Detailed Solutions to Limiting Reagent Problems

1. Disulfur dichloride is prepared by direct reaction of the elements:

$$S_8(s) + 4\ Cl_2(g) \rightarrow 4\ S_2Cl_2(l)$$

What is the maximum amount of S_2Cl_2 that could be made by the reaction of 64.0 g of sulfur with 142 g of chlorine? What quantity of which reagent would remain unreacted?

we have 64.0 / 256.5 = 0.249 mol S_8

and 142 / 71.0 = 2.00 mol Cl_2; the ratio Cl_2 / S_8 is 2.00 / 0.249 = 8.0

but the reaction only requires 4 mol of Cl_2 per mol of S_8

so Cl_2 is in excess and S_8 is limiting

0.249 mol S_8 give 0.249 × 4 = 0.998 mol S_2Cl_2

mass 0.998 × 135.1 = 135 g S_2Cl_2

this needs 0.249 × 4 = 0.998 mol Cl_2

remaining Cl_2 2.00 − 0.998 = 1.00 mol, mass 71.0 g

2. Phosphorus trichloride reacts with water according to the stoichiometry:

$$PCl_3 + 3\ H_2O \rightarrow H_3PO_3 + 3\ HCl$$

A 200 g sample of PCl_3 was reacted with excess water and 120 g of HCl was isolated. What was the percent yield of HCl in this experiment?

Either masses or moles may be compared. Here we compare 'moles expected' with 'moles obtained'

200 g PCl_3 is 200 / 137.5 = 1.45 mol

from equation, expect 1.45 × 3 = 4.36 mol HCl

actual yield 120 g or 120 / 36.5 = 3.29 mol

yield 100 × 3.29 / 4.36 = 75.3%

3. Silver, an expensive metal, may be recovered from waste AgCl by the reactions:

$$2\ AgCl + Na_2CO_3 \xrightarrow{600^o} Ag_2O + 2\ NaCl + CO_2$$

$$Ag_2O + 2\ HNO_3 \rightarrow 2\ AgNO_3 + H_2O$$

250 g of AgCl treated in this way yielded 236 of $AgNO_3$. What was the percent yield?

250 g AgCl is 250 / 143.4 = 1.74 mol, 1:1 stoich, expect 1.74 mol $AgNO_3$

obtained 236 g or 236 / 169.9 = 1.39 mol $AgNO_3$

yield 100 × 1.39 / 1.74 = 79.6%

4. Aluminum hydroxide is insoluble in water. Write a balanced equation for the reaction of aqueous $Al(NO_3)_3$ with aqueous NaOH. If 75.0 g of hydrated $Al(NO_3)_3.9H_2O$ is dissolved in water and reacted with 20.5 g of NaOH, what mass of $Al(OH)_3$ would be formed?

Al^{3+} + 3 OH^- → $Al(OH)_3(s)$

$Al(NO_3)_3.9H_2O$ 75.0 / 375 = 0.200 mol

NaOH 20.5 / 40.0 = 0.513 mol

ratio OH^- / Al = 2.56, less than required 3:1, OH^- limiting

$Al(OH)_3$ formed 0.513 / 3 = 0.171 mol, mass 0.171 × 78.0 = 13.3 g

5. Ethyl cyanide is prepared from ethyl bromide by the reaction:

C_2H_5Br + NaCN → C_2H_5CN + NaBr

If 8.53 g of NaCN is reacted with 11.0 g of C_2H_5Br, what mass of C_2H_5CN will be formed? If the density of C_2H_5CN is 0.783 g mL^{-1}, what volume would this occupy?

8.53 g NaCN is 8.53 / 49 = 0.174 mol

11.0 g C_2H_5Br is 11.0 / 108.9 = 0.101 mol

stoich required is 1:1, C_2H_5Br is limiting

obtain 0.101 mol C_2H_5CN, mass 0.101 × 55.0 = 5.56 g

volume (5.56 g) / (0.783 g mL^{-1}) = 7.10 mL

6. A 12.0 g sample of a mixture containing $NaNO_3$ and NaCl only is dissolved in water and excess $AgNO_3$ solution is added. If 0.120 mol of insoluble AgCl precipitates, what is the percent by mass of NaCl in the mixture?

1:1 stoich, 0.120 mol of NaCl present

mass of NaCl = 0.120 × 58.5 = 7.02 g

percent NaCl = 100 × 7.02 / 12.0 = 58.5%

7. Calcium carbide, CaC_2, reacts with water to produce acetylene, C_2H_2, and $Ca(OH)_2$.

(a) Write a balanced equation for this reaction. See answer

(b) What mass of pure CaC_2 must be added to excess water to produce 41.6 g C_2H_2?

41.6 g C_2H_2 is 41.6 / 26.0 = 1.60 mol

1:1 stoich, comes from 1.60 mol CaC_2

mass of CaC_2 1.60 × 64.0 = 102 g pure CaC_2

(c) Calcium carbide is commonly less than 100% pure. If the sample used in (b) above had a purity of 90% by mass, the remainder being unreactive $CaCO_3$, what mass would be required? 102 × 100 / 90 = 114 g impure CaC_2

8. Dinitrogen pentoxide is made by the reaction:

$$4\ HNO_3 + P_4O_{10} \rightarrow 2\ N_2O_5 + 4\ HPO_3$$

15.1 g of P_4O_{10} is heated with 10.7 g of HNO_3. Calculate:

(a) what is the maximum amount of N_2O_5 that could be formed?

15.1 g P_4O_{10} is 15.1 / 284 = 0.0532 mol

10.7 g HNO_3 is 10.7 / 63.0 = 0.170 mol

ratio HNO_3 / P_4O_{10} = 3.2, less than required 4:1, HNO_3 limiting

N_2O_5 produced 0.170 / 2 = 0.085 mol

mass 0.085 × 108 = 9.17 g

(b) if only 1.96 g of N_2O_5 is obtained, what is the percent yield in the reaction?

100 × 1.96 / 9.17 = 21.4% yield

9. A mixture of $CaCl_2$ and CaO is known to contain 55% by mass $CaCl_2$. What is the maximum amount of $CaCO_3$ that could be produced by the reaction of 100 g of this mixture with 50.0 g of CO_2? The reaction is: $CaO + CO_2 \rightarrow CaCO_3$

45% CaO, so 100 g contains 45 g CaO

this is 45 / 56 = 0.804 mol CaO

CO_2 present 50 / 44.0 = 1.14 mol

1:1 stoich, so CaO is limiting

obtain 0.804 mol $CaCO_3$, mass 0.804 × 100 = 80.4 g $CaCO_3$

10. Hydrazine hydrochloride, N_2H_5Cl, is oxidized by potassium iodate according to:

$$N_2H_5Cl + IO_3^- + H^+ \rightarrow N_2 + ICl + 3\ H_2O$$

When sample of impure N_2H_5Cl, mass 1.00 g, is oxidized in this way, 224 mL of N_2 gas are evolved. What is the percent purity of the sample?

(The molar volume of N_2 is 22.4 L mol^{-1})

mol of N_2 evolved 224 mL / 22400 mL mol^{-1} = 0.0100 mol

from 0.0100 mol N_2H_5Cl, mass 0.0100 × 68.5 = 0.685 g pure compound

purity 100 × 0.685 / 1.00 = 68.5%

11. A sample of a mixture of $CaCl_2$ and NaCl, total mass 5.34 g, was dissolved in water and excess of sodium oxalate, $Na_2C_2O_4$, solution added. If the mass of insoluble calcium oxalate, CaC_2O_4, precipitated was 3.84 g, what was the composition of the mixture?

(a) expressed as percent by mass of $CaCl_2$

$CaCl_2 + Na_2C_2O_4 \rightarrow CaC_2O_4 + 2\ NaCl$ 1:1 stoich

3.84 g CaC_2O_4 is 3.84 / 128 = 0.0300 mol

from 0.0300 mol $CaCl_2$, mass 0.0300 × 111 = 3.33 g $CaCl_2$

mass composition   100 × 3.33 / 5.34 = 62.4% $CaCl_2$

Note: It is not necessary to know the identity of the second component when working out the *mass* composition

(b) expressed as mole percent $CaCl_2$

defined as (mol of $CaCl_2$) / (total mol present)

now we must know the identity and molar mass of the second component

mass of NaCl = 5.34 − 3.33 = 2.01 g NaCl

which is 2.01 / 58.5 = 0.0344 mol NaCl

mol % $CaCl_2$ = 100 × 0.0300 / (0.0300 + 0.0256) = 46.6%

12. An impure sulfide ore contains 26.0% Cu_2S by mass. It is converted to copper metal by the sequence:

$$Cu_2S + 2\ O_2 \rightarrow 2\ CuO + SO_2$$
$$2\ CuO + C \rightarrow 2\ Cu + CO_2$$

What mass of ore would be needed to produce 1.00 kg of copper metal?

1.00 kg Cu is 1000 / 63.5 = 15.7 mol Cu from 15.7 / 2 = 7.87 mol Cu_2S

mass 7.87 × 159.1 = 1253 g or 1.25 kg Cu_2S

contained in 1.25 × 100 / 26.0 = 4.82 kg of ore

13. A deposit of uranium ore contains 0.40% by mass of the oxide U_3O_8.
What mass of this ore would be required to produce 1.0 kg of uranium metal?

see detailed answer, INTRO, p.10

14. Fluoride may be estimated gravimetrically as lead chloride fluoride, PbFCl.
A sample of mass 0.800 g of a mixed mineral known to contain CaF_2 yielded 2.615 g of PbFCl. What was the mass percent of CaF_2 in the mineral?

2.615 g PbClF is 2.165 / 261.7 = 0.0100 mol

since CaF_2 contains *two* F^- in the mole, this is from

0.0100 / 2 = 0.0500 mol CaF_2 of mass 0.0500 × 78.0 = 0.390 g

mass % CaF_2 = 100 × 0.390 / 0.800 = 48.8%

DETAILED ANSWERS to STRONG ACIDS AND BASES

1. (i) (a) monoprotic, $[H^+] = 0.025 / 0.400 = 0.0625\ M$, $pH = 1.20$

(b) diprotic, $[H^+] = 2 \times 0.600 / 1.50 = 0.800\ M$, $pH = 0.10$

(ii) (a) monoprotic, $[OH^-] = 0.350 / 0.600 = 0.583\ M$, $pOH = 0.23$, $pH = 13.77$

(b) diprotic, $[OH^-] = 2 \times 0.450 / 2.50 = 0.360\ M$, $pOH = 0.44$, $pH = 13.56$

(iii) (a) $[H^+] = [HCl] = 3.16 \times 10^{-3}\ M$

(b) $3.16 \times 10^{-3} \times 36.5 = 0.115$ g L^{-1}

(iv) (a) diprotic, $[H^+] = 0.126\ M$, $[H_2SO_4] = 0.126 / 2 = 0.063\ M$

(b) $0.063 \times 98 = 6.2$ g L^{-1}

(v) (a) monoprotic, $pOH = 14 - 12.50 = 1.50$, $[KOH] = 0.0316\ M$

(b) $0.0316 \times 56.0 = 1.77$ g L^{-1}

(vi) diprotic, $pOH = 3.50$, $[OH^-] = 3.2 \times 10^{-4}\ M$

$[Ca(OH)_2] = 3.2 \times 10^{-4} / 2 = 1.6 \times 10^{-4}\ M$

(b) $1.6 \times 10^{-4} \times 74.0 = 0.0117$ g L^{-1}

2. (i) $[H^+] = 0.200 \times 25.0 / 350 = 0.0143\ M$, $pH = 1.85$

(ii) $[OH^-] = 0.240 \times 0.125 / 1.00 = 0.0300\ M$, $pOH = 1.52$, $pH = 12.48$

3. take 1 L of HCl, mol of HCl = mol of NaCl = 0.150

vol NaOH required 0.150 / 0.100 = 1.5 L, total volume 2.5 L

$[NaCl] = 0.150 / 2.5 = 0.0600\ M$

4. need $0.250 \times 0.200 = 0.0500$ mol HCl

contained in 0.0500 / 12.0 = 0.00417 L = 4.17 mL conc HCl

5. diprotic. need $[H^+] = 0.316\ M$ or $[H_2SO_4] = 0.158\ M$

in 0.500 L, 0.0791 mol, $0.0791 \times 98.0 = 7.76$ g pure H_2SO_4

or 7.76 / 0.96 = 8.08 g impure acid, volume 8.08 / 1.83 = 4.41 mL

6. diprotic, $[Ca(OH)_2] = 1.7 / 74.0 = 0.023\ M$, $[OH^-] = 0.046\ M$, $pH = 12.66$

7. at $pH = 12.00$, $[OH^-] = 1.00 \times 10^{-2}\ M$

100 NaOH = 100 / 40.0 = 2.50 mol

volume $2.50 / (1.00 \times 10^{-2}) = 250$ L of solution

8. (i) (a) monoprotic, $40.0 \times 0.150 / 0.200 = 30.0$ mL

(b) diprotic, $2 \times 0.100 \times 0.250 / 0.200 = 0.250$ L

(ii) (a) monoprotic, $50.0 \times 0.400 / 0.150 = 133$ mL

(b) diprotic, $2 \times 0.400 \times 0.350 / 0.150 = 1.87$ L

9 . (i) monoprotic, $[HNO_3] = 15.00 \times 0.125 / 24.85 = 0.0755\ M$

(ii) diprotic, $[NaOH] = 2 \times 35.00 \times 0.480 / 65.00 = 0.517\ M$

10 (a) NaOH $25.0 \times 0.300 = 7.5$ mmol, HBr $15.0 \times 0.400 = 6.0$ mmol

NaOH excess, 1.5 mmol in total volume 40.0 mL, $[OH^-] = 0.0375\ M$, $pH = 12.57$

(b) HNO_3 $15.0 \times 0.250 = 3.75$ mmol, $Ba(OH)_2$ $10.0 \times 0.300 = 3.00$ mmol or

6.00 mmol OH^-, an excess. There remains $6.00 - 3.75 = 2.25$ mmol OH^- in

a total 25.0 mL, $[OH^-] = 0.0900\ M$, $pH = 12.95$

(c) H_2SO_4 $20.0 \times 0.125 = 2.50$ mmol $= 5.00$ mmol H^+

$CsOH = 38.0 \times 0.125 = 4.75$ mmol, excess $H^+ = 0.25$ mmol

total volume 58.0 mL, $[H^+] = 0.25 / 58.0 = 4.3 \times 10^{-3}\ M$, $pH = 2.37$

(d) NaOH $1.00 / 40.0 = 0.0250$ mol

HCl $0.100\ L \times 0.245\ M = 0.0245$ mol, excess 0.0005 mol OH^-

$[OH^-] = 0.0005 / 0.100 = 0.005\ M$, $pOH = 11.70$

11. (a) at pH 1.94, $[H^+] = 0.0115\ M$, monoprotic, so 1.00 mL contained 0.0115 mol

which is $0.0115 \times 100.5 = 1.15$ g $HClO_4$, purity $100 \times 1.15 / 1.66 = 69.5\%$

(b) 0.0115 mol in 1.00 mL is $0.0115 / 0.00100 = 11.5\ M$, $pH = -1.06$

yes, a negative pH is possible in the rare case of $[H^+] > 1\ M$

12. $K_2O(s) + H_2O \rightarrow 2\,K^+ + 2\,OH^-$

1.0 g K_2O is $1.0 / 94.0 = 0.0106$ mol, gives 0.02123 mol OH^-

$[OH^-] = 0.02123 / 0.500 = 0.04246\ M$, $pOH = 1.37$, $pH = 12.63$

13. initially $[H^+] = 0.398$, after dilution $0.398 \times 25.0 / 400 = 0.0249\ M$, $pH = 1.60$

14. initially $[OH^-] = 3.16 \times 10^{-2}$, require $[OH^-] = 1.00 \times 10^{-3}$

dilute by factor $(3.16 \times 10^{-2}) / (1.00 \times 10^{-3}) = 31.6$

shortcut: difference in pH is 1.5, dilute by $10^{1.5} = 31.6$

15. KHPh 1.472 / 204.2 = 7.209×10^{-3} mol, monoprotic

[NaOH] = (7.209×10^{-3}) / 0.03992 = 0.1806 *M*

16. mol of base 0.02350 × 0.549 = 0.01290 mol

mass 0.01290 × 91.0 = 1.17 g, conc 100 × 1.17 / 5.00 = 23.5% by mass

17. 0.0500 g $CaCO_3$ is 0.0500 / 100 = 5.00×10^{-4} mol, diprotic

reacts 1.00×10^{-3} mol H^+,

$[H^+]$ = 1.00×10^{-3} / 0.0400 = 0.0250 *M*

18. *pH* 0.90, $[H^+]$ = 0.126, in 1.50 L there are 0.126 × 1.50 = 0.189 mol H^+

pH 1.50, $[H^+]$ = 0.0316, in 1.50 L there are 0.316 × 1.50 = 0.0474 mol H^+

difference 0.189 − 0.0474 = 0.141 mol

need 0.141 / 2 = 0.071 mol of diprotic $Mg(OH)_2$

mass 0.071 × 58.3 = 4.12 g

19. 4.00 g Al is 4.00 / 27.0 = 0.148 mol, reacts 0.148 × 3 = 0.444 mol H^+

originally 0.500 mol H^+, remaining 0.0555 mol in 0.500 L,

$[H^+]$ = 0.111 *M*, *pH* = 0.95, up from original *pH* = 0.00

20. 9.78 g of KOH is 9.78 / 56.1 = 0.174 mol, monoprotic

HBr 0.175 mol in 0.0100 L, conc 17.4 *M*

(solution density is not needed!)

21. take 1 L of each in each case:

(a) H_2SO_4 diprotic, 0.0400 mol H^+

NaOH 0.0300 mol, excess 0.0100 mol H^+ in 2 L

$[H^+]$ = 0.00500, *pH* = 2.30

(b) 0.0180 mol H^+ from HCl

$Sr(OH)_2$ diprotic, 2 × 0.0120 = 0.0240 mol OH^-

excess 0.0060 mol $[OH^-]$ in 2 L, $[OH^-]$ = 0.0030 *M*, *pH* = 11.48

22 $[OH^-]$ = 3.16×10^{-3} *M*, 0.0158 mol in 5.00 L

required 3.16×10^{-4} *M*, 0.00158 mol in 5.00 L

difference 0.0142 mol, need 0.0142 mol of HCl

volume of conc acid 0.0142 / 12.0 = 0.00119 L or 1.19 mL

23. as given answer

24 final solution volume 0.450 L, $[OH^-] = 0.0122$,

$0.0122 \times 0.450 = 0.00505$ mol OH^- present

originally $0.250 \times 0.300 = 0.0750$ mol OH^- present

mols OH^- removed = mol HBr $= 0.0750 - 0.00505 = 0.0700$ mol

$[HBr] = 0.0700 / 0.200 = 0.350\ M$

25. originally $4.58 \times 10^{-3} \times 0.650 = 2.98 \times 10^{-3}$ mol OH^-

final $pH = 10.42$, $[OH^-] = 2.63 \times 10^{-4}$

in 650 mL, $2.63 \times 10^{-4} \times 0.650 = 1.71 \times 10^{-4}$ mol OH^-

difference 2.81×10^{-3} mol, need 1.40×10^{-3} mol diprotic H_2SO_4

26. Before reaction, 40.0 mL of 0.160 M HCl contain $0.0400 \times 0.160 = 6.4 \times 10^{-3}$ mol H^+

After reaction, need 20.0 mL 0.12 M NaOH, reacts $0.0200 \times 0.120 = 2.4 \times 10^{-3}$ mol H^+

difference 4.0×10^{-3} mol H^+ has reacted with $CaCO_3$

reacts 2:1, so reacted with 2.0×10^{-3} mol $CaCO_3$,

mass $2.0 \times 10^{-3} \times 100 = 0.200$ g $CaCO_3$

composition $100 \times 0.200 / 0.250 = 80\%$ $CaCO_3$

27. 1:1 reaction, molarity $112 \times 1.25 / 10.0 = 14.0\ M$

mass of NH_3 in 1 L, $14.0 \times 17.0 = 238$ g

mass of 1 L of solution 880 g, composition $100 \times 238 / 880 = 27.1\%$ NH_3 by mass