ 5.51 Carbonic acid H2CO3 = H ⁺ + HCO3 ⁻ 4.87 Hydrogen sulfide H2S = H ⁺ + HS 7.02 (&13.9) <td>Sulfuric acid</td> <td></td> <td>-3 (&2) ACIDS</td>	Sulfuric acid		-3 (&2) ACIDS
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Nitric acid		-0
Indic acid HiO3 = H ⁺ + IO3 ⁻ 2	Hydronium ion		0
Iodic acid HIO3 = H ⁺ + IO3 ⁻ 0.8 Bisulfate ion HSO4 ⁺ = H ⁺ + SO4 ⁺² 2 Phosphoric acid H3PO4 = H ⁺ + H2PO4 ⁺ 2.15 (&7.2,12.3) o-Phthalic acid C6H4(COOH)2 = H ⁺ + C6H4(COOH)COO ⁻ 2.89 (&5.51) Citric acid C3H5O(COOH)3 = H ⁺ + C3H5O(COOH)2COO ⁻ 3.14 (&4.77,6.4) Hydrofluoric acid HF = H ⁺ + F ⁻ 3.2 Aspartic acid C2H6N(COOH)2 = H ⁺ + C2H6N(COOH)COO ⁻ 3.86 (&9.82) m-Hydroxybenzoic acid C6H4(OH)COOH = H ⁺ + C6H4(OH)COO ⁻ 4.06 (&9.92) p-Hydroxybenzoic acid C6H4(OH)COOH = H ⁺ + C6H4(OH)COO ⁻ 4.48 (&9.32) Nitrous acid HNO2 = H ⁺ + NO2 ⁻ 4.5 Acetic acid CH3COOH = H ⁺ + CH3COO ⁻ 4.75 Propionic acid C2H3COOH = H ⁺ + C2H3COO ⁻ 4.87 o-Phthalate C6H4(COOH)COO ⁻ = H ⁺ + C6H4(COO-)2 5.51 Carbonic acid H2C3 = H ⁺ + HB ⁻ 7.02 (&13.9) Hydrogen sulfide H2S = H ⁺ + HB ⁻ 7.02 (&13.9) Dihydrogen phosphate H2PO4 ⁺ = H ⁺ + PO1 ⁻ 7.2 Hypochlorous acid H0C1 = H ⁺ +	Trichloroacetic acid	$CCl_3COOH = H^+ + CCl_3COO^-$	0.70
Bisulfate ion HSO4⁻ = H⁺ + SO4⁻² 2 Phosphoric acid H₃PO4 = H⁺ + H₂PO4⁻ 2.15 (&7.2,12.3) o-Phthalic acid C6H₄(COOH)₂ = H⁺ + C6H₄(COOH)COO⁻ 2.89 (&5.51) Citric acid C₃H₃O(COOH)₃ = H⁺ + C₃H₃O(COOH)₂COO⁻ 3.14 (&4.77,6.4) Hydrofluoric acid HF = H⁺ + F⁻ 3.2 Aspartic acid C₂H₆N(COOH)₂ = H⁺ + C₂H₆N(COOH)COO⁻ 3.86 (&9.82) m-Hydroxybenzoic acid C₆H₄(OH)COOH = H⁺ + C₆H₄(OH)COO⁻ 4.06 (&9.92) p-Hydroxybenzoic acid C₆H₄(OH)COOH = H⁺ + C₆H₄(OH)COO⁻ 4.48 (&9.32) Nitrous acid HNO₂ = H⁺ + NO₂⁻ 4.5 Acetic acid CH₃COOH = H⁺ + CH₃COO⁻ 4.75 Propionic acid C₂H₃COOH = H⁺ + C₂H₃COO⁻ 4.87 o-Phthalate C₆H₄(COOH)COO⁻ = H⁺ + C₆H₄(COO-)₂ 5.51 Carbonic acid H₂CO₃ = H⁺ + HCO₃⁻ 6.35 (&10.33) Hydrogen sulfide H₂S = H⁺ + HS⁻ 7.02 (&13.9) Dihydrogen phosphate H₂PO4⁻ = H⁺ + HPO4⁻² 7.2 Hypochlorous acid HOC1 = H⁺ + OC1⁻ 7.5 Boric acid HCOH = H⁺ + CN⁻ 9.2 P-H	Iodic acid	$HIO_3 = H^+ + IO_3^-$	0.8
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Bisulfate ion		2
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Phosphoric acid		2.15 (&7.2,12.3)
Citric acid $C_3H_5O(COOH)_3 = H^+ + C_3H_5O(COOH)_2COO^ 3.14 (\&4.77,6.4)$ Hydrofluoric acid $HF = H^+ + F^ 3.2$ Aspartic acid $C_2H_6N(COOH)_2 = H^+ + C_2H_6N(COOH)COO^ 3.86 (\&9.82)$ m-Hydroxybenzoic acid $C_6H_4(OH)COOH = H^+ + C_6H_4(OH)COO^ 4.06 (\&9.92)$ P-Hydroxybenzoic acid $C_6H_4(OH)COOH = H^+ + C_6H_4(OH)COO^ 4.48 (\&9.32)$ Nitrous acid $HNO_2 = H^+ + NO_2^ 4.5$ Acetic acid $H_3COOH = H^+ + C_3H_3COO^ 4.75$ Propionic acid $C_2H_5COOH = H^+ + C_3H_3COO^ 4.87$ o-Phthalate $C_6H_4(COOH)COO^- = H^+ + C_6H_4(COO^-)_2$ 5.51 Carbonic acid $H_2CO_3 = H^+ + HCO_3^ 6.35 (\&10.33)$ Hydrogen sulfide $H_2S = H^+ + HS^ 7.02 (\&13.9)$ Dihydrogen phosphate $H_2PO_4^+ = H^+ + HPO_4^{-2}$ 7.2 Hypochlorous acid $HOCI = H^+ + HPO_4^ 7.5$ Boric acid $B(OH)_3 + H_2O = H^+ + B(OH)_4^ 9.2 (\&12.7,13.8)$ Ammonium ion $NH_4^+ = H^+ + NH_3$ 9.24 Hydroxybenzoic acid $C_6H_3(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ <t< td=""><td>o-Phthalic acid</td><td>-</td><td>2.89 (&5.51)</td></t<>	o-Phthalic acid	-	2.89 (&5.51)
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Citric acid		3.14 (&4.77,6.4)
m-Hydroxybenzoic acid	Hydrofluoric acid		3.2
p-Hydroxybenzoic acid C6H4(OH)COOH = H ⁺ + C6H4(OH)COO ⁻ At 8 (&9.32) Nitrous acid HNO ₂ = H ⁺ + NO ₂ ⁻ Acetic acid CH ₃ COOH = H ⁺ + CH ₃ COO ⁻ Propionic acid C2H ₅ COOH = H ⁺ + C2H ₅ COO ⁻ C6H4(COOH)COO ⁻ = H ⁺ + C6H4(COO ⁻) ₂ 5.51 Carbonic acid H ₂ CO ₃ = H ⁺ + HCO ₃ ⁻ 6.35 (&10.33) Hydrogen sulfide H ₂ S = H ⁺ + HS ⁻ 7.02 (&13.9) Dihydrogen phosphate H ₂ PO ₄ ⁻ = H ⁺ + HPO ₄ ⁻² T.2 Hypochlorous acid HOCl = H ⁺ + OCl ⁻ Boric acid B(OH) ₃ + H ₂ O = H ⁺ + B(OH) ₄ ⁻ 9.2 (&12.7,13.8) Ammonium ion NH ₄ ⁺ = H ⁺ + NH ₃ Hydrocyanic acid HCN = H ⁺ + CN ⁻ P-Hydroxybenzoic acid C6H ₄ (OH)COO ⁻ = H ⁺ + C ₆ H ₄ (O)COO ⁻² 9.32 Phenol C ₆ H ₅ OH = H ⁺ + C ₆ H ₅ O ⁻ 0.99 m-Hydroxybenzoic acid C ₆ H ₄ (OH)COO ⁻ = H ⁺ + C ₆ H ₄ (O)COO ⁻² Bicarbonate ion HCO ₃ ⁻ = H ⁺ + CO ₃ ⁻² 10.33 Monohydrogen phosphate Bisulfide ion HS ⁻ = H ⁺ + S ⁻² 13.9 Water H ₂ O = H ⁺ + OH ⁻ 14.00 Ammonia NH ₃ = H ⁺ + NH ₂ ⁻ 23	Aspartic acid	$C_2H_6N(COOH)_2=H^+ + C_2H_6N(COOH)COO^-$	3.86 (&9.82)
Nitrous acid HNO2 = H ⁺ + NO2 ⁻ 4.5 Acetic acid CH3COOH = H ⁺ + CH3COO ⁻ 4.75 Propionic acid C2H5COOH = H ⁺ + CH3COO ⁻ 4.87 o-Phthalate C6H4(COOH)COO ⁻ = H ⁺ + C6H4(COO-)2 5.51 Carbonic acid H2CO3 = H ⁺ + HCO3 ⁻ 6.35 (&10.33) Hydrogen sulfide H2S = H ⁺ + HS ⁻ 7.02 (&13.9) Dihydrogen phosphate H2PO4 ⁻ = H ⁺ + HPO4 ⁻² 7.2 Hypochlorous acid HOCI = H ⁺ + OCI ⁻ 7.5 Boric acid B(OH)3 + H2O = H ⁺ + B(OH)4 ⁻ 9.2 (&12.7,13.8) Ammonium ion NH4 ⁺ = H ⁺ + NH3 9.24 Hydrocyanic acid HCN = H ⁺ + CN ⁻ 9.3 p-Hydroxybenzoic acid C6H4(OH)COO ⁻ = H ⁺ + C6H4(O)COO ⁻² 9.32 Phenol C6H5OH = H ⁺ + C6H5O ⁻ 9.9 m-Hydroxybenzoic acid C6H4(OH)COO ⁻ = H ⁺ + C6H4(O)COO ⁻² 9.92 Bicarbonate ion HCO3 ⁻ = H ⁺ + CO3 ⁻² 10.33 Monohydrogen phosphate HPO4 ⁻² = H ⁺ + PO4 ⁻³ 12.3 Monohydrogen Phosphate HPO4 ⁻² = H ⁺ + S-2 13.9	m-Hydroxybenzoic acid	$C_6H_4(OH)COOH = H^+ + C_6H_4(OH)COO^-$	4.06 (&9.92)
Acetic acid $CH_3COOH = H^+ + CH_3COO^-$ 4.75 Propionic acid $C_2H_5COOH = H^+ + CH_3COO^-$ 4.87 o-Phthalate $C_6H_4(COOH)COO^- = H^+ + C_6H_4(COO^-)_2$ 5.51 Carbonic acid $H_2CO_3 = H^+ + HCO_3^-$ 6.35 (&10.33) Hydrogen sulfide $H_2S = H^+ + HS^-$ 7.02 (&13.9) Dihydrogen phosphate $H_2PO_4^- = H^+ + HPO_4^{-2}$ 7.2 Hypochlorous acid $HOCl = H^+ + OCl^-$ 7.5 Boric acid $B(OH)_3 + H_2O = H^+ + B(OH)_4^-$ 9.2 (&12.7,13.8) Ammonium ion $NH_4^+ = H^+ + NH_3$ 9.24 Hydrocyanic acid $HCN = H^+ + CN^-$ 9.3 p-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 9.32 Phenol $C_6H_5OH = H^+ + C_6H_5O^-$ 9.9 m-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 9.92 Bicarbonate ion $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 10.33 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 12.3 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 12.3 Water $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 13.9 Water $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 14.00 Ammonia $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 15.3 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 16.33 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 16.33 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-2$ 17.3 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(OH)COO^-$ 18.4 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(OH)COO^-$ 19.4 Mydrogen $C_6H_4(OH)$	p-Hydroxybenzoic acid	$C_6H_4(OH)COOH = H^+ + C_6H_4(OH)COO^-$	4.48 (&9.32)
Propionic acid $C_2H_5COOH = H^+ + C_2H_5COO^-$ 4.87 o-Phthalate $C_6H_4(COOH)COO^- = H^+ + C_6H_4(COO-)_2$ 5.51 Carbonic acid $H_2CO_3 = H^+ + HCO_3^-$ 6.35 (&10.33) Hydrogen sulfide $H_2S = H^+ + HS^-$ 7.02 (&13.9) Dihydrogen phosphate $H_2PO_4^- = H^+ + HPO_4^{-2}$ 7.2 Hypochlorous acid $HOCl = H^+ + OCl^-$ 7.5 Boric acid $HOCl = H^+ + HOOl_4^-$ 9.2 (&12.7,13.8) Ammonium ion $H_4^+ = H^+ + HH_3^-$ 9.24 Hydrocyanic acid $HCN = H^+ + CN^-$ 9.3 p-Hydroxybenzoic acid $HCN = H^+ + C_0H_4(O)COO^-2$ 9.32 Phenol $HCN = H^+ + C_0H_2(O)COO^-2$ 9.92 Phenol $HCO_3^- = H^+ + C_0H_2(O)COO^-2$ 9.92 Bicarbonate ion $HCO_3^- = H^+ + C_0H_2(O)COO^-2$ 10.33 Monohydrogen $HCO_3^- = H^+ + C_0H_2(O)COO^-2$ 12.3 Monohydrogen $HCO_3^- = H^+ + C_0H_2(O)COO^-2$ 13.9 Water $HCO_3^- = H^+ + C_0H_2(O)COO^-2$ 13.9 Water $HCO_3^- = H^+ + C_0H_2(O)COO^-2$ 14.00 Ammonia $HCO_3^- = H^+ + C_0H_2(O)COO^-2$ 14.00	Nitrous acid	$HNO_2 = H^+ + NO_2^-$	4.5
o-Phthalate $C_6H_4(COOH)COO^- = H^+ + C_6H_4(COO^-)_2$ 5.51 Carbonic acid $H_2CO_3 = H^+ + HCO_3^-$ 6.35 (&10.33) Hydrogen sulfide $H_2S = H^+ + HS^-$ 7.02 (&13.9) Dihydrogen phosphate $H_2PO_4^- = H^+ + HPO_4^{-2}$ 7.2 Hypochlorous acid $HOCI = H^+ + OCI^-$ 7.5 Boric acid $B(OH)_3 + H_2O = H^+ + B(OH)_4^-$ 9.2 (&12.7,13.8) Ammonium ion $NH_4^+ = H^+ + NH_3$ 9.24 Hydrocyanic acid $HCN = H^+ + CN^-$ 9.3 p-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.32 Phenol $C_6H_5OH = H^+ + C_6H_5O^-$ 9.9 m-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.92 Bicarbonate ion $HCO_3^- = H^+ + CO_3^{-2}$ 10.33 Monohydrogen phosphate $HPO_4^{-2} = H^+ + PO_4^{-3}$ 12.3 Water $H_2O = H^+ + OH^-$ 14.00 Ammonia $NH_3 = H^+ + NH_2^-$ 23	Acetic acid	$CH_3COOH = H^+ + CH_3COO^-$	4.75
Carbonic acid $H_2CO_3 = H^+ + HCO_3^-$ 6.35 (&10.33) Hydrogen sulfide $H_2S = H^+ + HS^-$ 7.02 (&13.9) Dihydrogen phosphate $H_2PO_4^- = H^+ + HPO_4^{-2}$ 7.2 Hypochlorous acid $HOCl = H^+ + OCl^-$ 7.5 Boric acid $B(OH)_3 + H_2O = H^+ + B(OH)_4^-$ 9.2 (&12.7,13.8) Ammonium ion $NH_4^+ = H^+ + NH_3$ 9.24 Hydrocyanic acid $HCN = H^+ + CN^-$ 9.3 p-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.32 Phenol $C_6H_5OH = H^+ + C_6H_5O^-$ 9.9 m-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.92 Bicarbonate ion $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 10.33 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 12.3 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 12.3 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-$ 12.3 Water $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-$ 13.9 Water $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-$ 13.9 Water $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-$ 14.00 Ammonia $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-$ 14.00	Propionic acid	$C_2H_5COOH = H^+ + C_2H_5COO^-$	4.87
Hydrogen sulfide $H_2S = H^+ + HS^ 7.02 \text{ (\&13.9)}$ Dihydrogen phosphate $H_2PO4^- = H^+ + HPO4^{-2}$ 7.2 Hypochlorous acid $HOCl = H^+ + OCl^ 7.5$ Boric acid $B(OH)_3 + H_2O = H^+ + B(OH)_4^ 9.2 \text{ (\&12.7,13.8)}$ Ammonium ion $NH_4^+ = H^+ + NH_3$ 9.24 Hydrocyanic acid $HCN = H^+ + CN^ 9.3$ p-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.32 Phenol $C_6H_5OH = H^+ + C_6H_5O^ 9.9$ m-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.92 Bicarbonate ion $HCO_3^- = H^+ + CO_3^{-2}$ 10.33 Monohydrogen phosphate $HPO_4^{-2} = H^+ + PO_4^{-3}$ 12.3 Bisulfide ion $HS^- = H^+ + S^{-2}$ 13.9 Water $H_2O = H^+ + OH^ 14.00$ Ammonia $NH_3 = H^+ + NH_2^ 23$	o-Phthalate	$C_6H_4(COOH)COO^- = H^+ + C_6H_4(COO-)_2$	5.51
Dihydrogen phosphate $H_2PO_4^- = H^+ + HPO_4^{-2}$ 7.2 Hypochlorous acid $HOCl = H^+ + OCl^-$ 7.5 Boric acid $B(OH)_3 + H_2O = H^+ + B(OH)_4^-$ 9.2 (&12.7,13.8) Ammonium ion $NH_4^+ = H^+ + NH_3$ 9.24 Hydrocyanic acid $HCN = H^+ + CN^-$ 9.3 p-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.32 Phenol $C_6H_5OH = H^+ + C_6H_5O^-$ 9.9 m-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.92 Bicarbonate ion $HCO_3^- = H^+ + CO_3^{-2}$ 10.33 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 12.3 Monohydrogen $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 13.9 Water $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-$ 13.9 Water $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-$ 14.00 Ammonia $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^-$ 14.00	Carbonic acid	$H_2CO_3 = H^+ + HCO_3^-$	6.35 (&10.33)
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Hydrogen sulfide	$H_2S = H^+ + HS^-$	7.02 (&13.9)
Boric acid $B(OH)_3 + H_2O = H^+ + B(OH)_4^ 9.2 (\&12.7,13.8)$ Ammonium ion $NH_4^+ = H^+ + NH_3$ 9.24 Hydrocyanic acid $HCN = H^+ + CN^ 9.3$ p-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.32 Phenol $C_6H_5OH = H^+ + C_6H_5O^ 9.9$ m-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.92 Bicarbonate ion $HCO_3^- = H^+ + CO_3^{-2}$ 10.33 Monohydrogen phosphate $HPO_4^{-2} = H^+ + PO_4^{-3}$ 12.3 Bisulfide ion $HS^- = H^+ + S^{-2}$ 13.9 Water $H_2O = H^+ + OH^ 14.00$ Ammonia $NH_3 = H^+ + NH_2^ 23$	Dihydrogen phosphate		7.2
Boric acid $B(OH)_3 + H_2O = H^+ + B(OH)_4^ 9.2 \text{ (\&12.7,13.8)}$ Ammonium ion $NH4^+ = H^+ + NH3$ 9.24 Hydrocyanic acid $HCN = H^+ + CN^ 9.3$ p-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.32 Phenol $C_6H_5OH = H^+ + C_6H_5O^ 9.9$ m-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.92 Bicarbonate ion $HCO_3^- = H^+ + CO_3^{-2}$ 10.33 Monohydrogen phosphate $HPO_4^{-2} = H^+ + PO_4^{-3}$ 12.3 Bisulfide ion $HS^- = H^+ + S^{-2}$ 13.9 Water $H_2O = H^+ + OH^ 14.00$ Ammonia $NH_3 = H^+ + NH_2^ 23$	Hypochlorous acid	$HOCl = H^+ + OCl^-$	7.5
Hydrocyanic acid $HCN = H^+ + CN^-$ 9.3 p-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.32 Phenol $C_6H_5OH = H^+ + C_6H_5O^-$ 9.9 m-Hydroxybenzoic acid $C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$ 9.92 Bicarbonate ion $HCO_3^- = H^+ + CO_3^{-2}$ 10.33 Monohydrogen phosphate $HPO_4^{-2} = H^+ + PO_4^{-3}$ 12.3 Bisulfide ion $HS^- = H^+ + S^{-2}$ 13.9 Water $H_2O = H^+ + OH^-$ 14.00 Ammonia $NH_3 = H^+ + NH_2^-$ 23	Boric acid	$B(OH)_3 + H_2O = H^+ + B(OH)_4^-$	9.2 (&12.7,13.8)
p-Hydroxybenzoic acid $C_{6}H_{4}(OH)COO^{-} = H^{+} + C_{6}H_{4}(O)COO^{-2}$ 9.32 Phenol $C_{6}H_{5}OH = H^{+} + C_{6}H_{5}O^{-}$ 9.9 m-Hydroxybenzoic acid $C_{6}H_{4}(OH)COO^{-} = H^{+} + C_{6}H_{4}(O)COO^{-2}$ 9.92 Bicarbonate ion $HCO_{3}^{-} = H^{+} + CO_{3}^{-2}$ 10.33 Monohydrogen phosphate $HPO_{4}^{-2} = H^{+} + PO_{4}^{-3}$ 12.3 Water $H_{2}O = H^{+} + S^{-2}$ 13.9 Water $H_{2}O = H^{+} + OH^{-}$ 14.00 Ammonia $NH_{3} = H^{+} + NH_{2}^{-}$ 23	Ammonium ion	$NH4^{+} = H^{+} + NH3$	9.24
Phenol $C_{6}H_{5}OH = H^{+} + C_{6}H_{5}O^{-}$ 9.9 9.9 9.92 9.92 Bicarbonate ion $HCO_{3}^{-} = H^{+} + CO_{3}^{-2}$ 10.33 10.33 Monohydrogen phosphate Bisulfide ion $HS^{-} = H^{+} + S^{-2}$ 13.9 Water $H_{2}O = H^{+} + OH^{-}$ 14.00 Ammonia $NH_{3} = H^{+} + NH_{2}^{-}$ 23	•	$HCN = H^+ + CN^-$	9.3
m-Hydroxybenzoic acid $C_{6}H_{4}(OH)COO^{-} = H^{+} + C_{6}H_{4}(O)COO^{-2}$ 9.92 Bicarbonate ion $HCO_{3}^{-} = H^{+} + CO_{3}^{-2}$ 10.33 Monohydrogen phosphate $HCO_{4}^{-2} = H^{+} + PO_{4}^{-3}$ 12.3 Water $H_{2}O = H^{+} + S^{-2}$ 13.9 Water $H_{2}O = H^{+} + OH^{-}$ 14.00 Ammonia $NH_{3} = H^{+} + NH_{2}^{-}$ 23	p-Hydroxybenzoic acid	$C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$	9.32
Bicarbonate ion $HCO_3^- = H^+ + CO_3^{-2}$ 10.33 Monohydrogen phosphate $HPO_4^{-2} = H^+ + PO_4^{-3}$ 12.3 Bisulfide ion $HS^- = H^+ + S^{-2}$ 13.9 Water $H_2O = H^+ + OH^ 14.00$ Ammonia $NH_3 = H^+ + NH_2^ 23$		$C_6H_5OH = H^+ + C_6H_5O^-$	9.9
Monohydrogen phosphate $HPO4^{-2} = H^{+} + PO4^{-3}$ 12.3 Bisulfide ion $HS^{-} = H^{+} + S^{-2}$ 13.9 Water $H2O = H^{+} + OH^{-}$ 14.00 Ammonia $NH3 = H^{+} + NH2^{-}$ 23	m-Hydroxybenzoic acid	$C_6H_4(OH)COO^- = H^+ + C_6H_4(O)COO^{-2}$	
phosphate HS-4 H - 104 Bisulfide ion $HS^- = H^+ + S^{-2}$ 13.9 Water $H_2O = H^+ + OH^-$ 14.00 Ammonia $NH_3 = H^+ + NH_2^-$ 23		$HCO_3^- = H^+ + CO_3^{-2}$	10.33
Bisulfide ion $HS^- = H^+ + S^{-2}$ 13.9 Water $H_2O = H^+ + OH^-$ 14.00 Ammonia $NH_3 = H^+ + NH_2^-$ 23		$HPO_4^{-2} = H^+ + PO_4^{-3}$	12.3
Water $H_2O = H^+ + OH^-$ 14.00 Ammonia $NH_3 = H^+ + NH_2^-$ 23		$HS^{-} = H^{+} + S^{-}2$	13.9
Ammonia $NH_3 = H^+ + NH_2^-$ 23			
	Ammonia	_	23
	Methane	$CH_4 = H^+ + CH_3^-$	34

$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	<u> </u>	I	I
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Species	${}^\Delta \overline{H}{}^o_f$	${}^{\scriptscriptstyle \Delta} \overline{G}{}^{\scriptscriptstyle o}_{\scriptscriptstyle f}$
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		kcal/mole	kcal/mole
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Ca ⁺² (aq)	-129.77	-132.18
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	CaCO ₃ (s), calcite	-288.45	-269.78
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	CaO (s)	-151.9	-144.4
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	C(s), graphite	0	0
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$CO_2(g)$	-94.05	-94.26
H ₂ CO ₃ (aq)	CO ₂ (aq)	-98.69	-92.31
HCO ₃ ⁻ (aq)	CH ₄ (g)	-17.889	-12.140
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	H ₂ CO ₃ (aq)	-167.0	-149.00
HOCl (aq)	HCO ₃ - (aq)	-165.18	-140.31
HOCl (aq)	CO ₃ -2 (aq)	-161.63	-126.22
OCI- (aq) -25.60 -8.80 CH ₃ COOH -116.79 -95.5 CH ₃ COO ⁻ , acetate -116.84 -89.0 H ⁺ (aq) 0 0 HF (aq) -77.23 -71.63 F ⁻ (aq) -80.15 -67.28 Fe ⁺² (aq) -21.0 -20.30 Fe ⁺³ (aq) -11.4 -2.52 Fe(OH) ₃ (s) -197.0 -166.0 NO ₃ ⁻ (aq) -49.372 -26.43 NH ₃ (g) -11.04 -3.976 NH ₃ (aq) -19.32 -6.37 NH ₄ ⁺ (aq) -31.74 -19.00 HNO ₃ (aq) -49.372 -26.41 O ₂ (aq) -3.9 3.93 O ₂ (aq) -3.9 3.93 O ₂ (g) 0 0 OH (aq) -54.957 -37.595 H ₂ O (g) -57.7979 -54.6357 H ₂ O (l) -68.3174 -56.690 PO ₄ ⁻³ (aq) -305.30 -243.50 HPO ₄ ⁻² (aq) -308.8		-28.90	-19.10
CH ₃ COOH -116.79 -95.5 CH ₃ COO ⁻ , acetate -116.84 -89.0 H ⁺ (aq) 0 0 H ₂ (g) 0 0 HF (aq) -77.23 -71.63 F ⁻ (aq) -80.15 -67.28 Fe ⁺² (aq) -21.0 -20.30 Fe ⁺³ (aq) -11.4 -2.52 Fe(OH) ₃ (s) -197.0 -166.0 NO ₃ ⁻ (aq) -49.372 -26.43 NH ₃ (g) -11.04 -3.976 NH ₃ (aq) -19.32 -6.37 NH ₄ ⁺ (aq) -31.74 -19.00 HNO ₃ (aq) -49.372 -26.41 O ₂ (aq) -3.9 3.93 O ₂ (g) 0 0 OH ⁺ (aq) -54.957 -37.595 H ₂ O (g) -57.7979 -54.6357 H ₂ O (l) -68.3174 -56.690 PO ₄ ⁻³ (aq) -308.81 -260.34 H ₂ PO ₄ ⁻¹ (aq) -308.81 -260.34 H ₂ PO ₄ ⁻¹ (aq)	`	-25.60	
CH ₃ COO ⁻ , acetate -116.84 -89.0 H ⁺ (aq) 0 0 H ₂ (g) 0 0 HF (aq) -77.23 -71.63 F ⁻ (aq) -80.15 -67.28 Fe ⁺² (aq) -21.0 -20.30 Fe ⁺³ (aq) -11.4 -2.52 Fe(OH) ₃ (s) -197.0 -166.0 NO ₃ ⁻ (aq) -49.372 -26.43 NH ₃ (g) -11.04 -3.976 NH ₃ (aq) -19.32 -6.37 NH ₄ ⁺ (aq) -31.74 -19.00 HNO ₃ (aq) -49.372 -26.41 O ₂ (aq) -3.9 3.93 O ₂ (aq) -3.9 3.93 O ₂ (g) 0 0 OH ⁺ (aq) -54.957 -37.595 H ₂ O (g) -57.7979 -54.6357 H ₂ O (l) -68.3174 -56.690 PO ₄ ⁻³ (aq) -305.30 -243.50 HPO ₄ ⁻² (aq) -308.81 -260.34 H ₂ PO ₄ ⁻ (aq) -30		-116.79	-95.5
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	CH ₃ COO ⁻ , acetate	-116.84	-89.0
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	H ⁺ (aq)	0	0
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		0	0
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		-77.23	-71.63
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	F- (aq)	-80.15	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Fe ⁺² (aq)	-21.0	-20.30
NO3 ⁻ (aq) -49.372 -26.43 NH3 (g) -11.04 -3.976 NH3 (aq) -19.32 -6.37 NH4 ⁺ (aq) -31.74 -19.00 HNO3 (aq) -49.372 -26.41 O2 (aq) -3.9 3.93 O2 (g) 0 0 OH ⁺ (aq) -54.957 -37.595 H ₂ O (g) -57.7979 -54.6357 H ₂ O (l) -68.3174 -56.690 PO ₄ ⁻³ (aq) -305.30 -243.50 HPO ₄ ⁻² (aq) -308.81 -260.34 H ₂ PO ₄ ⁻ (aq) -309.82 -270.17 H ₃ PO ₄ (aq) -307.90 -273.08 SO ₄ ⁻² -216.90 -177.34 HS ⁻ (aq) -4.22 3.01 H ₂ S(g) -4.815 -7.892		-11.4	-2.52
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		-197.0	-166.0
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	NO ₃ - (aq)	-49.372	-26.43
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		-11.04	-3.976
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		-19.32	-6.37
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	NH_4^+ (aq)	-31.74	-19.00
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		-49.372	-26.41
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		-3.9	3.93
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		0	0
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	OH- (aq)	-54.957	-37.595
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	$H_2O(g)$	-57.7979	
PO4-3 (aq) -305.30 -243.50 HPO4-2 (aq) -308.81 -260.34 H2PO4 (aq) -309.82 -270.17 H3PO4 (aq) -307.90 -273.08 SO4-2 -216.90 -177.34 HS (aq) -4.22 3.01 H2S(g) -4.815 -7.892			
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$			
$\begin{array}{c ccccc} H_2PO_4^-(aq) & -309.82 & -270.17 \\ H_3PO_4(aq) & -307.90 & -273.08 \\ SO_4^{-2} & -216.90 & -177.34 \\ HS^-(aq) & -4.22 & 3.01 \\ H_2S(g) & -4.815 & -7.892 \\ \end{array}$		-308.81	-260.34
$\begin{array}{c cccc} H_3PO_4 \ (aq) & -307.90 & -273.08 \\ SO_4^{-2} & -216.90 & -177.34 \\ HS^- \ (aq) & -4.22 & 3.01 \\ H_2S(g) & -4.815 & -7.892 \end{array}$			
SO ₄ -2 -216.90 -177.34 HS ⁻ (aq) -4.22 3.01 H ₂ S(g) -4.815 -7.892			
HS ⁻ (aq) -4.22 3.01 H ₂ S(g) -4.815 -7.892			
$H_2S(g)$ -4.815 -7.892			
		-4.815	
·		-9.4	-6.54

Guntelberg Approximation:

$$\log f = -0.5z^2 \frac{\sqrt{I}}{1 + \sqrt{I}}$$



