Applied Hydrogeology | (4th Edition)

Chapter 9, Problem 8P (1 Bookmark) Show all steps: ON

Problem

Answers to odd-numbered problems appear at the end of the book.

Given the following ground-water analysis at 25°C:

Ca^{2+}	83.27 mg/L	HCO_3^-	366.78 mg/L
Mg^{2+}	24.32 mg/L	Cl^-	12.50 mg/L
Na^+	18.33 mg/L	pH = 7.8	
K^+	2.34 mg/L	TDS = 542 mg/L	
SO_4^{2-}	23.45 mg/L		

(A) Convert all analyses into molal concentrations.

(B) Compute ionic strength.

(C) Compute the activity coefficient for each ion.

(D) Find the activity of each ion.

(E) Convert analyses to meq/L.

(F) Do a cation-anion balance.

(G) Find the K_{iap} of anhydrite ($CaSO_4$).

(H) Compare the K_{iap} of anhydrite with the K_{sp} of anhydrite ($10^{-4.5}$).

(I) Find the K_{iap} of calcite ($CaCO_3$).

(J) Compare the K_{iap} of calcite with the K_{sp} of calcite ($10^{-8.4}$).

Step-by-step solution

Step 1 of 22

(A)

Consider bicarbonate anion (HCO_3^-).

Calculate the molecular weight of bicarbonate anion.

$$\text{Molecular weight of } HCO_3^- = \left[\begin{array}{l}\left(\begin{array}{l}\text{Number of molecules of Hydrogen}\\ \times\text{Atomic weigth of Hydrogen}\end{array}\right)\\ +\left(\begin{array}{l}\text{Number of molecules of Carbon}\\ \times\text{Atomic weigth of Carbon}\end{array}\right)\\ +\left(\begin{array}{l}\text{Number of molecules of Oxygen}\\ \times\text{Atomic weigth of Oxygen}\end{array}\right)\end{array}\right]$$

Get the values of Atomic weight of Hydrogen, Atomic weight of Carbon, and Atomic weight of Oxygen from Appendix 12, "Atomic weights and numbers of naturally occurring elements" corresponding to elements Hydrogen, Carbon, and Oxygen.

$$\text{Atomic weight of Hydrogen} = 1.00\frac{\text{g}}{\text{mol}}$$

$$\text{Atomic weight of Carbon} = 12.01\frac{\text{g}}{\text{mol}}$$

$$\text{Atomic weight of Oxygen} = 16.00\frac{\text{g}}{\text{mol}}$$

Substitute 1 for Number of molecules of Hydrogen, $1.00\,\text{g/mol}$ for Atomic weight of Hydrogen, 1 for Number of molecules of Carbon, $12.01\,\text{g/mol}$ for Atomic weight of Carbon, 3 for Number of molecules of Oxygen, and $16.0\,\text{g/mol}$ for Atomic weight of Oxygen.

$$\begin{aligned}\text{Molecular weight of } HCO_3^- &= \left[\left(1\times1.00\frac{\text{g}}{\text{mole}}\right)+\left(1\times12.01\frac{\text{g}}{\text{mole}}\right)+\left(3\times16.0\frac{\text{g}}{\text{mole}}\right)\right]\\ &= 61.01\frac{\text{g}}{\text{mol}}\end{aligned}$$

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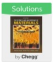

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Comment

Step 2 of 22

Show the expression to calculate the molal concentration.

$$\text{Molality} = \frac{\text{Concentation}, \frac{\text{mg}}{\text{L}}}{\text{Molecular weight}, \frac{\text{g}}{\text{mol}}}$$

$$= \frac{\left(\text{Concentation}, \frac{\text{mg}}{\text{L}}\right) \times \frac{1\,\text{g}}{1{,}000\,\text{mg}}}{\text{Molecular weight}, \frac{\text{g}}{\text{mol}}}$$

$$= \left[\frac{\left(\text{Concentation}, \frac{\text{mg}}{\text{L}}\right) \times 10^{-3}}{\text{Molecular weight}, \frac{\text{g}}{\text{mol}}}\right] \frac{\text{mol}}{\text{L}}$$

Calculate the molal concentration of bicarbonate anion $\left(\text{HCO}_3^-\right)$.

$$\text{Molality} = \left[\frac{\left(\text{Concentation of HCO}_3^-, \frac{\text{mg}}{\text{L}}\right) \times 10^{-3}}{\text{Molecular weight of HCO}_3^-, \frac{\text{g}}{\text{mol}}}\right] \frac{\text{mol}}{\text{L}}$$

Substitute $366.78\,\text{mg/L}$ for Concentration of HCO_3^- and $61.01\,\text{mol/L}$ for Molecular weight of HCO_3^-.

$$\text{Molality} = \left[\frac{\left(366.78\,\frac{\text{mg}}{\text{L}}\right) \times 10^{-3}}{61.01\,\frac{\text{g}}{\text{mol}}}\right] \frac{\text{mol}}{\text{L}}$$

$$= 6.01 \times 10^{-3}\,\frac{\text{mol}}{\text{L}}$$

Therefore, the molal concentration of bicarbonate anion $\left(\text{HCO}_3^-\right)$ is $\boxed{6.01 \times 10^{-3}\,\text{mol/L}}$.

Comment

Step 3 of 22

Similarly calculate the molal concentration of remaining anions and cations.

Show the results of calculation of molal concentration of anions and cations as in Table (1).

Ions	Molecularweight (g/mol)	Concentration in (mg/L)	Molal concentration (mol/L)	
Cations	Ca^{2+}	40.08	83.27	0.00208
	Mg^{2+}	24.31	24.32	0.00100
	Na^{+}	22.99	18.33	0.00080
	K^{+}	39.1	2.34	0.00006
				Cation total $= 0.00394$
Anions	SO_4^{2-}	96.06	23.45	0.00024
	HCO_3^-	61.01	366.78	0.00601
	Cl^-	35.45	12.5	0.00035
				Anion total $= 0.00661$

Comment

Step 4 of 22

(B)

Calculate the ionic strength of the solution.

$$I = \frac{1}{2}\sum m_i z_i^2$$

$$=\frac{1}{2}\left[\begin{array}{l}\left(m_{Ca^{2+}}\times z_{Ca^{2+}}^2\right)+\left(m_{Mg^{2+}}\times z_{Mg^{2+}}^2\right)+\left(m_{Na^+}\times z_{Na^+}^2\right)+\left(m_{K^+}\times z_{K^+}^2\right)\\+\left(m_{SO_4^{2-}}\times z_{SO_4^{2-}}^2\right)+\left(m_{HCO_3^-}\times z_{HCO_3^-}^2\right)+\left(m_{Cl^-}\times z_{Cl^-}^2\right)\end{array}\right]$$

Here, I is the ionic strength of the solution, m_i is the molality of *i*th ion, and z_i is the charge of *i*th ion.

Substitute $0.00208\,\text{mol/L}$ for $m_{Ca^{2+}}$, $0.00100\,\text{mol/L}$ for $m_{Mg^{2+}}$, $0.00080\,\text{mol/L}$ for m_{Na^+}, $0.00006\,\text{mol/L}$ for m_{K^+}, $0.00024\,\text{mol/L}$ for $m_{SO_4^{2-}}$, $0.00601\,\text{mol/L}$ for $m_{HCO_3^-}$, $0.00035\,\text{mol/L}$ for m_{Cl^-}, 2 for $z_{Ca^{2+}}$, 2 for $z_{Mg^{2+}}$, 1 for z_{Na^+}, 1 for z_{K^+}, 2 for $z_{SO_4^{2-}}$, 1 for $z_{HCO_3^-}$, and 1 for z_{Cl^-}.

$$\begin{aligned}I&=\frac{1}{2}\left[\begin{array}{l}\left[0.00208\times(2)^2\right]+\left[0.00100\times(2)^2\right]+\left[0.00080\times(1)^2\right]+\left[0.00006\times(1)^2\right]\\+\left[0.00024\times(2)^2\right]+\left[0.00601\times(1)^2\right]+\left[0.00035\times(1)^2\right]\end{array}\right]\\&=\frac{1}{2}(0.00831+0.00400+0.000797+0.00006+0.000976+0.006012+0.000353)\\&=\frac{1}{2}\times0.020510\\&=0.010255\end{aligned}$$

Therefore, the ionic strength is $\boxed{0.01025}$.

Comment

Step 5 of 22

(C)

Show the expression (Debye-Huckel equation) to calculate the activity coefficient of an ion.

$$-\log\gamma_i=\frac{Az_i^2\sqrt{I}}{1+a_iB\sqrt{I}}$$

Here, γ_i is the activity coefficient of ionic species *i*, z_i is the charge of ionic species *i*, *I* is the ionic strength of the solution, *A* is a constant that is temperature dependent, *B* is a constant that is temperature dependent, and a_i is the effective diameter of the ion.

Calculate the activity coefficient for calcium cation $\left(Ca^{2+}\right)$.

$$-\log\gamma_{Ca^{2+}}=\frac{Az_{Ca^{2+}}^2\sqrt{I}}{1+a_{Ca^{2+}}B\sqrt{I}}$$

Here, $\gamma_{Ca^{2+}}$ is the activity coefficient of calcium ion, $z_{Ca^{2+}}$ is charge of calcium ion, and $a_{Ca^{2+}}$ is the effective diameter of the calcium ion.

Get the value of constants *A* and *B* from Table 9.1, “Values for constants *A* and *B* in the Debye-Huckel equation” corresponding to the temperature value of $25°C$.

$$\begin{aligned}A&=0.5085\\B&=0.3281\end{aligned}$$

Get the value of effective diameter of the calcium ion, $a_{Ca^{2+}}$ from Table 9.2, “Values of the parameter a_i in the Debye-Huckel equation” corresponding to calcium ion $\left(Ca^{2+}\right)$.

$$a_{Ca^{2+}}=6$$

Substitute 0.5085 for *A*, 0.3281 for *B*, 0.010255 for *I*, 2 for $z_{Ca^{2+}}$, and 6 for $a_{Ca^{2+}}$.

$$\begin{aligned}-\log\gamma_{Ca^{2+}}&=\frac{0.5085\times(2)^2\times\sqrt{0.010255}}{1+\left(6\times0.3281\times\sqrt{0.010255}\right)}\\\log\gamma_{Ca^{2+}}&=-\frac{0.2060}{1+0.1994}\\\log\gamma_{Ca^{2+}}&=-0.1717\end{aligned}$$

$$\begin{aligned}\gamma_{Ca^{2+}}&=10^{-0.1717}\\&=1.485\end{aligned}$$

Similarly calculate the activity coefficient for the remaining anions and cations.

Comments (1)

Step 6 of 22

Tabulate the results of the calculation of activity coefficient for the anions and cations as in Table (2).

Ions	A	B	a_i	z_i	I	γ_i	
Cations	Ca^{2+}	0.5085	0.3281	6	2	0.010255	1.485
	Mg^{2+}	0.5085	0.3281	8	2	0.010255	1.455
	Na^{+}	0.5085	0.3281	4	1	0.010255	1.110
	K^{+}	0.5085	0.3281	3	1	0.010255	1.114
Anions	SO_4^{2-}	0.5085	0.3281	4	2	0.010255	1.485
	HCO_3^{-}	0.5085	0.3281	4	1	0.010255	1.455
	Cl^{-}	0.5085	0.3281	3	1	0.010255	1.110

Comment

Step 7 of 22

(D)

Show the expression to calculate the chemical activity of ions.

$$\alpha_i = \gamma_i m_i$$

Here, α_i is the chemical activity of *i*th ion and m_i is the molality of *i*th ion.

Calculate the chemical activity of calcium ion $\left(Ca^{2+}\right)$.

$$\alpha_{Ca^{2+}} = \gamma_{Ca^{2+}} m_{Ca^{2+}}$$

Here, $\alpha_{Ca^{2+}}$ is the chemical activity of calcium ion.

Substitute 1.485 for $\gamma_{Ca^{2+}}$ and $0.00831\,mol/L$ for $m_{Ca^{2+}}$.

$$\begin{aligned}\alpha_{Ca^{2+}} &= 1.485 \times 0.00831 \\ &= 0.01234\end{aligned}$$

Therefore, the chemical activity of calcium ion $\left(Ca^{2+}\right)$ is $\boxed{0.01234}$.

Similarly calculate the chemical activity for remaining cations and anions.

Comment

Step 8 of 22

Tabulate the results of the calculation of chemical activity for anions and cations as in Table (3).

Ions	Activity coefficient, γ_i	Molal concentration, m_i (mol/L)	Chemical activity, α_i	
Cations	Ca^{2+}	1.485	0.008310	0.012341
	Mg^{2+}	1.455	0.004002	0.005821
	Na^{+}	1.110	0.000797	0.000885
	K^{+}	1.114	0.000060	0.000067
Anions	SO_4^{2-}	1.520	0.000976	0.001484
	HCO_3^{-}	1.110	0.006012	0.006675
	Cl^{-}	1.114	0.000353	0.000393

Comment

Step 9 of 22

(E)

Show the expression to calculate the concentration of ions in units of milligram equivalent per liter (meq/L).

$$\text{Concentration}, \frac{\text{meq}}{\text{L}} = \frac{\text{Concentration}, \frac{\text{mg}}{\text{L}}}{\text{Equivalent weight}, \frac{\text{g}}{\text{eq}}}$$

$$= \frac{\left[\text{Concentration}, \frac{\text{mg}}{\text{L}}\right] \times \frac{1\,\text{g}}{1{,}000\,\text{mg}}}{\text{Equivalent weight}, \frac{\text{g}}{\text{eq}}}$$

$$= \frac{\text{Concentration}, \frac{\text{mg}}{\text{L}}}{\text{Equivalent weight}, \frac{\text{g}}{\text{eq}}} \times 10^{-3} \frac{\text{eq}}{\text{L}}$$

$$= \left[\frac{\text{Concentration}, \frac{\text{mg}}{\text{L}}}{\text{Equivalent weight}, \frac{\text{g}}{\text{eq}}}\right] \frac{\text{meq}}{\text{L}}$$

Comment

Step 10 of 22

Calculate the equivalent weight of calcium ion (Ca^{2+}).

$$\text{Equivalent weight of Ca}^{2+} = \left[\begin{array}{l}\left(\text{Molecular weight of Ca}^{2+}, \frac{\text{g}}{\text{mol}}\right) \\ \times \left(\frac{1\,\text{mole of Ca}^{2+}}{\text{Number of equivalents of Ca}^{2+}}\right)\end{array}\right]$$

$$= \left(\text{Molecular weight of Ca}^{2+}, \frac{\text{g}}{\text{mol}}\right) \times \frac{1\,\text{mole of Ca}^{2+}}{\text{Charge of Ca}^{2+}}$$

$$= \left[\frac{\text{Molecular weight of Ca}^{2+}, \frac{\text{g}}{\text{mol}}}{\text{Charge of Ca}^{2+}}\right] \frac{\text{g}}{\text{eq}}$$

Substitute $40.08\,\text{g/mol}$ for Molecular weight of Ca^{2+} and 2 for Charge of Ca^{2+}.

$$\text{Equivalent weight of Ca}^{2+} = \left[\frac{40.08 \frac{\text{g}}{\text{mol}}}{2}\right] \frac{\text{g}}{\text{eq}}$$

$$= 20.04 \frac{\text{g}}{\text{eq}}$$

Comment

Step 11 of 22

Calculate the concentration of calcium cation (Ca^{2+}) in units of milligram equivalent per liter (meq/L).

$$\text{Concentration of Ca}^{2+}, \frac{\text{meq}}{\text{L}} = \left[\frac{\text{Concentration of Ca}^{2+}, \frac{\text{mg}}{\text{L}}}{\text{Equivalent weight of Ca}^{2+}, \frac{\text{g}}{\text{eq}}}\right] \frac{\text{meq}}{\text{L}}$$

Substitute $20.04\,\text{g/eq}$ for Equivalent weight of Ca^{2+} and $83.27\,\text{mg/L}$ for Concentration of Ca^{2+}.

$$\text{Concentration of Ca}^{2+}, \frac{\text{meq}}{\text{L}} = \left[\frac{83.27 \frac{\text{mg}}{\text{L}}}{20.04 \frac{\text{g}}{\text{eq}}}\right] \frac{\text{meq}}{\text{L}}$$

$$= 4.16 \frac{\text{meq}}{\text{L}}$$

Similarly calculate the concentration of remaining anions and cations in units of milligram equivalent per liter.

Comment

Step 12 of 22

Tabulate the results of calculation of concentration of anions and cations as in Table (4).

Ions	Molecular weight (g/mol)	Charge of ions	Equivalent weight of ions, (g/eq)	Concentration in (mg/L)	Concentration in (meq/L)	
Cations	Ca^{2+}	40.08	2	20.04	83.27	4.16
	Mg^{2+}	24.31	2	12.155	24.32	2.00
	Na^{+}	22.99	1	22.99	18.33	0.80
	K^{+}	39.1	1	39.1	2.34	0.06
	Total cation concentration, $\sum(zm)_{\text{Cation}}$	7.01				
Anions	SO_4^{2-}	96.06	2	48.03	23.45	0.49
	HCO_3^{-}	61.01	1	61.01	366.78	6.01
	Cl^{-}	35.45	1	35.45	12.5	0.35
	Total anion concentration, $\sum(zm)_{\text{Anion}}$	6.85				

Comment

Step 13 of 22

(F)

To determine the cation-anion balance, compute charge balance error (CBE).

Calculate the charge balance error.

$$\text{CBE\%} = \frac{\left[\sum(zm)_{\text{Cation}}\right] - \left[\sum(zm)_{\text{Anion}}\right]}{\left[\sum(zm)_{\text{Cation}}\right] + \left[\sum(zm)_{\text{Anion}}\right]} \times 100\%$$

Substitute $7.01\,\text{meq/L}$ for $\sum(zm)_{\text{Cation}}$ and $6.85\,\text{meq/L}$ for $\sum(zm)_{\text{Anion}}$.

$$\begin{aligned}\text{CBE\%} &= \frac{7.01\frac{\text{meq}}{\text{L}} - 6.85\frac{\text{meq}}{\text{L}}}{7.01\frac{\text{meq}}{\text{L}} + 6.85\frac{\text{meq}}{\text{L}}} \times 100\% \\ &= \frac{0.16\frac{\text{meq}}{\text{L}}}{13.86\frac{\text{meq}}{\text{L}}} \times 100\% \\ &= -0.01\%\end{aligned}$$

The charge balance error is -0.01% (less than 5%). Thus, the cation-anion imbalance is acceptable.

Comment

Step 14 of 22

(G)

Show the equation of calcium sulfate dissolution in water.

$$CaSO_4 \rightleftarrows Ca^{2+} + SO_4^{2-}$$

Calculate the ion activity product of anhydrite calcium sulfate $(CaSO_4)$.

$$\begin{aligned}K_{\text{iap}}CaSO_4 &= \left(\alpha_{Ca^{2+}}\right)^1 \times \left(\alpha_{SO_4^{2-}}\right)^1 \\ &= \left(\alpha_{Ca^{2+}}\right)\left(\alpha_{SO_4^{2-}}\right)\end{aligned}$$

Here, $K_{\text{iap}}CaSO_4$ is the ion activity product of anhydrite calcium sulfate and $\alpha_{SO_4^{2-}}$ is the chemical activity of sulfate ion.

Substitute 0.012341 for $\alpha_{Ca^{2+}}$ and 0.001484 for $\alpha_{SO_4^{2-}}$.

$$\begin{aligned}K_{\text{iap}}CaSO_4 &= 0.012341 \times 0.001484 \\ &= 1.8314 \times 10^{-05} \\ &= 10^{-4.737}\end{aligned}$$

Therefore, the K_{iap} of anhydrite (CaSO_4) is $\boxed{10^{-4.737}}$.

Comment

Step 15 of 22

(H)

The solubility product, $K_{\text{sp}}\text{CaSO}_4$ of anhydrite calcium sulfate is $10^{-4.5}$.

The ion activity product, $K_{\text{iap}}\text{CaSO}_4$ of anhydrite calcium sulfate is $10^{-4.737}$.

Calculate ratio of ion activity product of anhydrite calcium sulfate to the solubility product of anhydrite calcium sulfate $\left(K_{\text{iap}}\text{CaSO}_4/K_{\text{sp}}\text{CaSO}_4\right)$.

Substitute $10^{-4.5}$ for $K_{\text{sp}}\text{CaSO}_4$ and $10^{-4.737}$ for $K_{\text{iap}}\text{CaSO}_4$.

$$\begin{aligned}\frac{K_{\text{iap}}\text{CaSO}_4}{K_{\text{sp}}\text{CaSO}_4} &= \frac{10^{-4.737}}{10^{-4.5}}\\ &= 0.5794\end{aligned}$$

Comment

Step 16 of 22

Show the classification of saturation of water based on the ratio of ion activity product to the solubility product.

$$\frac{K_{\text{iap}}}{K_{\text{sp}}} > 1 \rightarrow \text{Water is supersaturated with the mineral}$$

$$\frac{K_{\text{iap}}}{K_{\text{sp}}} < 1 \rightarrow \text{Water is undersaturated with the mineral}$$

$$\frac{K_{\text{iap}}}{K_{\text{sp}}} = 1 \rightarrow \text{Water is saturated with the mineral}$$

The ratio of ion activity product of anhydrite calcium sulfate to the solubility product of anhydrite calcium sulfate $\left(K_{\text{iap}}\text{CaSO}_4/K_{\text{sp}}\text{CaSO}_4\right)$ is less than 1. Thus, the water is under saturated.

Therefore, water is 57.94% saturated with respect to anhydrite.

Comment

Step 17 of 22

(I)

Calculate the activity coefficient for carbonate ion $\left(\text{CO}_3^{2-}\right)$.

$$-\log \gamma_{\text{CO}_3^{2-}} = \frac{A z_{\text{CO}_3^{2-}}^2 \sqrt{I}}{1 + a_{\text{CO}_3^{2-}} B \sqrt{I}}$$

Here, $\gamma_{\text{CO}_3^{2-}}$ is the activity coefficient of carbonate ion, $z_{\text{CO}_3^{2-}}$ is charge of carbonate ion, and $a_{\text{CO}_3^{2-}}$ is the effective diameter of the carbonate ion.

Get the value of constants *A* and *B* from Table 9.1, “Values for constants *A* and *B* in the Debye-Huckel equation” corresponding to the temperature value of $25°\text{C}$.

$$A = 0.5085$$
$$B = 0.3281$$

Get the value of effective diameter of the carbonate ion, $a_{\text{CO}_3^{2-}}$ from Table 9.2, “Values of the parameter a_i in the Debye-Huckel equation” corresponding to carbonate ion $\left(\text{CO}_3^{2-}\right)$.

$$a_{\text{CO}_3^{2-}} = 5$$

Substitute 0.5085 for *A*, 0.3281 for *B*, 0.010255 for *I*, 2 for $z_{\text{CO}_3^{2-}}$, and 5 for $a_{\text{CO}_3^{2-}}$.

$$\begin{aligned}-\log \gamma_{\text{CO}_3^{2-}} &= \frac{0.5085 \times (2)^2 \times \sqrt{0.010255}}{1 + \left(5 \times 0.3281 \times \sqrt{0.010255}\right)}\\ \log \gamma_{\text{CO}_3^{2-}} &= -\frac{0.2060}{1 + 0.1661}\\ \log \gamma_{\text{CO}_3^{2-}} &= -0.1767\end{aligned}$$

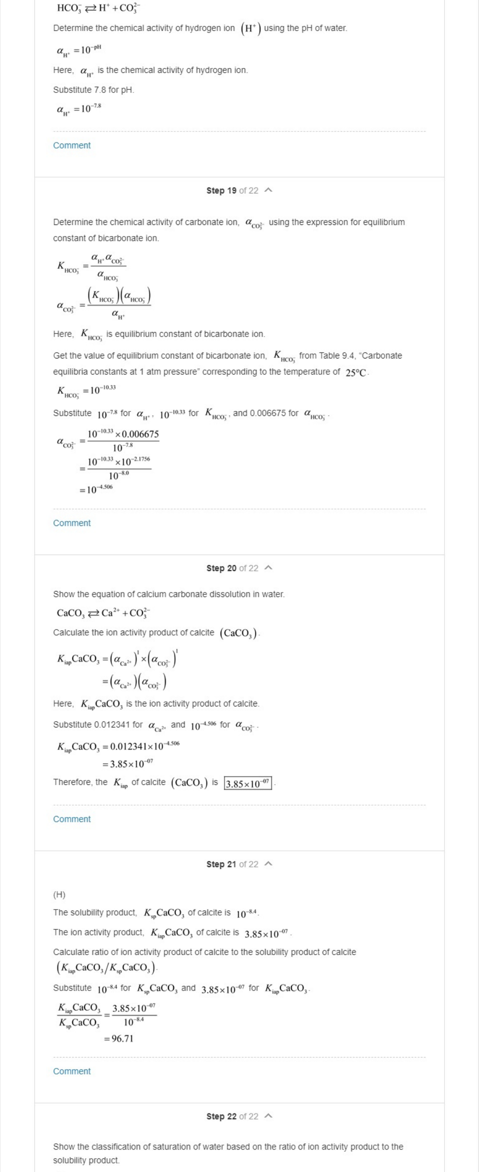
$$\begin{aligned}\gamma_{\text{CO}_3^{2-}} &= 10^{-0.24967}\\ &= 0.6658\end{aligned}$$

Comment

Step 18 of 22

The molality of CO_3^{2-} is below detectable limits. Thus, determine the chemical activity of carbonate ion, $\alpha_{\text{CO}_3^{2-}}$ using the expression for equilibrium constant of bicarbonate ion $\left(\text{HCO}_3^-\right)$.

Show the dissociation of bicarbonate ion $\left(\text{HCO}_3^-\right)$.



$$HCO_3^- \rightleftarrows H^+ + CO_3^{2-}$$

Determine the chemical activity of hydrogen ion (H^+) using the pH of water.

$$\alpha_{H^+} = 10^{-pH}$$

Here, α_{H^+} is the chemical activity of hydrogen ion.

Substitute 7.8 for pH.

$$\alpha_{H^+} = 10^{-7.8}$$

Comment

Step 19 of 22

Determine the chemical activity of carbonate ion, $\alpha_{CO_3^{2-}}$ using the expression for equilibrium constant of bicarbonate ion.

$$K_{HCO_3^-} = \frac{\alpha_{H^+}\alpha_{CO_3^{2-}}}{\alpha_{HCO_3^-}}$$

$$\alpha_{CO_3^{2-}} = \frac{\left(K_{HCO_3^-}\right)\left(\alpha_{HCO_3^-}\right)}{\alpha_{H^+}}$$

Here, $K_{HCO_3^-}$ is equilibrium constant of bicarbonate ion.

Get the value of equilibrium constant of bicarbonate ion, $K_{HCO_3^-}$ from Table 9.4, "Carbonate equilibria constants at 1 atm pressure" corresponding to the temperature of $25°C$.

$$K_{HCO_3^-} = 10^{-10.33}$$

Substitute $10^{-7.8}$ for α_{H^+}, $10^{-10.33}$ for $K_{HCO_3^-}$, and 0.006675 for $\alpha_{HCO_3^-}$.

$$\begin{aligned}\alpha_{CO_3^{2-}} &= \frac{10^{-10.33} \times 0.006675}{10^{-7.8}} \\ &= \frac{10^{-10.33} \times 10^{-2.1756}}{10^{-8.0}} \\ &= 10^{-4.506}\end{aligned}$$

Comment

Step 20 of 22

Show the equation of calcium carbonate dissolution in water.

$$CaCO_3 \rightleftarrows Ca^{2+} + CO_3^{2-}$$

Calculate the ion activity product of calcite $(CaCO_3)$.

$$\begin{aligned}K_{iap}CaCO_3 &= \left(\alpha_{Ca^{2+}}\right)^1 \times \left(\alpha_{CO_3^{2-}}\right)^1 \\ &= \left(\alpha_{Ca^{2+}}\right)\left(\alpha_{CO_3^{2-}}\right)\end{aligned}$$

Here, $K_{iap}CaCO_3$ is the ion activity product of calcite.

Substitute 0.012341 for $\alpha_{Ca^{2+}}$ and $10^{-4.506}$ for $\alpha_{CO_3^{2-}}$.

$$\begin{aligned}K_{iap}CaCO_3 &= 0.012341 \times 10^{-4.506} \\ &= 3.85 \times 10^{-07}\end{aligned}$$

Therefore, the K_{iap} of calcite $(CaCO_3)$ is $\boxed{3.85 \times 10^{-07}}$.

Comment

Step 21 of 22

(H)

The solubility product, $K_{sp}CaCO_3$ of calcite is $10^{-8.4}$.

The ion activity product, $K_{iap}CaCO_3$ of calcite is 3.85×10^{-07}.

Calculate ratio of ion activity product of calcite to the solubility product of calcite $\left(K_{iap}CaCO_3 / K_{sp}CaCO_3\right)$.

Substitute $10^{-8.4}$ for $K_{sp}CaCO_3$ and 3.85×10^{-07} for $K_{iap}CaCO_3$.

$$\begin{aligned}\frac{K_{iap}CaCO_3}{K_{sp}CaCO_3} &= \frac{3.85 \times 10^{-07}}{10^{-8.4}} \\ &= 96.71\end{aligned}$$

Comment

Step 22 of 22

Show the classification of saturation of water based on the ratio of ion activity product to the solubility product.

$$\frac{K_{\text{iap}}}{K_{\text{sp}}} > 1 \rightarrow \text{Water is supersaturated with the mineral}$$

$$\frac{K_{\text{iap}}}{K_{\text{sp}}} < 1 \rightarrow \text{Water is undersaturated with the mineral}$$

$$\frac{K_{\text{iap}}}{K_{\text{sp}}} = 1 \rightarrow \text{Water is saturated with the mineral}$$

The ratio of ion activity product of anhydrite calcium sulfate to the solubility product of anhydrite calcium sulfate $\left(K_{\text{iap}}\text{CaCO}_3/K_{\text{sp}}\text{CaCO}_3\right)$ is more than 1. Thus, water is supersaturated.

Therefore, water is 9,670% saturated with respect to calcite.

Comment

Was this solution helpful? 👍 0 👎 0

Recommended solutions for you in Chapter 1

Chapter 1, Problem 10P

Note that the answers to odd-numbered problems are at the end of the book and step-by-step solutions to the odd- numbered problems can be found on the Applied Hydrogeology home page: http://www.appliedhydrogeology.com.What mass of water at 15°C...

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Chapter 1, Problem 12P

Note that the answers to odd-numbered problems are at the end of the book and step-by-step solutions to the odd- numbered problems can be found on the Applied Hydrogeology home page: http://www.appliedhydrogeology.com.A 500-milliliter (mL)...

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