

## Chapter 1

- PbO, NaBr, MgSO<sub>4</sub>, ZnCl<sub>2</sub>, K<sub>2</sub>CO<sub>3</sub>, (NH<sub>4</sub>)<sub>2</sub>S, Ca(NO<sub>3</sub>)<sub>2</sub>, Fe(OH)<sub>3</sub>, FeSO<sub>4</sub>, CuCO<sub>3</sub>, Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, Ca(OH)<sub>2</sub>, CoCl<sub>2</sub>, CaO, AgNO<sub>3</sub>, FeF<sub>3</sub>, NH<sub>4</sub>NO<sub>3</sub>, RbI, Na<sub>2</sub>SO<sub>4</sub>, Cr<sub>2</sub>O<sub>3</sub>
- Ca + 2H<sub>2</sub>O → Ca(OH)<sub>2</sub> + H<sub>2</sub>
  - 2Al + Cr<sub>2</sub>O<sub>3</sub> → Al<sub>2</sub>O<sub>3</sub> + 2Cr
  - Fe<sub>2</sub>O<sub>3</sub> + 3CO → 2Fe + 3CO<sub>2</sub>
  - CH<sub>4</sub> + 2O<sub>2</sub> → CO<sub>2</sub> + 2H<sub>2</sub>O
  - 2C<sub>8</sub>H<sub>18</sub> + 25O<sub>2</sub> → 16CO<sub>2</sub> + 18H<sub>2</sub>O
  - 2NaHCO<sub>3</sub> + H<sub>2</sub>SO<sub>4</sub> → Na<sub>2</sub>SO<sub>4</sub> + 2CO<sub>2</sub> + 2H<sub>2</sub>O
- Na<sub>2</sub>CO<sub>3</sub> + 2HCl → 2NaCl + CO<sub>2</sub> + H<sub>2</sub>O
  - 2NaOH + H<sub>2</sub>SO<sub>4</sub> → Na<sub>2</sub>SO<sub>4</sub> + 2H<sub>2</sub>O
  - 2Na + 2H<sub>2</sub>O → 2NaOH + H<sub>2</sub>
  - 2Na + Cl<sub>2</sub> → 2NaCl
  - Fe<sub>2</sub>O<sub>3</sub> + 6HNO<sub>3</sub> → 2Fe(NO<sub>3</sub>)<sub>3</sub> + 3H<sub>2</sub>O
- Ag<sup>+</sup><sub>(aq)</sub> + Br<sup>-</sup><sub>(aq)</sub> → AgBr<sub>(s)</sub>
  - Ca<sup>2+</sup><sub>(aq)</sub> + CO<sub>3</sub><sup>2-</sup><sub>(aq)</sub> → CaCO<sub>3(s)</sub>
  - Mg<sup>2+</sup><sub>(aq)</sub> + 2OH<sup>-</sup><sub>(aq)</sub> → Mg(OH)<sub>2(s)</sub>
- Fe<sub>(s)</sub> + Cu<sup>2+</sup><sub>(aq)</sub> → Fe<sup>2+</sup><sub>(aq)</sub> + Cu<sub>(s)</sub>
  - Ca<sup>2+</sup><sub>(aq)</sub> + 2OH<sup>-</sup><sub>(aq)</sub> → Ca(OH)<sub>2(s)</sub>
  - H<sup>+</sup><sub>(aq)</sub> + OH<sup>-</sup><sub>(aq)</sub> → H<sub>2</sub>O<sub>(l)</sub>
  - CO<sub>3</sub><sup>2-</sup><sub>(s)</sub> + 2H<sup>+</sup><sub>(aq)</sub> → CO<sub>2(g)</sub> + H<sub>2</sub>O<sub>(l)</sub>
- H<sub>2</sub>O<sub>2</sub> → O<sub>2</sub> + 2H<sup>+</sup> + 2e<sup>-</sup>
  - SO<sub>3</sub><sup>2-</sup> + H<sub>2</sub>O → SO<sub>4</sub><sup>2-</sup> + 2H<sup>+</sup> + 2e<sup>-</sup>
  - CH<sub>3</sub>CH<sub>2</sub>OH + H<sub>2</sub>O → CH<sub>3</sub>COOH + 4H<sup>+</sup> + 4e<sup>-</sup>
  - Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> + 14H<sup>+</sup> + 6e<sup>-</sup> → 2Cr<sup>3+</sup> + 7H<sub>2</sub>O
- Multiply equation (c) by 3, and equation (d) by 2. In this way you transfer 12 electrons. If you transferred 24 electrons, your final equation can be simplified by dividing by 2. The addition leaves you with water molecules and hydrogen ions on both sides of the equation. The version below has had the spare ones cancelled out:

$$3\text{CH}_3\text{CH}_2\text{OH} + 2\text{Cr}_2\text{O}_7^{2-} + 16\text{H}^+ \rightarrow 3\text{CH}_3\text{COOH} + 4\text{Cr}^{3+} + 11\text{H}_2\text{O}$$
- 3, +4, +5, +3, -2
  - 2, +4, +4, +6
  - +5, +3, +4, +5
  - +2, +2, +3

- 2Mg + O<sub>2</sub> → 2MgO
  - 2Li + 2H<sub>2</sub>O → 2LiOH + H<sub>2</sub>
  - C<sub>5</sub>H<sub>12</sub> + 8O<sub>2</sub> → 5CO<sub>2</sub> + 6H<sub>2</sub>O
  - either: Ca + 2HCl → CaCl<sub>2</sub> + H<sub>2</sub>  
or: Ca<sub>(s)</sub> + 2H<sup>+</sup><sub>(aq)</sub> → Ca<sup>2+</sup><sub>(aq)</sub> + H<sub>2(g)</sub>
  - either: MgCO<sub>3</sub> + 2HCl → MgCl<sub>2</sub> + CO<sub>2</sub> + H<sub>2</sub>O  
or: CO<sub>3</sub><sup>2-</sup><sub>(s)</sub> + 2H<sup>+</sup><sub>(aq)</sub> → CO<sub>2(g)</sub> + H<sub>2</sub>O<sub>(l)</sub>
  - either: Na<sub>2</sub>CO<sub>3</sub> + MgCl<sub>2</sub> → MgCO<sub>3</sub> + 2NaCl  
or: Mg<sup>2+</sup><sub>(aq)</sub> + CO<sub>3</sub><sup>2-</sup><sub>(aq)</sub> → MgCO<sub>3(s)</sub>
  - either: AgNO<sub>3</sub> + KI → AgI + KNO<sub>3</sub>  
or: Ag<sup>+</sup><sub>(aq)</sub> + I<sup>-</sup><sub>(aq)</sub> → AgI<sub>(s)</sub>
  - either: Cr<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub> + 6NaOH → 2Cr(OH)<sub>3</sub> + 3Na<sub>2</sub>SO<sub>4</sub>  
or: Cr<sup>3+</sup><sub>(aq)</sub> + 3OH<sup>-</sup><sub>(aq)</sub> → Cr(OH)<sub>3(s)</sub>
  - 6Fe<sup>2+</sup> + Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> + 14H<sup>+</sup> → 6Fe<sup>3+</sup> + 2Cr<sup>3+</sup> + 7H<sub>2</sub>O
  - 2MnO<sub>4</sub><sup>-</sup> + 6H<sup>+</sup> + 5SO<sub>3</sub><sup>2-</sup> → 2Mn<sup>2+</sup> + 3H<sub>2</sub>O + 5SO<sub>4</sub><sup>2-</sup>
- Fe<sup>2+</sup> has been oxidised to Fe<sup>3+</sup>. Cl<sub>2</sub> has been reduced to Cl<sup>-</sup>.
  - Na has been oxidised to Na<sup>+</sup>. H<sub>2</sub> has been reduced to H<sup>-</sup>.
  - Fe has been oxidised to Fe<sup>2+</sup>. H<sup>+</sup> has been reduced to H<sub>2</sub>.
  - Zn has been oxidised to Zn<sup>2+</sup>. Cu<sup>2+</sup> has been reduced to Cu.
  - MnO<sub>2</sub> has been oxidised to MnO<sub>4</sub><sup>2-</sup>. ClO<sub>3</sub><sup>-</sup> has been reduced to Cl<sup>-</sup>.

## Chapter 2

- Taking the relative abundance as a count of the number of atoms:

Total number of atoms = 100 + 5.10 + 3.36  
= 108.46

Total mass of 108 atoms = (100 × 28) + (5.10 × 29) + (3.36 × 30)  
= 3048.7

Average mass of 1 atom (RAM) = 3048.7 ÷ 108.46 = 28.1
- Assuming 100 atoms:

Total mass of 100 atoms = (60.2 × 69) + (39.8 × 71)  
= 6979.6

Average mass of 1 atom (RAM) = 6979.6/100  
= 69.8 (to 3 significant figures)
- There would be lines at 79 and 81 due to Br<sup>+</sup>. There would also be lines at 158 (79 + 79), 160 (79 + 81) and 162 (81 + 81) due to Br<sub>2</sub><sup>+</sup>.
- RFM of CO<sub>2</sub> = 12 + (2 × 16) = 44
  - RFM of (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> = [14 + (4 × 1)] × 2 + 32 + (4 × 16) = 132
  - RFM of Na<sub>2</sub>CO<sub>3</sub> · 10H<sub>2</sub>O = (2 × 23) + 12 + (3 × 16) + 10 × [(2 × 1) + 16]  
= 286

➤ More than 3 significant figures is wrong!

5. (a) RFM of  $C_3H_8 = (3 \times 12) + (8 \times 1) = 44$   
Of this,  $(3 \times 12)$  is carbon.  
Percentage of carbon =  $\frac{(3 \times 12)}{44} \times 100 = 81.8\%$
- (b) RFM of  $MgSO_4 \cdot 7H_2O = 24 + 32 + (4 \times 16) + 7 \times [(2 \times 1) + 16] = 246$   
Of this,  $(7 \times 18)$  is water.  
Percentage of water =  $\frac{(7 \times 18)}{246} \times 100 = 51.2\%$
6. 1 mol NaCl weighs  $23 + 35.5 \text{ g} = 58.5 \text{ g}$   
Therefore, 4 mol weighs  $4 \times 58.5 \text{ g} = 234 \text{ g}$
7. 1 mol  $Ca(OH)_2$  weighs  $40 + (16 + 1) \times 2 \text{ g} = 74 \text{ g}$   
Number of moles =  $\frac{\text{mass (g)}}{\text{mass of 1 mole (g)}} = \frac{37}{74} = 0.5 \text{ mol}$
8. 1 mol Ca weighs 40 g  
Number of moles =  $\frac{\text{mass (g)}}{\text{mass of 1 mole (g)}} = \frac{1000}{40} = 25 \text{ mol}$
9. 1 mol CuO weighs  $64 + 16 \text{ g} = 80 \text{ g}$   
Mass (g) = number of moles  $\times$  mass of 1 mole (g) =  $0.125 \times 80 = 10 \text{ g}$
10. Mass of 1 mole (g) =  $\frac{\text{mass (g)}}{\text{no of moles}} = \frac{4}{0.1} = 40 \text{ g}$
11. Mass of 1 mole (g) =  $\frac{\text{mass (g)}}{\text{no of moles}} = \frac{1}{0.004} = 250 \text{ g}$   
Therefore the RFM is 250. (RFM is a relative mass – it hasn't got any units.)
12. 1 mol  $H_2O$  weighs 18 g  
1 drop of water =  $0.05 \text{ cm}^3 = 0.05 \text{ g}$   
Number of moles of water in 1 drop =  $\frac{0.05}{18}$   
Number of molecules of water in 1 drop =  $\frac{0.05}{18} \times 6 \times 10^{23}$   
 $= 1.67 \times 10^{21}$
13. 1 mol of NaCl weighs 58.5 g  
30 g of NaCl is  $\frac{30}{58.5}$  mol and contains  $\frac{30}{58.5} \times 6 \times 10^{23}$  ion pairs,  $Na^+Cl^-$   
 $= 3.077 \times 10^{23}$  ion pairs in  $1000 \text{ cm}^3$  of sea water.  
To get  $10^{20}$  ion pairs you would need  $\frac{10^{20}}{3.077 \times 10^{23}} \times 1000 \text{ cm}^3$  of sea water  
 $= 0.325 \text{ cm}^3$  of sea water

► Hint: if the maths bothers you, work out the volume containing 1 ion pair (divide 1000 by  $3.077 \times 10^{23}$ ) and then multiply by  $10^{20}$ .

14. To have the greatest number of stated particles, you need the greatest number of moles of those particles.  
A 1 mol  $H_2$  weighs 2 g, and so you have 1/2 mol.  
B 1 mol He weighs 4 g, and so you have 1/4 mol.  
C 1 mol Be weighs 9 g, and so you have 1/9 mol.  
You have the largest number of moles (and so the largest number of stated particles) of hydrogen molecules.
15. (a) Mass of oxygen =  $2.84 - 1.24 \text{ g} = 1.60 \text{ g}$
- |                          | P                | O               |
|--------------------------|------------------|-----------------|
| Combining masses         | 1.24 g           | 1.60 g          |
| Number of moles of atoms | $1.24/31 = 0.04$ | $1.60/16 = 0.1$ |
| Ratio of moles           | 1                | 2.5             |
|                          | 2                | 5               |
| Empirical formula:       | $P_2O_5$         |                 |
- (b) RFM of  $P_2O_5 = 142$ . To get a RFM of 284, the molecular formula must be  $P_4O_{10}$ .
16. (a)
- |                           | C                 | H               | O                 |
|---------------------------|-------------------|-----------------|-------------------|
| Given percentages         | 66.7%             | 11.1%           | 22.2%             |
| Combining masses in 100 g | 66.7 g            | 11.1 g          | 22.2 g            |
| Number of moles of atoms  | $66.7/12 = 5.558$ | $11.1/1 = 11.1$ | $22.2/16 = 1.388$ |
| Ratio of moles            | 4                 | 8               | 1                 |
| Empirical formula:        | $C_4H_8O$         |                 |                   |
- (b) RFM of  $C_4H_8O$  is 72. This is also the desired RFM of the compound – so in this case the molecular formula is the same as the empirical formula.  
Molecular formula:  $C_4H_8O$
17. RFM of AgI = 235, of which 127 is iodine.  
Fraction of iodine in AgI =  $\frac{127}{235}$   
Mass of iodine =  $\frac{127}{235} \times 9.40 \text{ g} = 5.08 \text{ g}$   
RFM of  $CaCO_3 = 100$ , of which 40 is calcium.  
Fraction of calcium in  $CaCO_3 = \frac{40}{100}$   
Mass of calcium =  $\frac{40}{100} \times 2.00 \text{ g} = 0.8 \text{ g}$
- |                          | Ca              | I                 |
|--------------------------|-----------------|-------------------|
| Combining masses         | 0.8 g           | 5.08 g            |
| Number of moles of atoms | $0.8/40 = 0.02$ | $5.08/127 = 0.04$ |
| Ratio of moles           | 1               | 2                 |
| Empirical formula:       | $CaI_2$         |                   |
- This is a rather long-winded way of doing this sum. The advantage of the method given here is that it is entirely in line with everything else you have done, and therefore avoids excessive thought. If you have found a better method, that's fine.

18.  $\text{TiCl}_4 + 4\text{Na} \rightarrow \text{Ti} + 4\text{NaCl}$   
 4 mol Na gives 1 mol Ti  
 $4 \times 23 \text{ g Na gives } 48 \text{ g Ti}$   
 $4 \times 23 \text{ tonnes Na gives } 48 \text{ tonnes Ti}$   
 To get 1 tonne Ti you would need  $\frac{4 \times 23}{48}$  tonnes Na = 1.92 tonnes Na
19.  $\text{AlCl}_3(\text{aq}) + 3\text{AgNO}_3(\text{aq}) \rightarrow \text{Al}(\text{NO}_3)_3(\text{aq}) + 3\text{AgCl}(\text{s})$   
 1 mol  $\text{AlCl}_3$  gives 3 mol AgCl  
 $133.5 \text{ g AlCl}_3 \text{ gives } 3 \times 143.5 \text{ g AgCl}$   
 $2.67 \text{ g AlCl}_3 \text{ gives } \frac{2.67}{133.5} \times 3 \times 143.5 \text{ g AgCl} = 8.61 \text{ g AgCl}$
20.  $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$   
 $\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2$   
 1 mol  $\text{CaCO}_3$  gives 1 mol CaO which reacts with 1 mol  $\text{H}_2\text{O}$  to give 1 mol  $\text{Ca}(\text{OH})_2$   
 $100 \text{ g CaCO}_3 \text{ gives } 1 \text{ mol CaO}$  which needs 18 g  $\text{H}_2\text{O}$  and gives 74 g  $\text{Ca}(\text{OH})_2$   
 (It's pointless working out the mass of 1 mole of CaO. You aren't interested in it.)  
 So, 100 tonnes of  $\text{CaCO}_3$  would produce lots of CaO which would need 18 tonnes of water and give 74 tonnes of  $\text{Ca}(\text{OH})_2$ .
- (a) The CaO made from 1 tonne of  $\text{CaCO}_3$  would need  $\frac{18}{100}$  tonnes  $\text{H}_2\text{O}$   
 = 0.18 tonnes
- (b) Mass of  $\text{Ca}(\text{OH})_2$  made from 1 tonne of  $\text{CaCO}_3 = \frac{74}{100}$  tonnes  
 = 0.74 tonnes
21.  $\text{Mg} + \text{H}_2\text{SO}_4 \rightarrow \text{MgSO}_4 + \text{H}_2$   
 $\text{MgSO}_4 + 7\text{H}_2\text{O} \rightarrow \text{MgSO}_4 \cdot 7\text{H}_2\text{O}$   
 1 mol Mg gives 1 mol  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$   
 $24 \text{ g Mg gives } 246 \text{ g MgSO}_4 \cdot 7\text{H}_2\text{O}$   
 $1.20 \text{ g gives } \frac{1.20}{24} \times 246 \text{ g} = 12.3 \text{ g MgSO}_4 \cdot 7\text{H}_2\text{O}$   
 Because only 9.84 g was formed, the percentage yield =  $\frac{9.84}{12.3} \times 100\% = 80\%$
22. Mass of  $\text{SiCl}_4$  produced =  $3.5 \times 1.48 \text{ g} = 5.18 \text{ g}$   
 $\text{Si}(\text{s}) + 2\text{Cl}_2(\text{g}) \rightarrow \text{SiCl}_4(\text{l})$   
 1 mol Si gives 1 mol  $\text{SiCl}_4$   
 $28 \text{ g Si gives } 170 \text{ g SiCl}_4$   
 $1.0 \text{ g Si gives } \frac{1.0}{28} \times 170 \text{ g} = 6.07 \text{ g}$   
 Because only 5.18 g was produced, the percentage yield =  $\frac{5.18}{6.07} \times 100\% = 85\%$
23. (b) Cu = 63.6; S = 32.1; CuS = 95.7
24. Ti = 47.9; Cl = 35.5;  $\text{TiCl}_4 = 189.9$
25. (a) 100 (b) 392 (c) 392

➤ You could make this look simpler by working out  $3 \times 143.5$ .

➤ Care! No more than 2 significant figures.

26. Urea; 46.7%
27. (a) 331 g (b) 68.8 g (c) 68.64 g
28. (a) 0.2 (b) 17900 (c)  $5 \times 10^{-4}$  (0.0005)
29. (a)  $1.8 \times 10^{24}$  (b)  $2.5 \times 10^{27}$  (c)  $6.4 \times 10^{26}$
30.  $1.7 \times 10^{12} \text{ m}^3$
31. (a)  $\text{KNO}_2$  (b)  $\text{Na}_2\text{S}_2\text{O}_3$  (c)  $\text{C}_2\text{H}_5\text{Br}$
32.  $\text{C}_4\text{H}_{10}$
33. (a) 0.333 tonnes (b) 0.533 tonnes
34. 9.98 g
35. (a) 0.02 mol (b) 0.01 mol (c) 203 g (d) 24
36. 84%
37. 80.2%

### Chapter 3

1.  $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})$   
 You need half as many molecules of oxygen as you do of hydrogen, and so you need half the volume.  
 Volume of oxygen needed =  $250 \text{ cm}^3$   
 Volume of air needed =  $5 \times 250 \text{ cm}^3$  (to allow for the fact that air is only 1/5 oxygen)  
 =  $1250 \text{ cm}^3$
2.  $2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{l})$   
 You get 4 times as many carbon dioxide molecules formed as you had butane to start with, and so you will also get 4 times the volume.  
 Volume of carbon dioxide =  $4 \times 1 \text{ dm}^3 = 4 \text{ dm}^3$
3. The volumes are in the ratio of  $1\text{C}_x\text{H}_y : 6\text{O}_2 : 4\text{CO}_2$ , and so the numbers of molecules of these must be in that same ratio:  
 $\text{C}_x\text{H}_y + 6\text{O}_2 \rightarrow 4\text{CO}_2 + \text{some H}_2\text{O}$   
 Balancing the carbons gives you  $x = 4$ .  
 Balancing the oxygens shows that there must be  $4\text{H}_2\text{O}$ , and so  $y = 8$ .  
 Hydrocarbon is  $\text{C}_4\text{H}_8$  (butene)

4.  $10 \text{ cm}^3$  of  $\text{C}_x\text{H}_y$  were used.  
 $50 \text{ cm}^3$  of oxygen was used up. (You start with  $90 \text{ cm}^3$ ; the gas left over at the end is the excess oxygen ( $40 \text{ cm}^3$ ).)  
 $30 \text{ cm}^3$  of  $\text{CO}_2$  are formed. (The volume contraction with sodium hydroxide solution is caused by the  $\text{CO}_2$  reacting.)  
 The volumes are in the ratio  $1\text{C}_x\text{H}_y : 5\text{O}_2 : 3\text{CO}_2$ , and so the numbers of molecules of these must be in that same ratio:  
 $\text{C}_x\text{H}_y + 5\text{O}_2 \rightarrow 3\text{CO}_2 + \text{some H}_2\text{O}$   
 Balancing the carbons gives you  $x = 3$ .  
 Balancing the oxygens shows that there must be  $4\text{H}_2\text{O}$ , and so  $y = 8$ .  
 Hydrocarbon is  $\text{C}_3\text{H}_8$  (propane)
5. (a)  $24\,000 \text{ cm}^3$  of chlorine would weigh  $71 \text{ g}$  (1 mol  $\text{Cl}_2$ )  
 $200 \text{ cm}^3$  of chlorine would weigh  $\frac{200}{24\,000} \times 71 \text{ g} = 0.592 \text{ g}$
- (b)  $24 \text{ dm}^3$  of argon weighs  $40 \text{ g}$  (1 mol Ar)  
 $1 \text{ dm}^3$  of argon weighs  $\frac{40}{24} \text{ g} = 1.67 \text{ g}$   
 The density is therefore  $1.67 \text{ g dm}^{-3}$ .
- (c)  $32 \text{ g}$  of oxygen (1 mol  $\text{O}_2$ ) occupies  $24 \text{ dm}^3$   
 $0.16 \text{ g}$  oxygen occupies  $\frac{0.16}{32} \times 24 \text{ dm}^3 = 0.12 \text{ dm}^3$  (or  $120 \text{ cm}^3$ )
- (d)  $1.42 \text{ g dm}^{-3}$  means that  $1 \text{ dm}^3$  weighs  $1.42 \text{ g}$   
 $24 \text{ dm}^3$  (the volume of 1 mole) weighs  $24 \times 1.42 \text{ g} = 34.1 \text{ g}$
6.  $1.25 \text{ g}$  of nitrogen occupies a volume of  $1 \text{ dm}^3$ . (That's what a density of  $1.25 \text{ g dm}^{-3}$  means.)  
 $28 \text{ g}$  of nitrogen (1 mol  $\text{N}_2$ ) occupies a volume of  $\frac{28}{1.25} \times 1 \text{ dm}^3 = 22.4 \text{ dm}^3$
7.  $\text{MnO}_2 + 4\text{HCl} \rightarrow \text{MnCl}_2 + \text{Cl}_2 + 2\text{H}_2\text{O}$   
 1 mol  $\text{MnO}_2$  gives 1 mol  $\text{Cl}_2$   
 $87 \text{ g MnO}_2$  gives  $24 \text{ dm}^3 \text{ Cl}_2$  at rtp  
 $2 \text{ g MnO}_2$  gives  $\frac{2}{87} \times 24 \text{ dm}^3 = 0.552 \text{ dm}^3$  (or  $552 \text{ cm}^3$ )
8.  $2\text{KNO}_3 \rightarrow 2\text{KNO}_2 + \text{O}_2$   
 2 mol  $\text{KNO}_3$  gives 1 mol  $\text{O}_2$   
 $2 \times 101 \text{ g KNO}_3$  gives  $24 \text{ dm}^3 \text{ O}_2$  at rtp  
 $202 \text{ g KNO}_3$  gives  $24 \text{ dm}^3 \text{ O}_2$  at rtp  
 $1 \text{ dm}^3$  of oxygen would be given by  $\frac{1}{24} \times 202 \text{ g KNO}_3 = 8.42 \text{ g}$
9.  $pV = nRT$   
 $pV = \frac{\text{mass (g)}}{\text{mass of 1 mole (g)}} \times RT$   
 $V = \frac{\text{mass (g)}}{\text{mass of 1 mole (g)}} \times \frac{RT}{P}$   
 $= \frac{0.100}{2} \times \frac{8.31 \times 293}{100\,000} \text{ m}^3 = 1.22 \times 10^{-3} \text{ m}^3$  ( $1.22 \text{ dm}^3$ )

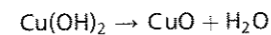
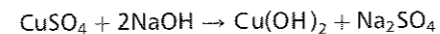
10. Rearranging the second equation from Q9:  
 $\text{Mass (g)} = \frac{pV}{RT} \times \text{mass of 1 mole (g)}$   
 $= \frac{98\,900 \times 200 \times 10^{-6}}{8.31 \times 290} \times 28 = 0.230 \text{ g}$
11. Again rearranging the second equation from Q9:  
 $\text{Mass of 1 mole (g)} = \text{mass (g)} \times \frac{RT}{pV}$   
 $= 1.25 \times \frac{8.31 \times 290}{102\,000 \times 923 \times 10^{-6}} = 32.0 \text{ g}$   
 Therefore, RFM = 32.0
12. (a)  $3.5 \text{ dm}^3$  (b)  $2 \text{ dm}^3$
13. (a)  $6.25 \text{ m}^3$  (b)  $1 \text{ m}^3$  of NO;  $1.5 \text{ m}^3$  of steam;  $5 \text{ m}^3$  of nitrogen (from the air)
14.  $\text{C}_3\text{H}_6$
15.  $\text{C}_4\text{H}_{10}$
16. (a)  $1.83 \text{ g dm}^{-3}$  (b)  $0.0658 \text{ dm}^3$  ( $65.8 \text{ cm}^3$ )  
 (c)  $0.160 \text{ g}$  (d)  $64.0 \text{ g}$  (e)  $71.0 \text{ g}$
17.  $240 \text{ cm}^3$
18.  $41\,700 \text{ g}$  ( $41.7 \text{ kg}$ )
19. (a)  $0.02$  (b)  $138 \text{ g}$  (c)  $39$
20. (a)  $0.204 \text{ g}$  (b)  $8.61 \times 10^{-3} \text{ m}^3$  ( $8.61 \text{ dm}^3$ )  
 (c)  $141\,000 \text{ Pa}$  (d)  $854 \text{ K}$  (e)  $46.1$
21. (a)  $40\,000$  moles (b)  $372$  moles,  $2.24 \times 10^{26}$  molecules
22.  $4.76 \times 10^{-4} \text{ m}^3$  ( $0.476 \text{ dm}^3$  or  $476 \text{ cm}^3$ )
23. (a)  $0.0136 \text{ mol}$  (b)  $1.36 \text{ g}$  (c)  $90.7\%$
24. (a)  $10.8$  (b)  $117.3 \text{ g}$  (c)  $3$

## Chapter 4

1. 1 mol  $\text{H}_2\text{SO}_4$  weighs  $98 \text{ g}$ .  
 $4.90 \text{ g H}_2\text{SO}_4$  is  $4.90/98 \text{ mol} = 0.0500 \text{ mol}$   
 Concentration is  $0.0500 \text{ mol dm}^{-3}$ .
2. 1 mol KOH weighs  $56 \text{ g}$ .  
 $0.200 \text{ mol KOH}$  weighs  $0.200 \times 56 \text{ g} = 11.2 \text{ g}$   
 Concentration is  $11.2 \text{ g dm}^{-3}$ .

3. 1 mol  $\text{Na}_2\text{CO}_3$  weighs 106 g.  
 $0.100 \text{ mol dm}^{-3}$  would need  $0.100 \times 106 \text{ g} = 10.6 \text{ g Na}_2\text{CO}_3$  dissolved in  $1 \text{ dm}^3$  ( $1000 \text{ cm}^3$ )  
 If you only had  $100 \text{ cm}^3$  (a tenth as much), you would only need 1.06 g.

4. Number of moles of copper(II) sulphate solution =  $\frac{20.0}{1000} \times 0.400$   
 $= 0.00800 \text{ mol}$



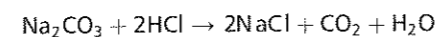
1 mol  $\text{CuSO}_4$  gives 1 mol  $\text{Cu(OH)}_2$  which in turn gives 1 mol  $\text{CuO}$

1 mol  $\text{CuSO}_4$  gives 80 g  $\text{CuO}$  (1 mol)

$0.00800 \text{ mol CuSO}_4$  gives  $0.00800 \times 80 \text{ g CuO} = 0.640 \text{ g CuO}$

5. Start from what you know everything about.

$$\text{Number of moles of sodium carbonate} = \frac{25.0}{1000} \times 0.500 = 0.0125$$



You need twice as many moles of HCl as of sodium carbonate.

Number of moles of HCl needed =  $2 \times 0.0125 = 0.0250 \text{ mol}$

Concentration of HCl is  $2.00 \text{ mol dm}^{-3}$ , i.e.  $2.00 \text{ mol}$  in every  $1 \text{ dm}^3$  ( $1000 \text{ cm}^3$ )

You therefore need  $\frac{0.0250}{2.00} \times 1000 \text{ cm}^3 = 12.5 \text{ cm}^3$  of HCl

6. Calculate the numbers of moles of everything.

$$\text{Number of moles of NaHCO}_3 = \frac{25.0}{1000} \times 0.100 = 2.50 \times 10^{-3}$$

$$\text{Number of moles of H}_2\text{SO}_4 = \frac{12.5}{1000} \times 0.100 = 1.25 \times 10^{-3}$$

$$\text{Number of moles of CO}_2 = \frac{60.0}{24\,000} = 2.50 \times 10^{-3}$$

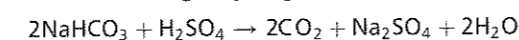
$$\text{Number of moles of Na}_2\text{SO}_4 = \frac{0.178}{142} = 1.25 \times 10^{-3} \text{ (where 142 is the RFM)}$$

So, looking at the ratios:

2 mol  $\text{NaHCO}_3$  react with 1 mol  $\text{H}_2\text{SO}_4$  to give 2 mol  $\text{CO}_2$  and 1 mol  $\text{Na}_2\text{SO}_4$

The equation:  $2\text{NaHCO}_3 + \text{H}_2\text{SO}_4 \rightarrow 2\text{CO}_2 + \text{Na}_2\text{SO}_4 + ?$

This is as far as you can go with the data. Now you need to check the balancing. You are missing 4 hydrogens and 2 oxygens – i.e.  $2\text{H}_2\text{O}$ . The final equation is:



7. Number of moles of  $\text{Na}_2\text{CO}_3 = \frac{25.0}{1000} \times 0.200 = 0.00500$

From the equation, 1 mol  $\text{Na}_2\text{CO}_3$  reacts with 2 mol HCl.

Number of moles of HCl =  $2 \times 0.00500 = 0.0100$  (in  $20.0 \text{ cm}^3$  of solution)

$$\text{Concentration of HCl} = \frac{1000}{20.0} \times 0.0100 = 0.500 \text{ mol dm}^{-3}$$

1 mol HCl weighs 36.5 g

Therefore concentration of HCl =  $0.500 \times 36.5 \text{ g dm}^{-3} = 18.3 \text{ g dm}^{-3}$

► Hint: If you need to take the last step in this problem more slowly, use one of the formula methods. For example

$$\text{Volume in dm}^3 = \frac{\text{moles}}{\text{concentration}}$$

$$= \frac{0.0250}{2.00}$$

$$= 0.0125$$

This is  $12.5 \text{ cm}^3$  – as before.

► Hint:  $24\,000 \text{ cm}^3$  of  $\text{CO}_2$  at rtp contains 1 mol  $\text{CO}_2$ .

$1 \text{ cm}^3$  contains  $1/24\,000 \text{ mol}$ .  
 $60 \text{ cm}^3$  contains  $60/24\,000 \text{ mol}$ .

8.  $25.0 \text{ cm}^3$  of unknown  $\text{Sr(OH)}_2 \equiv 32.8 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$  HCl

$$\text{Number of moles of HCl} = \frac{32.8}{1000} \times 0.100 = 3.28 \times 10^{-3}$$

From the equation, you only need half as many moles of  $\text{Sr(OH)}_2$  as HCl.

Number of moles of  $\text{Sr(OH)}_2 = 0.5 \times 3.28 \times 10^{-3} = 1.64 \times 10^{-3}$  (in  $25.0 \text{ cm}^3$  of solution)

$$\text{Concentration of Sr(OH)}_2 = \frac{1000}{25.0} \times 1.64 \times 10^{-3} = 0.0656 \text{ mol dm}^{-3}$$

1 mol  $\text{Sr(OH)}_2$  weighs 122 g.

$$\text{Concentration of Sr(OH)}_2 = 0.0656 \times 122 \text{ g dm}^{-3} = 8.00 \text{ g dm}^{-3}$$

9. 1 mol NaOH weighs 40 g.

$$1.00 \text{ g in } 250 \text{ cm}^3 \equiv 4.00 \text{ g dm}^{-3} = 0.100 \text{ mol dm}^{-3}$$

$$\text{Number of moles of NaOH} = \frac{25.0}{1000} \times 0.100 = 2.50 \times 10^{-3}$$

From the equation, you only need half as much sulphuric acid as sodium hydroxide.

$$\text{Number of moles of H}_2\text{SO}_4 = 0.5 \times 2.50 \times 10^{-3}$$

$$= 1.25 \times 10^{-3} \text{ (in } 23.5 \text{ cm}^3 \text{ of solution)}$$

$$\text{Concentration of H}_2\text{SO}_4 = \frac{1000}{23.5} \times 1.25 \times 10^{-3} = 0.0532 \text{ mol dm}^{-3}$$

But the original acid was 10 times more concentrated than this, i.e.  $0.532 \text{ mol dm}^{-3}$

10. Number of moles of  $\text{Na}_2\text{S}_2\text{O}_3 = \frac{18.8}{1000} \times 0.100 = 1.88 \times 10^{-3}$

From the equation, you only need half as much iodine as sodium thiosulphate.

$$\text{Number of moles of I}_2 = 0.5 \times 1.88 \times 10^{-3}$$

$$= 9.4 \times 10^{-4} \text{ (in } 25.0 \text{ cm}^3 \text{ of solution)}$$

$$\text{Concentration of I}_2 = \frac{1000}{25.0} \times 9.4 \times 10^{-4} = 0.0376 \text{ mol dm}^{-3}$$

1 mol  $\text{I}_2$  weighs 254 g.

$$\text{Concentration of I}_2 = 0.0376 \times 254 \text{ g dm}^{-3} = 9.55 \text{ g dm}^{-3}$$

11. Number of moles of  $\text{MnO}_4^-$  (aq) = no of moles of  $\text{KMnO}_4$  because each  $\text{KMnO}_4$  contains 1  $\text{MnO}_4^-$  ion.

$$\text{Number of moles of MnO}_4^- \text{ (aq)} = \frac{28.1}{1000} \times 0.0200 = 5.62 \times 10^{-4}$$

The equation shows that you need more hydrogen peroxide than  $\text{MnO}_4^-$  ions. Specifically, you need 2.5 times as much (5/2 times as much).

$$\text{Number of moles of H}_2\text{O}_2 = 2.5 \times 5.62 \times 10^{-4}$$

$$= 1.405 \times 10^{-3} \text{ (in } 25.0 \text{ cm}^3 \text{ of solution)}$$

$$\text{Concentration of H}_2\text{O}_2 = \frac{1000}{25.0} \times 1.405 \times 10^{-3} = 0.0562 \text{ mol dm}^{-3}$$

► Care! It's  $\text{I}_2$ , not I.

12. Number of moles of  $\text{KMnO}_4 = \frac{24.0}{1000} \times 0.0200 = 4.80 \times 10^{-4}$   
 The equation shows that you need 5/2 times as much  $\text{K}_2\text{SO}_3$  as  $\text{KMnO}_4$ .  
 Number of moles of  $\text{K}_2\text{SO}_3 = \frac{5}{2} \times 4.80 \times 10^{-4}$   
 $= 1.20 \times 10^{-3}$  (in  $25.0 \text{ cm}^3$  of solution)  
 Total moles of  $\text{K}_2\text{SO}_3$  in  $250 \text{ cm}^3 = 10 \times 1.20 \times 10^{-3} = 0.0120$   
 1 mol  $\text{K}_2\text{SO}_3$  weighs 158 g.  
 Mass of  $\text{K}_2\text{SO}_3$  in  $250 \text{ cm}^3 = 0.0120 \times 158 \text{ g} = 1.896 \text{ g}$   
 Percentage purity  $= \frac{1.896}{2.00} \times 100 = 94.8\%$
13. Number of moles  $\text{NaOH} = \frac{18.0}{1000} \times 0.200 = 3.60 \times 10^{-3}$   
 The equation shows that you need half as much  $\text{H}_2\text{SO}_4$  as  $\text{NaOH}$ .  
 Number of moles of  $\text{H}_2\text{SO}_4 = 1.80 \times 10^{-3}$  (in  $25.0 \text{ cm}^3$  of solution)  
 Number of moles of  $\text{H}_2\text{SO}_4$  in  $250 \text{ cm}^3 = 10 \times 1.80 \times 10^{-3} = 0.0180$   
 i.e.  $0.0180$  moles of  $\text{H}_2\text{SO}_4$  was left after reaction with the zinc.  
 Number of moles of  $\text{H}_2\text{SO}_4$  originally  $= \frac{50.0}{1000} \times 0.500 = 0.0250$   
 Number of moles of  $\text{H}_2\text{SO}_4$  used by  $\text{Zn} = 0.0250 - 0.0180 = 0.0070$   
 The equation shows that 1 mole of  $\text{H}_2\text{SO}_4$  reacts with 1 mole of  $\text{Zn}$ .  
 Number of moles of  $\text{Zn} = 0.0070$   
 Mass of zinc  $= 0.0070 \times 65 \text{ g} = 0.455 \text{ g}$   
 Percentage purity  $= \frac{0.455}{0.462} \times 100 = 98.5\%$
14. Number of moles of  $\text{NaHCO}_3$  in titration  $= \frac{40.0}{1000} \times 0.100 = 4.00 \times 10^{-3}$   
 The equation shows that 1 mole  $\text{NaHCO}_3$  reacts with 1 mole  $\text{HCl}$ .  
 Number of moles  $\text{HCl} = 4.00 \times 10^{-3}$  (in  $25.0 \text{ cm}^3$  of diluted solution)  
 Number of moles  $\text{HCl}$  left over in mixture  $= 10 \times 4.00 \times 10^{-3} = 0.0400$   
 Number of moles of  $\text{HCl}$  originally  $= \frac{100}{1000} \times 1.00 = 0.100$   
 Number of moles of  $\text{HCl}$  used up  $= 0.100 - 0.0400 = 0.060$   
 The equation shows that  $\text{HCl}$  and  $\text{NaOH}$  react 1:1.  
 Number of moles of  $\text{NaOH}$  in original mixture  $= 0.060$
15. A1  $\text{Na}_2\text{CO}_3 + \text{HCl} \rightarrow \text{NaCl} + \text{NaHCO}_3$   
 This reaction needs  $12.7 \text{ cm}^3$  of  $\text{HCl}$   
 A2  $\text{NaHCO}_3 + \text{HCl} \rightarrow \text{NaCl} + \text{CO}_2 + \text{H}_2\text{O}$   
 B  $\text{NaHCO}_3 + \text{HCl} \rightarrow \text{NaCl} + \text{CO}_2 + \text{H}_2\text{O}$   
 The two sodium hydrogencarbonate reactions need  $20.9 \text{ cm}^3$  of  $\text{HCl}$   
 If reaction A1 needs  $12.7 \text{ cm}^3$ , then so does reaction A2. That means that the sodium hydrogencarbonate originally in the solution (reaction B) needs  $(20.9 - 12.7) \text{ cm}^3 = 8.2 \text{ cm}^3$ .

Finding the concentration of the sodium carbonate:

$$\text{Number of moles of HCl} = \frac{12.7}{1000} \times 0.250 = 3.175 \times 10^{-3} \text{ mol}$$

Equation A1 shows the reaction is 1:1 for this first stage.

$$\text{Number of moles of Na}_2\text{CO}_3 = 3.175 \times 10^{-3} \text{ (in } 25.0 \text{ cm}^3\text{)}$$

$$\text{Concentration of Na}_2\text{CO}_3 = 3.175 \times 10^{-3} \times \frac{1000}{25.0} = 0.127 \text{ mol dm}^{-3}$$

Finding the concentration of the sodium hydrogencarbonate:

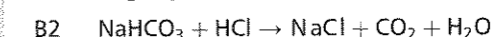
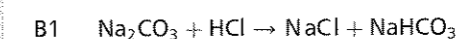
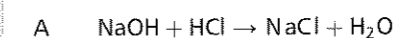
$$\text{Number of moles of HCl} = \frac{8.2}{1000} \times 0.250 = 2.05 \times 10^{-3} \text{ mol}$$

Equation B shows the reaction is 1:1.

$$\text{Number of moles of NaHCO}_3 = 2.05 \times 10^{-3} \text{ (in } 25.0 \text{ cm}^3\text{)}$$

$$\text{Concentration of NaHCO}_3 = 2.05 \times 10^{-3} \times \frac{1000}{25.0} = 0.082 \text{ mol dm}^{-3}$$

16.



Reactions A and B1 are picked up by the phenolphthalein. Reaction B2 needs an extra  $(50.0 - 46.9 \text{ cm}^3) = 3.1 \text{ cm}^3$  acid. Reaction B1 needs the same amount as reaction B2 because it is the first half of the overall reaction between sodium carbonate and  $\text{HCl}$ .

(a) Finding the concentration of the sodium carbonate:

$$\text{Number of moles of HCl} = \frac{3.1}{1000} \times 0.100 = 3.1 \times 10^{-4} \text{ mol}$$

Equation B1 shows the reaction is 1:1 for this first stage.

$$\text{Number of moles of Na}_2\text{CO}_3 = 3.1 \times 10^{-4} \text{ (in } 25.0 \text{ cm}^3\text{)}$$

$$\text{Concentration of Na}_2\text{CO}_3 = 3.1 \times 10^{-4} \times \frac{1000}{25.0} = 0.0124 \text{ mol dm}^{-3}$$

(b) The total volume of the solution made up was  $1.00 \text{ dm}^3$ , and so  $0.0124 \text{ mol}$  of  $\text{Na}_2\text{CO}_3$  was produced. The equation shows that 1 mol  $\text{CO}_2$  gives 1 mol  $\text{Na}_2\text{CO}_3$ .

$$\text{Number of moles of CO}_2 \text{ present in } 1.0 \text{ m}^3 \text{ of air} = 0.0124$$

(c) Volume of  $\text{CO}_2 = 0.0124 \times 0.024 \text{ m}^3 = 2.976 \times 10^{-4} \text{ m}^3$

$$\text{Percentage of CO}_2 = \frac{2.976 \times 10^{-4}}{1.0} \times 100 = 0.030\% \text{ (to 2 significant figures)}$$

17.

$$\text{(a) } 0.0738 \text{ mol dm}^{-3}$$

$$\text{(b) } 3.16 \text{ g dm}^{-3}$$

$$\text{(c) } 0.180 \text{ mol dm}^{-3}$$

$$\text{(d) } 3.58 \text{ g}$$

18. (a)  $0.600 \text{ dm}^3$  (b)  $2.50 \text{ g}$
19.  $14.9 \text{ cm}^3$
20.  $1.2 \text{ dm}^3$  (no more than 2 significant figures acceptable)
21.  $31.8 \text{ g dm}^{-3}$
22. (a)  $\text{YCl}_2$  (b)  $\text{Y} + 2\text{HCl} \rightarrow \text{YCl}_2 + \text{H}_2$
23. (a)  $0.179 \text{ mol dm}^{-3}$  (b)  $0.0444 \text{ mol dm}^{-3}$  (c)  $0.394 \text{ mol dm}^{-3}$
24.  $1.11 \text{ g dm}^{-3}$
25. (a)  $0.0206 \text{ mol dm}^{-3}$  (b)  $0.115 \text{ mol dm}^{-3}$
26.  $1.05 \text{ mol dm}^{-3}$
27.  $91.7\%$
28. (a)  $0.0250 \text{ mol}$  (b)  $4.00 \times 10^{-3}$  ( $0.00400$ )  $\text{mol}$   
(c)  $0.0210 \text{ mol}$  (d)  $44.9 \text{ g dm}^{-3}$
29. (a)  $0.0250 \text{ mol}$  (b)  $0.0205 \text{ mol}$   
(c)  $0.00225 \text{ mol}$  (d)  $0.466 \text{ tonnes}$
30. (a)  $0.00100 \text{ mol}$  (b)  $\text{Cl}^- 0.355 \text{ g}; \text{Mn}^{2+} 0.855 \text{ g}$  (c)  $\text{MCl}$
31.  $\text{Na}_2\text{CO}_3 0.0500 \text{ mol dm}^{-3}; \text{NaHCO}_3 0.0800 \text{ mol dm}^{-3}$
32.  $\text{Na}_2\text{CO}_3 4.24 \text{ g dm}^{-3}; \text{NaOH } 4.80 \text{ g dm}^{-3}$

## Chapter 5

1. (a)  $29.7^\circ\text{C}$  (The temperature is falling by a steady  $0.2^\circ\text{C}$  per minute.)  
(b) Temperature increase of sodium hydroxide solution =  $29.7 - 20.5^\circ\text{C}$   
=  $9.2^\circ\text{C}$   
Temperature increase of acid =  $29.7 - 20.8^\circ\text{C}$   
=  $8.9^\circ\text{C}$   
Heat evolved = mass  $\times$  specific heat  $\times$  temperature rise  
Total heat evolved =  $(50 \times 4.18 \times 9.2) + (25 \times 4.18 \times 8.9) \text{ J}$   
=  $2850 \text{ J}$  (or  $2.85 \text{ kJ}$ )

► If you were talking about the heat change during the reaction, you would have to quote this as  $-57 \text{ kJ mol}^{-1}$  to show that the heat was evolved.

► See the side note above.

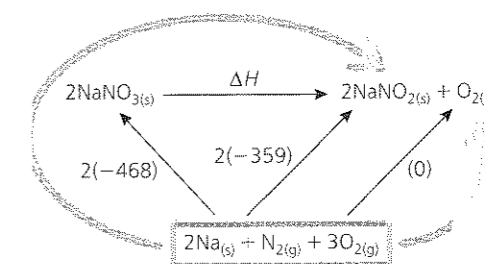
- (c) Number of moles of water produced = number of moles of NaOH at start (see equation)

$$\text{Number of moles of NaOH} = \frac{50}{1000} \times 1 = 0.05$$

$2.85 \text{ kJ}$  are evolved when  $0.05$  moles of water are formed.

$$\text{Heat evolved per mole of water} = \frac{2.85}{0.05} \text{ kJ mol}^{-1} = 57 \text{ kJ mol}^{-1}$$

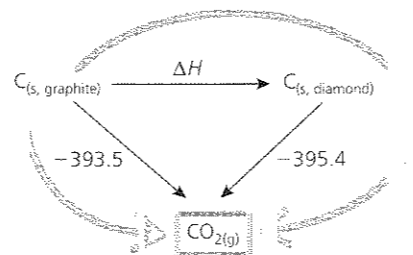
2. (a) Temperature increase =  $24.9 - 19.7^\circ\text{C}$   
=  $5.2^\circ\text{C}$   
Heat evolved =  $5.2 \times 1.15 \text{ kJ}$   
=  $5.98 \text{ kJ}$  ( $6.0 \text{ kJ}$  to 2 significant figures)
- (b) Mass of hexane burnt =  $45.63 - 45.50 \text{ g}$   
=  $0.13 \text{ g}$   
1 mole of hexane weighs  $86 \text{ g}$ .  
If  $0.13 \text{ g}$  evolves  $5.98 \text{ kJ}$ , then  $86 \text{ g}$  evolves  
 $5.98 \times \frac{86}{0.13} \text{ kJ mol}^{-1} = 4000 \text{ kJ mol}^{-1}$  (to 2 significant figures)
3. (a)  $\text{C}_{(s)} + \text{O}_{2(g)} \rightarrow \text{CO}_{2(g)}$   
(b)  $\text{CH}_{4(g)} + 2\text{O}_{2(g)} \rightarrow \text{CO}_{2(g)} + 2\text{H}_2\text{O}_{(l)}$   
(c)  $\text{C}_2\text{H}_5\text{OH}_{(l)} + 3\text{O}_{2(g)} \rightarrow 2\text{CO}_{2(g)} + 3\text{H}_2\text{O}_{(l)}$   
(d)  $\text{C}_8\text{H}_{18(l)} + 12\frac{1}{2}\text{O}_{2(g)} \rightarrow 8\text{CO}_{2(g)} + 9\text{H}_2\text{O}_{(l)}$
4. (a)  $\text{Na}_{(s)} + \frac{1}{2}\text{I}_{2(s)} \rightarrow \text{NaI}_{(s)}$   
(b)  $\text{H}_{2(g)} + \frac{1}{2}\text{O}_{2(g)} \rightarrow \text{H}_2\text{O}_{(l)}$   
(c)  $2\text{C}_{(s)} + 3\text{H}_{2(g)} + \frac{1}{2}\text{O}_{2(g)} \rightarrow \text{C}_2\text{H}_5\text{OH}_{(l)}$   
(d)  $\text{Ca}_{(s)} + \text{C}_{(s)} + 1\frac{1}{2}\text{O}_{2(g)} \rightarrow \text{CaCO}_{3(s)}$   
(e)  $\text{Na}_{(s)} + \frac{1}{2}\text{Cl}_{2(g)} + 1\frac{1}{2}\text{O}_{2(g)} \rightarrow \text{NaClO}_{3(s)}$
- 5.



$$\Delta H + 2(-468) = 2(-359)$$

$$\text{Giving: } \Delta H = +218 \text{ kJ mol}^{-1}$$

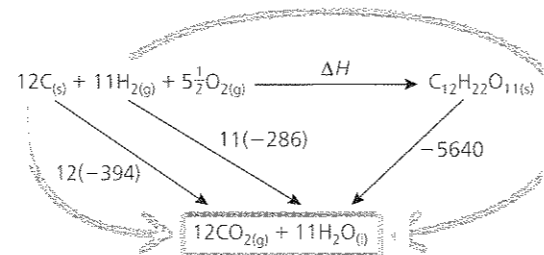
6.



$\Delta H - 395.4 = -393.5$   
 Giving:  $\Delta H = +1.9 \text{ kJ mol}^{-1}$

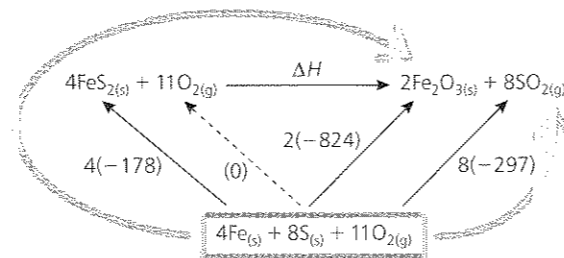
7.

► People sometimes worry about the oxygen in a question like this – there isn't an arrow attaching it to anything else. In any cycle involving combustion, we don't bother to include the oxygens coming from the air – they will automatically balance. In this case, because of the oxygen present already in the equation, we simply need a correspondingly smaller amount from the air. The oxygens in the equation are part of those ending up in  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .



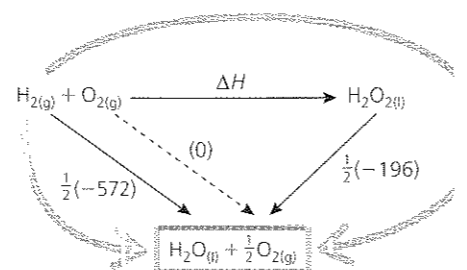
$\Delta H - 5640 = 12(-394) + 11(-286)$   
 Giving:  $\Delta H = -2234 \text{ kJ mol}^{-1}$

8.



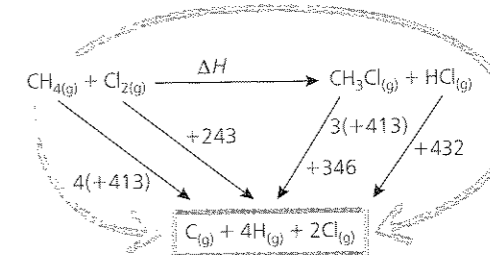
$\Delta H + 4(-178) = 2(-824) + 8(-297)$   
 Giving:  $\Delta H = -3312 \text{ kJ mol}^{-1}$

9.



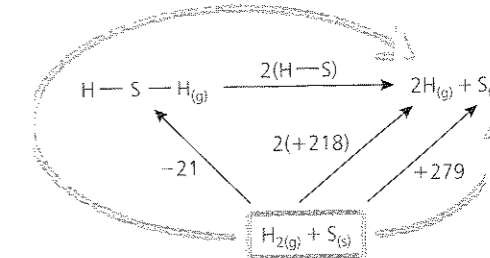
$\Delta H + \frac{1}{2}(-196) = \frac{1}{2}(-572)$   
 Giving:  $\Delta H = -188 \text{ kJ mol}^{-1}$

10.



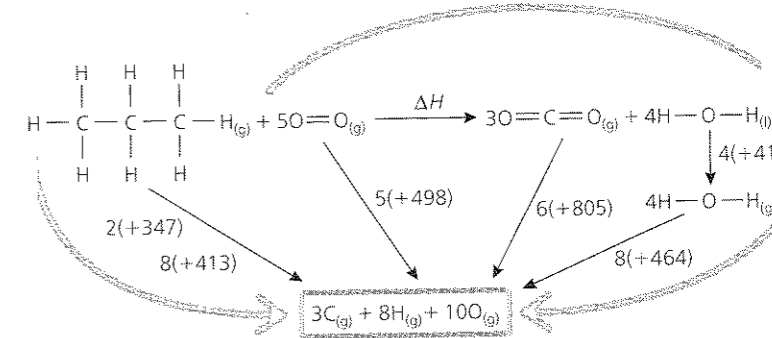
$\Delta H + 3(+413) + 346 + 432 = 4(+413) + 243$   
 Giving:  $\Delta H = -122 \text{ kJ mol}^{-1}$

11.



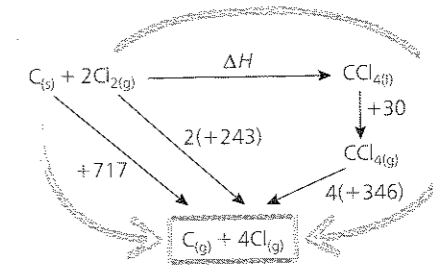
$2(\text{H-S}) - 21 = 2(+218) + 279$   
 Giving:  $(\text{H-S}) = +368 \text{ kJ mol}^{-1}$

12.



$\Delta H + 6(+805) + 4(+41) + 8(+464) = 2(+347) + 8(+413) + 5(+498)$   
 Giving:  $\Delta H = -2218 \text{ kJ mol}^{-1}$

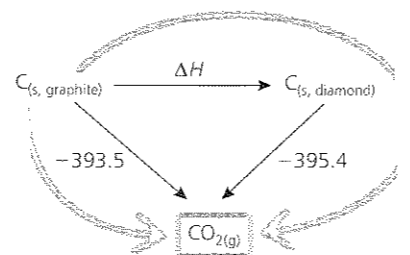
13.



$\Delta H + 30 + 4(+346) = +717 + 2(+243)$   
 Giving:  $\Delta H = -211 \text{ kJ mol}^{-1}$



6.

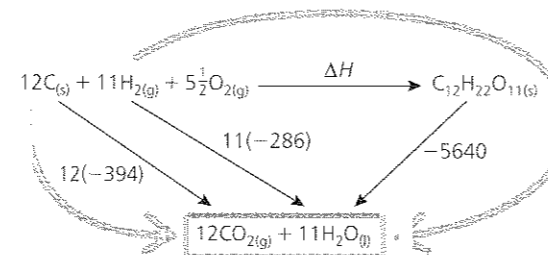


$$\Delta H - 395.4 = -393.5$$

$$\text{Giving: } \Delta H = +1.9 \text{ kJ mol}^{-1}$$

7.

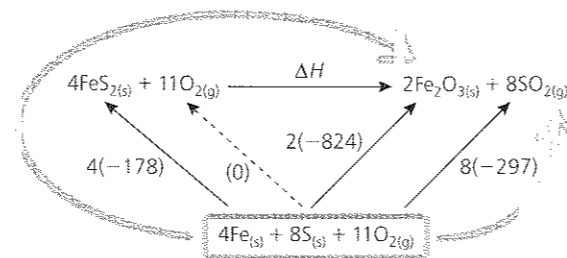
► People sometimes worry about the oxygen in a question like this – there isn't an arrow attaching it to anything else. In any cycle involving combustion, we don't bother to include the oxygens coming from the air – they will automatically balance. In this case, because of the oxygen present already in the equation, we simply need a correspondingly smaller amount from the air. The oxygens in the equation are part of those ending up in  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .



$$\Delta H - 5640 = 12(-394) + 11(-286)$$

$$\text{Giving: } \Delta H = -2234 \text{ kJ mol}^{-1}$$

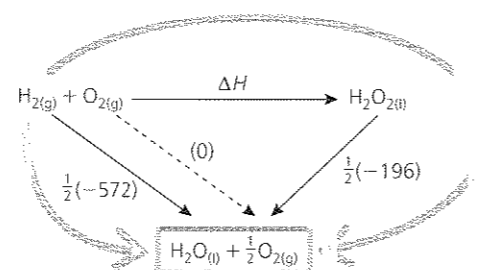
8.



$$\Delta H + 4(-178) = 2(-824) + 8(-297)$$

$$\text{Giving: } \Delta H = -3312 \text{ kJ mol}^{-1}$$

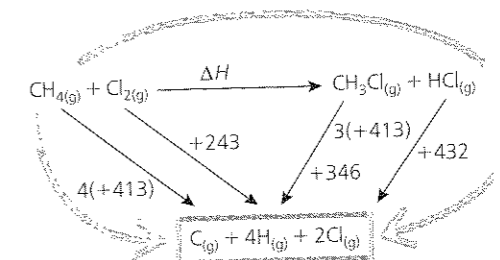
9.



$$\Delta H + \frac{1}{2}(-196) = \frac{1}{2}(-572)$$

$$\text{Giving: } \Delta H = -188 \text{ kJ mol}^{-1}$$

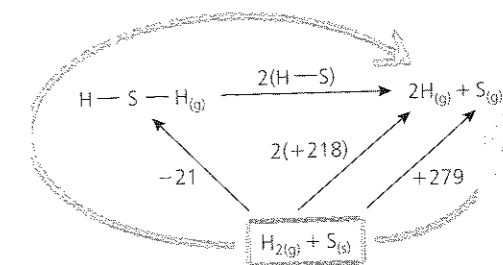
10.



$$\Delta H + 3(+413) + 346 + 432 = 4(+413) + 243$$

$$\text{Giving: } \Delta H = -122 \text{ kJ mol}^{-1}$$

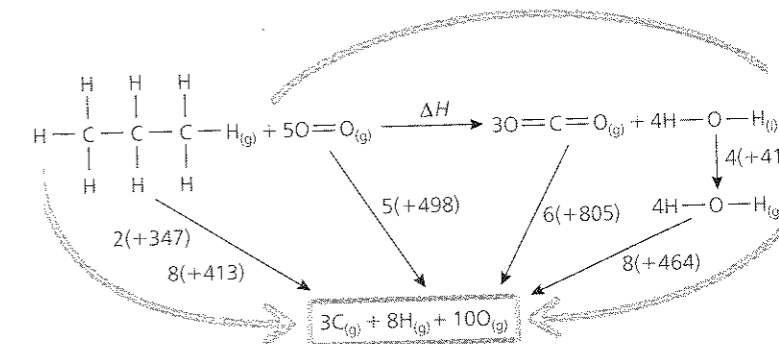
11.



$$2(\text{H-S}) - 21 = 2(+218) + 279$$

$$\text{Giving: } (\text{H-S}) = +368 \text{ kJ mol}^{-1}$$

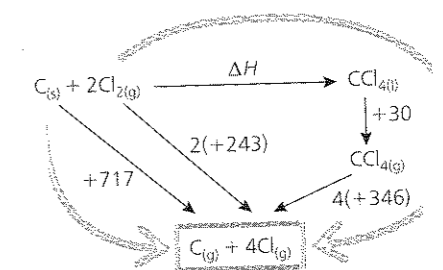
12.



$$\Delta H + 6(+805) + 4(+41) + 8(+464) = 2(+347) + 8(+413) + 5(+498)$$

$$\text{Giving: } \Delta H = -2218 \text{ kJ mol}^{-1}$$

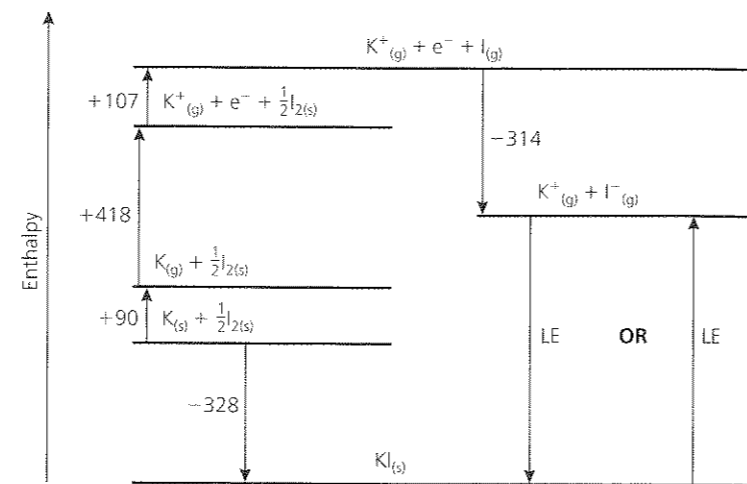
13.



$$\Delta H + 30 + 4(+346) = +717 + 2(+243)$$

$$\text{Giving: } \Delta H = -211 \text{ kJ mol}^{-1}$$

14.



If you define LE as the exothermic change when the solid is formed from the gaseous ions:

$$+90 + 418 + 107 - 314 + LE = -328$$

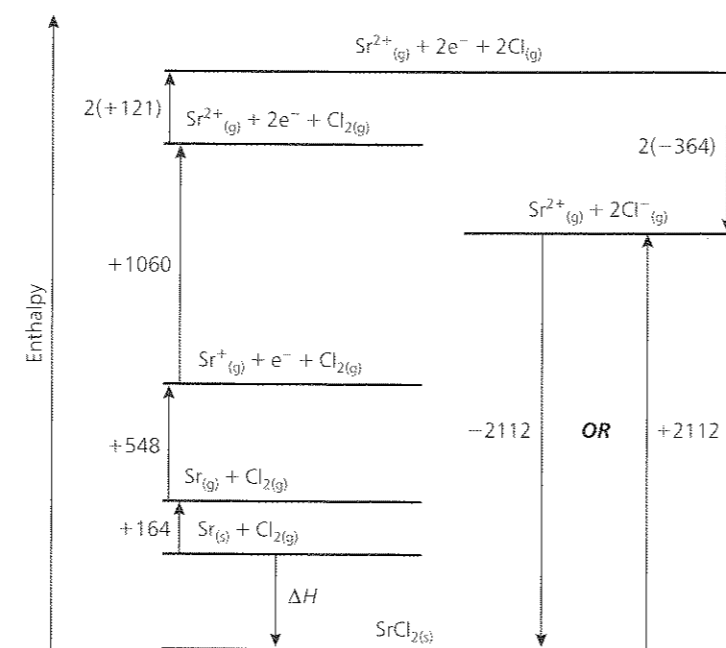
Giving:  $LE = -629 \text{ kJ mol}^{-1}$

If you define LE as the endothermic change when gaseous ions are formed from the solid:

$$+90 + 418 + 107 - 314 = -328 + LE$$

Giving:  $LE = +629 \text{ kJ mol}^{-1}$

15.



If you define LE as the exothermic change when the solid is formed from the gaseous ions:

$$\Delta H = +164 + 548 + 1060 + 2(+121) + 2(-364) - 2112$$

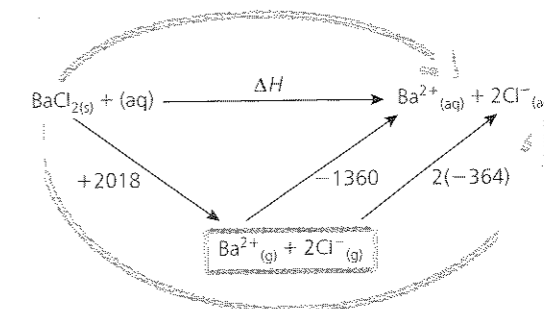
Giving  $\Delta H = -826 \text{ kJ mol}^{-1}$

16.

If you define LE as the endothermic change when gaseous ions are formed from the solid:

$$\Delta H + 2112 = +164 + 548 + 1060 + 2(+121) + 2(-364)$$

Giving:  $\Delta H = -826 \text{ kJ mol}^{-1}$



$$\Delta H = +2018 - 1360 + 2(-364)$$

Giving:  $\Delta H = -70 \text{ kJ mol}^{-1}$

17.

(a)  $32.0 \text{ }^\circ\text{C}$  (b)  $5390 \text{ J (5.39 kJ)}$

(c)  $-54 \text{ kJ mol}^{-1}$  (2 significant figures)

18.

(a)  $1.21 \text{ kJ }^\circ\text{C}^{-1}$  (b)  $-1800 \text{ kJ mol}^{-1}$  (2 sig figs)

19.

$-205 \text{ kJ mol}^{-1}$

20.

(a)  $+224 \text{ kJ mol}^{-1}$  (b)  $+323 \text{ kJ mol}^{-1}$

21.

$-279 \text{ kJ mol}^{-1}$

22.

$-1302 \text{ kJ mol}^{-1}$

23.

(a)  $-534.6 \text{ kJ mol}^{-1}$  (b)  $1.67 \times 10^7 \text{ kJ}$

24.

$-90.5 \text{ kJ mol}^{-1}$

25.

HF  $-542 \text{ kJ mol}^{-1}$ ; HCl  $-185 \text{ kJ mol}^{-1}$

26.

$-307 \text{ kJ mol}^{-1}$

27.

(a)  $+327 \text{ kJ mol}^{-1}$  (b)  $+323 \text{ kJ mol}^{-1}$

28.

$-281.6 \text{ kJ mol}^{-1}$

29.

(a)  $-349 \text{ kJ mol}^{-1}$  (b)  $-860 \text{ kJ mol}^{-1}$

30.

$-3 \text{ kJ mol}^{-1}$

## Chapter 6

1. Second order with respect to A. Tripling the concentration of A between experiments 2 and 3 causes the rate to go up 9 times ( $9 = 3^2$ ).  
Zero order with respect to B. Changing the concentration of B between experiments 1 and 2 has no effect on the rate.  
Rate =  $k[A]^2$   
 $k = \frac{\text{rate}}{[A]^2} = \frac{1.0 \times 10^{-5}}{(0.010)^2} = 0.10 \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$   
(See example 2 on pages 130 to 131 if you have problems with the units.)
2. (a) D: first order. Tripling the concentration between experiments 1 and 4 triples the rate.  
E: zero order. Halving the concentration between experiments 1 and 3 has no effect on rate.  
F: first order. Doubling the concentration between experiments 1 and 2 doubles the rate.  
Rate =  $k[D][F]$   
 $k = \frac{\text{rate}}{[D][F]} = \frac{4.40 \times 10^{-6}}{0.10 \times 0.20} = 2.2 \times 10^{-4} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$   
(See example 2 on pages 130 to 131 if you have problems with the units.)
- (b) (i)  $8.80 \times 10^{-6} \text{ mol dm}^{-3} \text{ s}^{-1}$ . Compare experiments 1 and 5. The change in the concentration of E will not affect the rate. The concentration of D has doubled and so the rate doubles as well. (Alternatively you could feed the concentration values into the rate equation now that you have worked out the rate constant,  $k$ .)  
(ii)  $0.40 \text{ mol dm}^{-3}$ . Compare experiments 1 and 6. The concentration of F has halved and that would halve the rate to  $2.20 \times 10^{-6} \text{ mol dm}^{-3} \text{ s}^{-1}$ . To increase the rate to the desired value, the concentration of D would have to increase 4 times. (Alternatively – saving some thought, but using more maths – slot the known numbers from experiment 6 into the rate equation and solve it for [D].)
3. R: zero order. Changing the concentration between experiments 1 and 2 does not change the rate.  
S: first order. You can ignore the concentrations of R since they have no effect. Multiplying the concentration of S four times (experiments 1 and 3 or experiments 2 and 3) increases the rate four times.  
Rate =  $k[S]$   
 $k = \frac{\text{rate}}{[S]} = \frac{1.6 \times 10^{-7}}{0.10} = 1.6 \times 10^{-6} \text{ s}^{-1}$   
(See the side box on page 138 if you have problems with the units.)

4. L: second order. Doubling the concentration between experiments 1 and 2 increases the rate four times.  
M: zero order. Changing the concentration of M between experiments 2 and 3 has no effect on rate.  
N: first order. Doubling its concentration between experiments 3 and 4 doubles the rate.  
Rate =  $k[L]^2[N]$   
 $k = \frac{\text{rate}}{[L]^2[N]} = \frac{9.60 \times 10^{-5}}{(0.10)^2 \times 0.10} = 0.096 \text{ mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$   
(See pages 129 to 130 if you have problems with the units.)
5. (a) rate =  $k[X]^2 = 1.44 \times 10^4 \times (0.200)^2 = 5.76 \times 10^{-6} \text{ mol dm}^{-3} \text{ s}^{-1}$   
(b)  $[X]^2 = \frac{\text{rate}}{k} = \frac{1.20 \times 10^{-5}}{1.44 \times 10^{-4}} = 0.08333$   
 $[X] = \sqrt{0.08333} = 0.289 \text{ mol dm}^{-3}$
6. Your graph should be a straight line through the origin (0,0) with a slope of 0.055. Because it is a straight line, the rate is proportional to the concentration of X – in other words, it is first order with respect to X. Because rate =  $k[X]$ , the slope gives you the rate constant, which is  $0.055 \text{ s}^{-1}$ . (See the side box on page 138 if you have problems with the units.)
7. Plotting rate against [Y] gives a curve, but a plot of rate against  $[Y]^2$  gives a straight line through the origin (0,0). This graph shows that the rate is proportional to  $[Y]^2$  – in other words the reaction is second order with respect to Y. Because rate =  $k[Y]^2$ , the slope gives you the rate constant, which is  $1.20 \times 10^{-4} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$ . (See example 2 on pages 130 to 131 if you have problems with the units.)  
Incidentally, it would save you time if you didn't plot the unnecessary graph of rate against [Y]. Look at the figures before you start – it is fairly obvious that the rate is **not** proportional to [Y]. Look, for example, at the rates corresponding to concentrations of 0.200 and 0.445. The concentration has slightly more than doubled, but the rate has gone up much more than that.
8. Your graph will be a straight line starting at 1.00 and sloping down as time increases. The concentration is falling at a steady rate throughout. Because this rate is constant even though the concentration is falling, the reaction is zero order. Rate =  $k$ . The rate of the reaction is given by the slope of the line, and the rate constant has the same value.  $k = 0.0075 \text{ mol dm}^{-3} \text{ s}^{-1}$ . The units are the units of rate.
9. The graph will be a curve, with a constant half life showing that it is first order. The half life is 500 seconds. (To be precise, the half life is 499 seconds, but your graph will not produce that degree of accuracy.)
10. (a)
- |             |     |    |    |      |      |
|-------------|-----|----|----|------|------|
| Time (mins) | 0   | 5  | 10 | 15   | 20   |
| %           | 100 | 50 | 25 | 12.5 | 6.25 |
- After 20 minutes, 6.25% remains.

- (b) The concentration falls to a quarter (25%) in two half lives (see table in part (a) for example). If 36 minutes is two half lives, one half life is 18 minutes.

Time (mins)	0	8	16	24	32	40	48
Concentration (mol dm <sup>-3</sup> )	0.64	0.32	0.16	0.08	0.04	0.02	0.01

It takes 48 minutes for the concentration to fall to 0.01 mol dm<sup>-3</sup>.

Time (mins)	0	5	10	15	20	25	30
[A] (mol dm <sup>-3</sup> )	1.00	?	?	0.50	?	?	0.25
[B] (mol dm <sup>-3</sup> )	2.00	?	1.00	?	0.50	?	0.25

You can see that the two concentrations become equal after 30 minutes. (The question marks are for concentrations that you can't work out from half lives. You can only work out the concentration easily if you have a whole number of half lives – one half life, two half lives, etc.)

11. Reorganise the table so that you have values of  $1/T$  and  $\ln k$ . The values of  $k$  quoted in the table have been multiplied by  $10^3$ . Don't forget to multiply them by  $10^{-3}$  (or divide by  $10^3$ ) before you find  $\ln k$ . In the table below, the  $1/T$  values have been multiplied by  $10^3$  to make them easier to plot.

$1/T \times 10^3$	3.448	3.226	3.030	2.857
$\ln k$	-6.90	-5.29	-3.88	-2.63

You should get a straight line with a slope of  $-7220 \text{ K}$  (theoretical value). The slope is equal to  $-E_A/R$ .

$$-E_A/R = -7220$$

$$E_A = 7220 \times 8.31 = 60,000 \text{ J mol}^{-1} \text{ (60 kJ mol}^{-1}\text{)}$$

12. K first order; L first order; Rate =  $k[K][L]$   
 $k = 5.5 \times 10^{-3} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$
13. (a) A zero order; B second order; C first order; Rate =  $k[B]^2[C]$   
 $k = 2.10 \times 10^{-3} \text{ mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$
- (b)  $3.28 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1}$
14. (a) Rate =  $k[G][F]$
- (b)  $1.4 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$
- (c)  $0.50 \text{ mol dm}^{-3}$
15.  $a = 0.20$ ;  $b = 5.0 \times 10^{-4}$ ;  $c = 0.30$

16. Reaction U: first order;  $k = 2.0 \times 10^{-3} \text{ s}^{-1}$ . (Graph of rate against [U] gives a straight line; slope gives  $k$ .)  
 Reaction V: zero order;  $k = 0.016 \text{ mol dm}^{-3} \text{ s}^{-1}$ . (Rate is independent of concentration. Rate =  $k$ .)  
 Reaction W: second order;  $k = 1.0 \times 10^{-4} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$ . (Graph of rate against  $[W]^2$  gives a straight line; slope gives  $k$ .)  
 Reaction X: first order;  $k = 4.5 \times 10^{-3} \text{ s}^{-1}$ . (Graph of rate against [X] gives a straight line; slope gives  $k$ .)
17. Graph of concentration against time has a constant half life = 240 seconds.
18. (a) 8 minutes (b)  $0.025 \text{ mol dm}^{-3}$
19.  $83 \text{ kJ mol}^{-1}$

## Chapter 7

1. (a)  $K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]} \text{ mol}^{-1} \text{ dm}^3$  (b)  $K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]} \text{ mol dm}^{-3}$
- (c)  $K_c = \frac{[\text{H}_2][\text{I}_2]}{[\text{HI}]^2}$  (no units) (d)  $K_c = \frac{[\text{N}_2][\text{H}_2]^3}{[\text{NH}_3]^2} \text{ mol}^2 \text{ dm}^{-6}$

2.  $K_c = \frac{[\text{N}]}{[\text{M}]^2} = \frac{0.872}{(0.141)^2} = 43.9 \text{ mol}^{-1} \text{ dm}^3$

3. (a)
- |   | X                   | ⇌ | Y                                  | + | Z                                  |
|---|---------------------|---|------------------------------------|---|------------------------------------|
| Start (moles)                                     | 1.00                |   | 0                                  |   | 0                                  |
| Equilibrium (moles)                               | 1.00 - 0.200        |   | 0.200                              |   | 0.200                              |
| Equilibrium concentration (mol dm <sup>-3</sup> ) | 0.800/25.0 = 0.0320 |   | 0.200/25.0 = $8.00 \times 10^{-3}$ |   | 0.200/25.0 = $8.00 \times 10^{-3}$ |
- $$K_c = \frac{[\text{Y}][\text{Z}]}{[\text{X}]}$$

$$= \frac{(8.00 \times 10^{-3})(8.00 \times 10^{-3})}{0.0320} = 2.00 \times 10^{-3} \text{ mol dm}^{-3}$$

- (b)  $K_c$  increases with temperature. Therefore more Y and Z are formed at the higher temperature. Therefore the forward reaction is endothermic. According to Le Chatelier, the system "tries" to reduce the higher temperature by favouring the reaction which absorbs heat.

- 4.
- |   | A                    | + | B       | ⇌ | C       | + | D       |
|---|----------------------|---|---------|---|---------|---|---------|
| Start (moles)                                     | 2.00                 |   | 1.00    |   | 0       |   | 0       |
| Equilibrium (moles)                               | 2.00 - 0.600 = 1.400 |   | 0.400   |   | 0.600   |   | 0.600   |
| Equilibrium concentration (mol dm <sup>-3</sup> ) | 1.400/V              |   | 0.400/V |   | 0.600/V |   | 0.600/V |

► Hint: It is easy to mis-read 25.0 dm<sup>3</sup> in the question as 25.0 cm<sup>3</sup>, because this is such a familiar value. Read questions carefully!

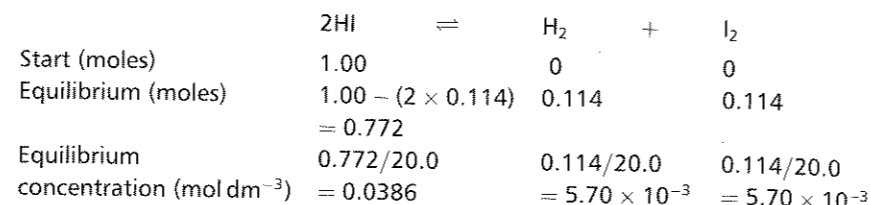
► Hint: If there is 0.400 mole of B left, 1.00 - 0.400 mole has been used up = 0.600 mole. This means that 0.600 mole of A will be used up as well, and 0.600 mole of C and D will be formed.

$$K_c = \frac{[C][D]}{[A][B]}$$

$$= \frac{(0.600/V)(0.600/V)}{(1.400/V)(0.400/V)} = \frac{0.600 \times 0.600}{1.400 \times 0.400} = 0.643 \text{ (no units)}$$

5.

► Hint: For each mole of I<sub>2</sub> formed, 2 moles of HI are used up.



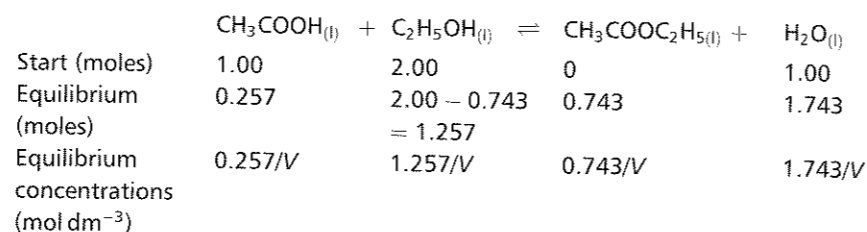
$$K_c = \frac{[\text{H}_2][\text{I}_2]}{[\text{HI}]^2}$$

$$= \frac{(5.70 \times 10^{-3})(5.70 \times 10^{-3})}{(0.0386)^2} = 0.0218 \text{ (no units)}$$

6.

► Hint: If there is 0.257 mole of ethanoic acid left, 1.00 - 0.257 mole has been used up = 0.743 mole.

► In the case of the water, the 0.743 mole formed is added to the 1.00 mole there to start with.



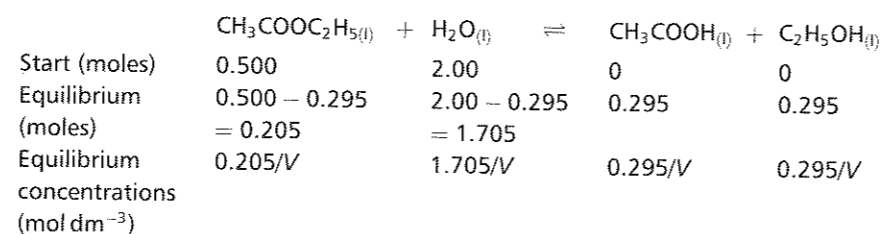
$$K_c = \frac{[\text{CH}_3\text{COOC}_2\text{H}_5][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{C}_2\text{H}_5\text{OH}]}$$

$$= \frac{(0.743/V)(1.743/V)}{(0.257/V)(1.257/V)} = \frac{0.743 \times 1.743}{0.257 \times 1.257} = 4.01 \text{ (no units)}$$

7.

Moles of CH<sub>3</sub>COOC<sub>2</sub>H<sub>5</sub> at start = 44.0/88 = 0.500 mol

Moles of water at start = 36.0/18 = 2.00 mol

Moles of NaOH used in titration =  $\frac{29.5}{1000} \times 1.00 = 0.0295$ Because the neutralisation reaction is 1:1, number of moles of CH<sub>3</sub>COOH in 25.0 cm<sup>3</sup> = 0.0295Therefore number of moles of CH<sub>3</sub>COOH in 250 cm<sup>3</sup> = 0.295 mol

$$K_c = \frac{[\text{CH}_3\text{COOH}][\text{C}_2\text{H}_5\text{OH}]}{[\text{CH}_3\text{COOC}_2\text{H}_5][\text{H}_2\text{O}]}$$

$$= \frac{(0.295/V)(0.295/V)}{(0.205/V)(1.705/V)} = \frac{0.295 \times 0.295}{0.205 \times 1.705} = 0.249 \text{ (no units)}$$

8.

► Hint: Let the number of moles of A at equilibrium be "a". (2.0 - a) moles of A will have converted into B.

Start (moles) 2.0  
Equilibrium (moles) a  
Equilibrium concentrations (mol dm<sup>-3</sup>) a/V

A = 2.0  
B = 0  
2.0 - a  
(2.0 - a)/V

$$K_c = \frac{[B]}{[A]}$$

$$39 = \frac{(2.0 - a)/V}{a/V} = \frac{2.0 - a}{a}$$

39a = 2.0 - a

40a = 2.0

a = 0.050 mol

9.

► Hint: Let the percentage converted be "p" and start with 100 moles. You could also start with 1 mole, work out the fraction converted and then multiply by 100 at the end.

Start (moles) 100  
Equilibrium (moles) 100 - p  
Equilibrium concentrations (mol dm<sup>-3</sup>) (100 - p)/V

S = 100  
T = 0  
100 - p  
(100 - p)/V

$$K_c = \frac{[T]}{[S]}$$

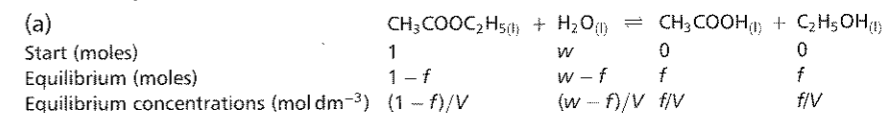
$$24 = \frac{p/V}{(100 - p)/V} = \frac{p}{100 - p}$$

2400 - 24p = p

25p = 2400

p = 96%

10.



$$K_c = \frac{[\text{CH}_3\text{COOH}][\text{C}_2\text{H}_5\text{OH}]}{[\text{CH}_3\text{COOC}_2\text{H}_5][\text{H}_2\text{O}]}$$

$$0.25 = \frac{(f/V)(f/V)}{[(1 - f)/V][(w - f)/V]} = \frac{f^2}{(1 - f)(w - f)}$$

(b) If w = 1:

$$\frac{f^2}{(1 - f)(1 - f)} = 0.25$$

Since the left hand side is a perfect square, you can take the square root of both sides:

$$\frac{f}{(1 - f)} = \pm 0.5$$

Solving this gives f = 0.33 or f = -1. Since the negative answer is impossible, f = 0.33.

If w = 10:

$$\frac{f^2}{(1 - f)(10 - f)} = 0.25$$

$$\frac{f^2}{(10 - 11f + f^2)} = 0.25$$

$$f^2 = 2.5 - 2.75f + 0.25f^2$$

0.75f<sup>2</sup> + 2.75f - 2.5 = 0

Solving this by the standard equation, gives f = 0.75 (the negative root is impossible).

► If you have forgotten the equation, see page 164.

$$11. K_p = \frac{P_{\text{PCl}_3} \times P_{\text{Cl}_2}}{P_{\text{PCl}_5}} = \frac{80 \times 80}{40} = 160 \text{ kPa}$$

$$12. P_{\text{NO}_2} = 101 - 72.0 = 29.0 \text{ kPa}$$

$$K_p = \frac{P_{\text{NO}_2}^2}{P_{\text{N}_2\text{O}_4}} = \frac{(29.0)^2}{72.0} = 11.7 \text{ kPa}$$

$$13. \text{ If } P_{\text{HI}} = 0.786$$

$$P_{\text{H}_2} + P_{\text{I}_2} = 1.00 - 0.786 = 0.214 \text{ atm}$$

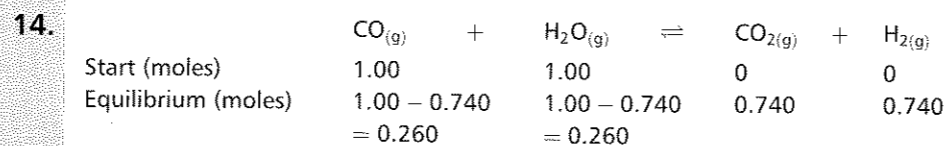
$$\text{But } P_{\text{H}_2} = P_{\text{I}_2}$$

$$\text{So each of them} = 0.107 \text{ atm}$$

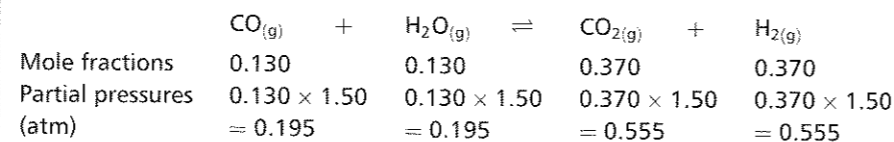
$$K_p = \frac{P_{\text{H}_2} \times P_{\text{I}_2}}{P_{\text{HI}}^2} = \frac{0.107 \times 0.107}{(0.786)^2} = 0.0185 \text{ (no units)}$$

➤ **Remember:** The total pressure is the sum of the partial pressures.

The partial pressures of hydrogen and iodine are identical because you are producing equal numbers of moles of them. Equal numbers of moles in the same container at the same temperature implies equal pressures.

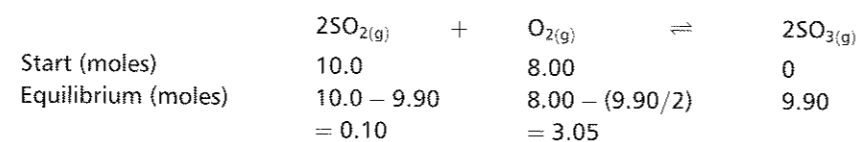


$$\text{The total number of moles} = 0.260 + 0.260 + 0.740 + 0.740 = 2.00$$

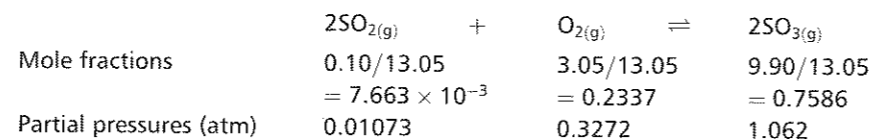


$$K_p = \frac{P_{\text{CO}_2} \times P_{\text{H}_2}}{P_{\text{CO}} \times P_{\text{H}_2\text{O}}} = \frac{0.555 \times 0.555}{0.195 \times 0.195} = 8.10 \text{ (no units)}$$

$$15. 640 \text{ g of SO}_2 \text{ is } 10.0 \text{ mol; } 256 \text{ g of O}_2 \text{ is } 8.00 \text{ mol; } 792 \text{ g of SO}_3 \text{ is } 9.90 \text{ mol.}$$



$$\text{The total number of moles} = 0.10 + 3.05 + 9.90 = 13.05$$



$$K_p = \frac{P_{\text{SO}_3}^2}{P_{\text{SO}_2}^2 \times P_{\text{O}_2}} = \frac{(1.062)^2}{(0.01073)^2 \times 0.3272} = 29\,900 \text{ atm}^{-1}$$

➤ **Hint:** Multiply the mole fractions by the total pressure (1.40 atm) to get the partial pressures.

$$16. \text{ If the partial pressure of H}_2 = p, \text{ then the partial pressure of I}_2 = p \text{ as well.}$$

$$K_p = \frac{P_{\text{H}_2} \times P_{\text{I}_2}}{P_{\text{HI}}^2}$$

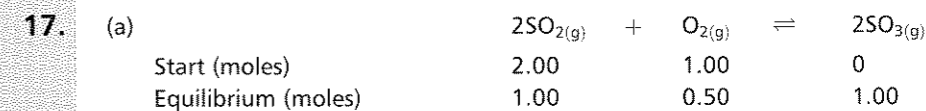
$$0.0185 = \frac{p \times p}{(1.32)^2}$$

$$p^2 = 0.0185 \times (1.32)^2$$

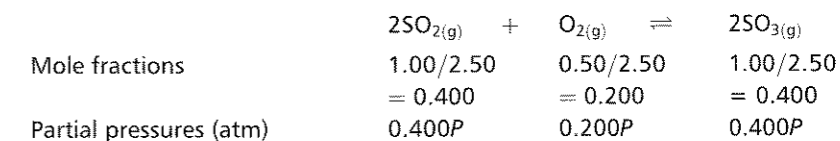
$$p = 0.180$$

Partial pressures of hydrogen and iodine are both 0.180 atm.

$$\text{Total pressure} = 1.32 + 0.180 + 0.180 = 1.68 \text{ atm}$$



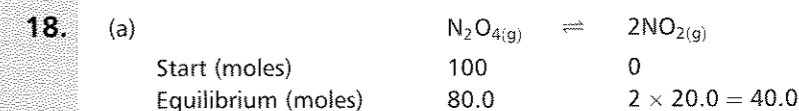
$$(b) \text{ The total number of moles} = 2.50$$



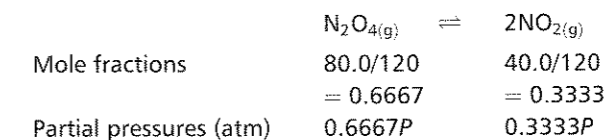
$$(c) K_p = \frac{P_{\text{SO}_3}^2}{P_{\text{SO}_2}^2 \times P_{\text{O}_2}}$$

$$0.130 = \frac{(0.400P)^2}{(0.400P)^2 \times 0.200P}$$

$$P = \frac{1}{0.200 \times 0.130} = 38.5 \text{ atm}$$



$$(b) \text{ Total moles} = 120$$



$$(c) K_p = \frac{P_{\text{NO}_2}^2}{P_{\text{N}_2\text{O}_4}}$$

$$0.115 = \frac{(0.3333P)^2}{0.6667P}$$

$$P = \frac{0.115 \times 0.6667}{(0.3333)^2} = 0.690 \text{ atm}$$

$$(d) P_{\text{N}_2\text{O}_4} = 0.6667 \times 0.690 \text{ atm} = 0.460 \text{ atm}$$

$$P_{\text{NO}_2} = 0.3333 \times 0.690 \text{ atm} = 0.230 \text{ atm}$$

➤ **Hint:** It would make your answer more accurate if you realised that 80.0/120 is 2/3, and that 40.0/120 is 1/3, and then used these fractions rather than converting to decimals.

19. (a) The partial pressures of chlorine and  $\text{PCl}_3$  will both be " $p$ " because they are produced 1:1.

The partial pressure of  $\text{PCl}_5$  will be the total pressure minus the other partial pressures =  $400 - 2p$

$$K_p = \frac{P_{\text{PCl}_3} \times P_{\text{Cl}_2}}{P_{\text{PCl}_5}}$$

$$160 = \frac{p \times p}{(400 - 2p)}$$

$$160(400 - 2p) = p^2$$

$$p^2 + 320p - 64\,000 = 0$$

$$p = \frac{-320 \pm \sqrt{320^2 + (4 \times 64\,000)}}{2}$$

$$= 139 \text{ kPa (the negative root is impossible)}$$

- (c) The partial pressures are:

$\text{Cl}_2$ : 139 kPa  
 $\text{PCl}_3$ : 139 kPa  
 $\text{PCl}_5$ :  $400 - (2 \times 139) = 122 \text{ kPa}$

20.	$\text{C}_{(s)}$	+	$\text{CO}_{2(g)}$	$\rightleftharpoons$	$2\text{CO}_{(g)}$
	Mole fractions		0.217		0.783
	Partial pressures (atm)		$0.217 \times 5.00$ $= 1.085$		$0.783 \times 5.00$ $= 3.915$

$$K_p = \frac{P_{\text{CO}}^2}{P_{\text{CO}_2}} = \frac{(3.915)^2}{1.085} = 14.1 \text{ atm}$$

21.	$\text{Sn}_{(s)}$	+	$\text{Pb}^{2+}_{(aq)}$	$\rightleftharpoons$	$\text{Pb}_{(s)}$	+	$\text{Sn}^{2+}_{(aq)}$
	Start concentration (mol dm <sup>-3</sup> )		1.0		0		
	Equilibrium concentration (mol dm <sup>-3</sup> )		$1.0 - f$		$f$		

$$K_c = \frac{[\text{Sn}^{2+}]}{[\text{Pb}^{2+}]}$$

$$2.2 = \frac{f}{(1.0 - f)}$$

$$2.2(1.0 - f) = f$$

$$3.2f = 2.2$$

$$f = 0.69$$

22.	$\text{H}_2\text{O}$	$\text{H}_2$	$\text{CO}$	
	Mole fractions	0.50	0.25	0.25
	Partial pressures (atm)	$0.50P$	$0.25P$	$0.25P$

$$K_p = \frac{P_{\text{H}_2} \times P_{\text{CO}}}{P_{\text{H}_2\text{O}}}$$

$$3.7 = \frac{(0.25P) \times (0.25P)}{0.50P}$$

$$P = \frac{3.7 \times 0.50}{0.25 \times 0.25} = 30 \text{ atm (no more than 2 significant figures)}$$

23. (a)  $K_c = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} = 53.8$  (no units)

(b)  $K_p = \frac{P_{\text{HI}}^2}{P_{\text{H}_2} \times P_{\text{I}_2}} = 53.8$  (no units)

24. (a) 0.600 mol  $\text{N}_2\text{O}_4$ ; 0.800 mol  $\text{NO}_2$

(b)  $K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]} = 0.135 \text{ mol dm}^{-3}$

- (c)  $\text{N}_2\text{O}_4$  222 kPa;  $\text{NO}_2$  295 kPa

(d)  $K_p = \frac{P_{\text{NO}_2}^2}{P_{\text{N}_2\text{O}_4}} = 392 \text{ kPa}$

25. (a)  $\text{N}_2$  18.7%;  $\text{H}_2$  56.1%

- (b)  $\text{N}_2$  18.7 atm;  $\text{H}_2$  56.1 atm;  $\text{NH}_3$  25.2 atm

(c)  $K_p = \frac{P_{\text{NH}_3}^2}{P_{\text{N}_2} \times P_{\text{H}_2}^3} = 1.92 \times 10^{-4} \text{ atm}^{-2}$

26. (a) 0.0400 mol  $\text{PCl}_5$ ; 0.160 mol  $\text{PCl}_3$ ; 0.160 mol  $\text{Cl}_2$

(b)  $K_c = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} = 0.0408 \text{ mol dm}^{-3}$

- (c)  $\text{PCl}_5$  10 kPa;  $\text{PCl}_3$  40 kPa;  $\text{Cl}_2$  40 kPa

(d)  $K_p = \frac{P_{\text{PCl}_3} \times P_{\text{Cl}_2}}{P_{\text{PCl}_5}} = 160 \text{ kPa}$

27. 4.0 (no units)

28. (a) Both partial pressures are 741 kPa.

(b)  $K_p = \frac{P_{\text{H}_2} \times P_{\text{CO}}}{P_{\text{H}_2\text{O}}} = 1730 \text{ kPa}$

29. Both partial pressures are 0.330 atm.

30. Partial pressure of  $\text{NO}_2 = 0.240 \text{ atm}$ . Total pressure = 0.740 atm.

31.  $[\text{Pb}^{2+}] = 0.47 \text{ mol dm}^{-3}$ ;  $[\text{Sn}^{2+}] = 1.03 \text{ mol dm}^{-3}$

32. (a) Partial pressures:  $\text{PCl}_5$  0.0526P;  $\text{PCl}_3$  0.474P;  $\text{Cl}_2$  0.474P

(b)  $K_p = \frac{P_{\text{PCl}_3} \times P_{\text{Cl}_2}}{P_{\text{PCl}_5}}$

$$P = 37.5 \text{ kPa}$$

- (c) Partial pressures:  $\text{PCl}_5$  1.97 kPa;  $\text{PCl}_3$  17.8 kPa;  $\text{Cl}_2$  17.8 kPa

33. 9.6 atm

## Chapter 8

1. (a) 2.00 (b) 1.60 (c) 3.52 (d) 7.00 (e) 9.12
2. (a)  $3.80 \times 10^{-4}$  (b) 0.0631 (c)  $2.24 \times 10^{-6}$   
(d)  $3.98 \times 10^{-9}$  (e)  $1.00 \times 10^{-13}$
3. (a) 3.00 (b)  $7.08 \times 10^{-5} \text{ mol dm}^{-3}$  (c) 2.57 (d)  $5.01 \times 10^{-11} \text{ mol dm}^{-3}$
4. (a)  $[\text{H}^+] = 0.0300 \text{ mol dm}^{-3}$ ;  $\text{pH} = -\log_{10}[\text{H}^+] = 1.52$   
(b)  $[\text{H}^+] = 2 \times 0.00500 = 0.0100 \text{ mol dm}^{-3}$ ;  $\text{pH} = -\log_{10}[\text{H}^+] = 2.00$   
(c)  $[\text{H}^+] = 0.120 \text{ mol dm}^{-3}$ ;  $\text{pH} = -\log_{10}[\text{H}^+] = 0.92$
5. (a)  $[\text{H}^+] = 0.20 \text{ mol dm}^{-3}$ ;  $[\text{HCl}] = 0.20 \text{ mol dm}^{-3}$   
(b)  $[\text{H}^+] = 0.032 \text{ mol dm}^{-3}$ ;  $[\text{H}_2\text{SO}_4] = 0.016 \text{ mol dm}^{-3}$   
(c)  $[\text{H}^+] = 0.010 \text{ mol dm}^{-3}$ ;  $[\text{HNO}_3] = 0.010 \text{ mol dm}^{-3}$
6. (a)  $K_w = [\text{H}^+][\text{OH}^-]$   
 $[\text{OH}^-] = [\text{H}^+]$  because the water is pure  
 $K_w = [\text{H}^+]^2$   
 $[\text{H}^+]^2 = 4.52 \times 10^{-15}$   
 $[\text{H}^+] = 6.72 \times 10^{-8}$   
 $\text{pH} = -\log_{10}[\text{H}^+] = 7.17$   
(b) Repeating (a) with the different value of  $K_w$  gives  $\text{pH} = 6.63$ .
7. (a)  $[\text{OH}^-] = 0.250$   
 $[\text{H}^+][\text{OH}^-] = 1.00 \times 10^{-14}$   
 $[\text{H}^+] \times 0.250 = 1.00 \times 10^{-14}$   
 $[\text{H}^+] = \frac{1.00 \times 10^{-14}}{0.250} = 4.00 \times 10^{-14} \text{ mol dm}^{-3}$   
 $\text{pH} = -\log_{10}[\text{H}^+] = 13.4$   
(b) Each  $\text{Ba}(\text{OH})_2$  gives  $2\text{OH}^-$ .  
 $[\text{OH}^-] = 2 \times 0.100$   
 $[\text{H}^+][\text{OH}^-] = 1.00 \times 10^{-14}$   
 $[\text{H}^+] \times 0.200 = 1.00 \times 10^{-14}$   
 $[\text{H}^+] = \frac{1.00 \times 10^{-14}}{0.200} = 5.00 \times 10^{-14} \text{ mol dm}^{-3}$   
 $\text{pH} = -\log_{10}[\text{H}^+] = 13.3$   
(c)  $[\text{OH}^-] = 0.00500$   
 $[\text{H}^+][\text{OH}^-] = 1.00 \times 10^{-14}$   
 $[\text{H}^+] \times 0.00500 = 1.00 \times 10^{-14}$   
 $[\text{H}^+] = \frac{1.00 \times 10^{-14}}{0.00500} = 2.00 \times 10^{-12} \text{ mol dm}^{-3}$   
 $\text{pH} = -\log_{10}[\text{H}^+] = 11.7$

➤ Answers to 2 significant figures only.

8. (a) "Unlog" pH to find  $[\text{H}^+]$ .  
 $[\text{H}^+] = 6.310 \times 10^{-14}$   
 $[\text{H}^+][\text{OH}^-] = 1.00 \times 10^{-14}$   
 $6.310 \times 10^{-14} \times [\text{OH}^-] = 1.00 \times 10^{-14}$   
 $[\text{OH}^-] = \frac{1.00 \times 10^{-14}}{6.310 \times 10^{-14}} = 0.158 \text{ mol dm}^{-3}$   
Therefore,  $[\text{NaOH}] = 0.158 \text{ mol dm}^{-3}$
- (b) "Unlog" pH to find  $[\text{H}^+]$ .  
 $[\text{H}^+] = 5.012 \times 10^{-12}$   
 $[\text{H}^+][\text{OH}^-] = 1.00 \times 10^{-14}$   
 $5.012 \times 10^{-12} \times [\text{OH}^-] = 1.00 \times 10^{-14}$   
 $[\text{OH}^-] = \frac{1.00 \times 10^{-14}}{5.012 \times 10^{-12}} = 2.00 \times 10^{-3} \text{ mol dm}^{-3}$   
 $[\text{Sr}(\text{OH})_2] = \frac{1}{2} \times 2.00 \times 10^{-3} = 1.00 \times 10^{-3} \text{ mol dm}^{-3}$   
(Each  $\text{Sr}(\text{OH})_2$  gives  $2\text{OH}^-$ .)
9. (a) Moles of  $\text{H}^+ = \frac{30.0}{1000} \times 1.00 = 0.0300$   
Moles of  $\text{OH}^- = \frac{25.0}{1000} \times 1.00 = 0.0250$   
Moles of excess  $\text{H}^+ = 0.0300 - 0.0250 = 0.0050$   
 $[\text{H}^+] = \frac{1000}{55.0} \times 0.0050 = 0.09091 \text{ mol dm}^{-3}$   
 $\text{pH} = 1.04$
- (b) Moles of  $\text{H}^+ = \frac{15.0}{1000} \times 1.00 = 0.0150$   
Moles of  $\text{OH}^- = \frac{25.0}{1000} \times 1.00 = 0.0250$   
Moles of excess  $\text{OH}^- = 0.0250 - 0.0150 = 0.0100$   
 $[\text{OH}^-] = \frac{1000}{40.0} \times 0.0100 = 0.250 \text{ mol dm}^{-3}$   
 $[\text{H}^+][\text{OH}^-] = 1.00 \times 10^{-14}$   
 $[\text{H}^+] \times 0.250 = 1.00 \times 10^{-14}$   
 $[\text{H}^+] = \frac{1.00 \times 10^{-14}}{0.250} = 4.00 \times 10^{-14} \text{ mol dm}^{-3}$   
 $\text{pH} = 13.4$
- (c) Moles of  $\text{H}^+ = \frac{40.0}{1000} \times 0.100 = 4.00 \times 10^{-3}$   
Moles of  $\text{OH}^- = \frac{25.0}{1000} \times 0.200 = 5.00 \times 10^{-3}$   
Moles of excess  $\text{OH}^- = 1.00 \times 10^{-3}$   
 $[\text{OH}^-] = \frac{1000}{65.0} \times 1.00 \times 10^{-3} = 0.01538 \text{ mol dm}^{-3}$

➤ Hint: The total volume of the solution is  $55 \text{ cm}^3$ .



➤ Each mole of sulphuric acid gives 2 moles of  $H^+$ .

➤ Each mole of barium hydroxide gives 2 moles of  $OH^-$ .

$$[H^+][OH^-] = 1.00 \times 10^{-14}$$

$$[H^+] \times 0.01538 = 1.00 \times 10^{-14}$$

$$[H^+] = \frac{1.00 \times 10^{-14}}{0.01538} = 6.50 \times 10^{-13} \text{ mol dm}^{-3}$$

$$\text{pH} = 12.2$$

(d) Moles of  $H^+$  =  $2 \times \frac{25.0}{1000} \times 0.0500 = 2.50 \times 10^{-3}$

Moles of  $OH^-$  =  $\frac{10.0}{1000} \times 0.100 = 1.00 \times 10^{-3}$

Moles of excess  $H^+$  =  $1.50 \times 10^{-3}$

$$[H^+] = \frac{1000}{35.0} \times 1.50 \times 10^{-3} = 0.04286 \text{ mol dm}^{-3}$$

$$\text{pH} = 1.37$$

(e) Moles of  $H^+$  =  $\frac{20.0}{1000} \times 0.100 = 2.00 \times 10^{-3}$

Moles of  $OH^-$  =  $2 \times \frac{25.0}{1000} \times 0.0500 = 2.50 \times 10^{-3}$

Moles of excess  $OH^-$  =  $0.50 \times 10^{-3}$

$$[OH^-] = \frac{1000}{45.0} \times 0.50 \times 10^{-3} = 0.01111 \text{ mol dm}^{-3}$$

$$[H^+][OH^-] = 1.00 \times 10^{-14}$$

$$[H^+] \times 0.01111 = 1.00 \times 10^{-14}$$

$$[H^+] = \frac{1.00 \times 10^{-14}}{0.01111} = 9.00 \times 10^{-13} \text{ mol dm}^{-3}$$

$$\text{pH} = 12.0$$

10. pH at  $0 \text{ cm}^3 = 14$ ; pH at  $25 \text{ cm}^3 = 7$ . The pHs from 5 to 24.9 are calculated in exactly the same way as Q9(b). The pHs from 25.1 to 40 are calculated in exactly the same way as Q9(a). If you don't get an absolutely smooth version of the typical strong acid-strong base pH curve, you have made a careless error.

11. (a)  $K_a = \frac{[H^+][CN^-]}{[HCN]} \text{ mol dm}^{-3}$

(b)  $K_a = \frac{[H^+][NO_2^-]}{[HNO_2]} \text{ mol dm}^{-3}$

(c)  $K_a = \frac{[CH_2ClCOO^-][H^+]}{[CH_2ClCOOH]} \text{ mol dm}^{-3}$

12. (a) 3.91 (b) 4.43 (c) 2.25

13. (a)  $1.05 \times 10^{-3} \text{ mol dm}^{-3}$

(b)  $2.88 \times 10^{-6} \text{ mol dm}^{-3}$

(c)  $2.40 \times 10^{-5} \text{ mol dm}^{-3}$

14. (a)

	$\text{HOCl}_{(aq)}$	$\rightleftharpoons$	$\text{H}^+_{(aq)}$	+	$\text{OCl}^-_{(aq)}$
Start concentration ( $\text{mol dm}^{-3}$ )	0.0200		0		0
Equilibrium concentration ( $\text{mol dm}^{-3}$ )	$0.0200 - [H^+]$ $\approx 0.0200$		$[H^+]$		$[H^+]$

$$K_a = \frac{[H^+][OCl^-]}{[HOCl]}$$

$$3.72 \times 10^{-8} = \frac{[H^+]^2}{0.0200}$$

$$[H^+]^2 = 0.0200 \times 3.72 \times 10^{-8}$$

$$[H^+] = \sqrt{0.0200 \times 3.72 \times 10^{-8}} = 2.728 \times 10^{-5} \text{ mol dm}^{-3}$$

$$\text{pH} = 4.56$$

(b)

	$\text{HNO}_{2(aq)}$	$\rightleftharpoons$	$\text{H}^+_{(aq)}$	+	$\text{NO}_2^-_{(aq)}$
Start concentration ( $\text{mol dm}^{-3}$ )	0.0500		0		0
Equilibrium concentration ( $\text{mol dm}^{-3}$ )	$0.0500 - [H^+]$ $\approx 0.0500$		$[H^+]$		$[H^+]$

$$K_a = \frac{[H^+][NO_2^-]}{[HNO_2]}$$

$$4.57 \times 10^{-4} = \frac{[H^+]^2}{0.0500}$$

$$[H^+]^2 = 0.0500 \times 4.57 \times 10^{-4}$$

$$[H^+] = \sqrt{0.0500 \times 4.57 \times 10^{-4}} = 4.780 \times 10^{-3} \text{ mol dm}^{-3}$$

$$\text{pH} = 2.32$$

(c)

	$\text{CH}_2\text{ClCOOH}_{(aq)}$	$\rightleftharpoons$	$\text{CH}_2\text{ClCOO}^-_{(aq)}$	+	$\text{H}^+_{(aq)}$
Start concentration ( $\text{mol dm}^{-3}$ )	1.00		0		0
Equilibrium concentration ( $\text{mol dm}^{-3}$ )	$1.00 - [H^+]$ $\approx 1.00$		$[H^+]$		$[H^+]$

$$K_a = \frac{[\text{CH}_2\text{ClCOO}^-][H^+]}{[\text{CH}_2\text{ClCOOH}]}$$

$$6.76 \times 10^{-4} = \frac{[H^+]^2}{1.00}$$

$$[H^+]^2 = 1.00 \times 6.76 \times 10^{-4}$$

$$[H^+] = \sqrt{1.00 \times 6.76 \times 10^{-4}} = 0.0260 \text{ mol dm}^{-3}$$

$$\text{pH} = 1.59$$

(d) "Unlogging"  $\text{p}K_a$  gives  $K_a = 1.35 \times 10^{-5} \text{ mol dm}^{-3}$ .

	$\text{C}_2\text{H}_5\text{COOH}_{(aq)}$	$\rightleftharpoons$	$\text{C}_2\text{H}_5\text{COO}^-_{(aq)}$	+	$\text{H}^+_{(aq)}$
Start concentration ( $\text{mol dm}^{-3}$ )	0.100		0		0
Equilibrium concentration ( $\text{mol dm}^{-3}$ )	$0.100 - [H^+]$ $\approx 0.100$		$[H^+]$		$[H^+]$

$$K_a = \frac{[\text{C}_2\text{H}_5\text{COO}^-][\text{H}^+]}{[\text{C}_2\text{H}_5\text{COOH}]}$$

$$1.35 \times 10^{-5} = \frac{[\text{H}^+]^2}{0.100}$$

$$[\text{H}^+]^2 = 0.100 \times 1.35 \times 10^{-5}$$

$$[\text{H}^+] = \sqrt{0.100 \times 1.35 \times 10^{-5}} = 1.162 \times 10^{-3} \text{ mol dm}^{-3}$$

$$\text{pH} = 2.93$$

(e) "Unlogging"  $\text{p}K_a$  gives  $K_a = 3.98 \times 10^{-10} \text{ mol dm}^{-3}$ .

	$\text{HCN}_{(\text{aq})}$	$\rightleftharpoons$	$\text{H}^+_{(\text{aq})}$	+	$\text{CN}^-_{(\text{aq})}$
Start concentration ( $\text{mol dm}^{-3}$ )	0.250		0		0
Equilibrium concentration ( $\text{mol dm}^{-3}$ )	$0.250 - [\text{H}^+]$ $\approx 0.250$		$[\text{H}^+]$		$[\text{H}^+]$

$$K_a = \frac{[\text{H}^+][\text{CN}^-]}{[\text{HCN}]}$$

$$3.98 \times 10^{-10} = \frac{[\text{H}^+]^2}{0.250}$$

$$[\text{H}^+]^2 = 0.250 \times 3.98 \times 10^{-10}$$

$$[\text{H}^+] = \sqrt{0.250 \times 3.98 \times 10^{-10}} = 9.975 \times 10^{-6} \text{ mol dm}^{-3}$$

$$\text{pH} = 5.00$$

15. (a) If the pH is 4.50, then  $[\text{H}^+] = 3.16 \times 10^{-5} \text{ mol dm}^{-3}$

	$\text{HX}_{(\text{aq})}$	$\rightleftharpoons$	$\text{H}^+_{(\text{aq})}$	+	$\text{X}^-_{(\text{aq})}$
Start concentration ( $\text{mol dm}^{-3}$ )	0.0400		0		0
Equilibrium concentration ( $\text{mol dm}^{-3}$ )	$0.0400 -$ $3.16 \times 10^{-5}$ $= 0.03997$		$3.16 \times 10^{-5}$		$3.16 \times 10^{-5}$

$$K_a = \frac{[\text{H}^+][\text{X}^-]}{[\text{HX}]} = \frac{(3.16 \times 10^{-5})^2}{0.03997} = 2.498 \times 10^{-8} \text{ mol dm}^{-3}$$

$$\text{p}K_a = -\log_{10} K_a = 7.60$$

(b) If the pH is 3.25, then  $[\text{H}^+] = 5.26 \times 10^{-4} \text{ mol dm}^{-3}$

	$\text{HY}_{(\text{aq})}$	$\rightleftharpoons$	$\text{H}^+_{(\text{aq})}$	+	$\text{Y}^-_{(\text{aq})}$
Start concentration ( $\text{mol dm}^{-3}$ )	0.125		0		0
Equilibrium concentration ( $\text{mol dm}^{-3}$ )	$0.125 -$ $5.62 \times 10^{-4}$ $= 0.1244$		$5.62 \times 10^{-4}$		$5.62 \times 10^{-4}$

$$K_a = \frac{[\text{H}^+][\text{Y}^-]}{[\text{HY}]} = \frac{(5.62 \times 10^{-4})^2}{0.1244} = 2.539 \times 10^{-6} \text{ mol dm}^{-3}$$

$$\text{p}K_a = -\log_{10} K_a = 5.60$$

➤ It would be perfectly sensible in this instance to make the approximation that  $0.0400 - 3.16 \times 10^{-5} \approx 0.0400$ . To 3 significant figures this is true.

(c) If the pH is 5.70, then  $[\text{H}^+] = 2.00 \times 10^{-6} \text{ mol dm}^{-3}$

	$\text{HZ}_{(\text{aq})}$	$\rightleftharpoons$	$\text{H}^+_{(\text{aq})}$	+	$\text{Z}^-_{(\text{aq})}$
Start concentration ( $\text{mol dm}^{-3}$ )	0.885		0		0
Equilibrium concentration ( $\text{mol dm}^{-3}$ )	$0.885 -$ $2.00 \times 10^{-6}$ $= 0.885$		$2.00 \times 10^{-6}$		$2.00 \times 10^{-6}$

$$K_a = \frac{[\text{H}^+][\text{Z}^-]}{[\text{HZ}]} = \frac{(2.00 \times 10^{-6})^2}{0.885} = 4.520 \times 10^{-12} \text{ mol dm}^{-3}$$

$$\text{p}K_a = -\log_{10} K_a = 11.3$$

16. The steep bit of the curve (which gives you the end-point) occurs at  $25 \text{ cm}^3$ . Half way through the titration is therefore  $12.5 \text{ cm}^3$ . The pH half way through is equal to  $\text{p}K_a$ . If your graph is accurate, you should get a value close to 4.76. (This is the value the results were calculated on.)

17. (a) "Unlogging"  $\text{p}K_a$  gives  $K_a = 1.74 \times 10^{-5} \text{ mol dm}^{-3}$

$$(b) K_a = \frac{[\text{CH}_3\text{COO}^-][\text{H}^+]}{[\text{CH}_3\text{COOH}]}$$

$$[\text{H}^+] = \frac{K_a \times [\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COO}^-]} = \frac{1.74 \times 10^{-5} \times [\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COO}^-]}$$

(c)  $K_w = [\text{H}^+][\text{OH}^-] = 1.00 \times 10^{-14}$

$$[\text{OH}^-] = \frac{1.00 \times 10^{-14}}{[\text{H}^+]}$$

(d)  $[\text{CH}_3\text{COOH}] = [\text{OH}^-] = \frac{1.00 \times 10^{-14}}{[\text{H}^+]}$

(e)  $0.200 \text{ mol dm}^{-3}$ . The ethanoate ion is such a weak base that its equilibrium concentration is approximately the same as its original concentration.

$$(f) [\text{H}^+] = \frac{1.74 \times 10^{-5} \times [\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COO}^-]} = \frac{1.74 \times 10^{-5}}{0.200} \times \frac{1.00 \times 10^{-14}}{[\text{H}^+]}$$

$$[\text{H}^+]^2 = \frac{1.74 \times 10^{-5} \times 1.00 \times 10^{-14}}{0.200} = 8.70 \times 10^{-19}$$

$$[\text{H}^+] = 9.327 \times 10^{-10} \text{ mol dm}^{-3}$$

$$\text{pH} = 9.03$$

(g)  $\text{pH} = 7 + \frac{1}{2} \times 4.76 + \frac{1}{2} \log_{10} 0.200 = 9.03$

18. (a) (i) "Unlogging"  $pK_a$  gives  $K_a = 1.45 \times 10^{-11} \text{ mol dm}^{-3}$   
 $\text{C}_3\text{H}_7\text{NH}_3^+_{(\text{aq})} \rightleftharpoons \text{C}_3\text{H}_7\text{NH}_{2(\text{aq})} + \text{H}^+_{(\text{aq})}$   

$$K_a = \frac{[\text{C}_3\text{H}_7\text{NH}_2][\text{H}^+]}{[\text{C}_3\text{H}_7\text{NH}_3^+]} = 1.45 \times 10^{-11}$$

$$[\text{H}^+] = \frac{1.45 \times 10^{-11} \times [\text{C}_3\text{H}_7\text{NH}_3^+]}{[\text{C}_3\text{H}_7\text{NH}_2]}$$

$$[\text{C}_3\text{H}_7\text{NH}_3^+] = [\text{OH}^-] = \frac{1.00 \times 10^{-14}}{[\text{H}^+]}$$

$$[\text{C}_3\text{H}_7\text{NH}_2] = 0.0500 \text{ to a reasonable approximation}$$

$$[\text{H}^+] = \frac{1.45 \times 10^{-11}}{0.0500} \times \frac{1.00 \times 10^{-14}}{[\text{H}^+]}$$

$$[\text{H}^+]^2 = \frac{1.45 \times 10^{-11} \times 1.00 \times 10^{-14}}{0.0500} = 2.90 \times 10^{-24}$$

$$[\text{H}^+] = 1.703 \times 10^{-12} \text{ mol dm}^{-3}$$

pH = 11.8

(a) (ii)  $\text{pH} = 7 + \frac{1}{2}pK_a + \frac{1}{2}\log_{10}c = 7 + \frac{1}{2} \times 10.84 + \frac{1}{2}\log_{10}0.0500 = 11.8$

(b) (i) "Unlogging"  $pK_a$  gives  $K_a = 2.40 \times 10^{-5} \text{ mol dm}^{-3}$   
 $\text{C}_6\text{H}_5\text{NH}_3^+_{(\text{aq})} \rightleftharpoons \text{C}_6\text{H}_5\text{NH}_{2(\text{aq})} + \text{H}^+_{(\text{aq})}$   

$$K_a = \frac{[\text{C}_6\text{H}_5\text{NH}_2][\text{H}^+]}{[\text{C}_6\text{H}_5\text{NH}_3^+]} = 2.40 \times 10^{-5}$$

$$[\text{H}^+] = \frac{2.40 \times 10^{-5} \times [\text{C}_6\text{H}_5\text{NH}_3^+]}{[\text{C}_6\text{H}_5\text{NH}_2]}$$

$$[\text{C}_6\text{H}_5\text{NH}_3^+] = [\text{OH}^-] = \frac{1.00 \times 10^{-14}}{[\text{H}^+]}$$

$$[\text{C}_6\text{H}_5\text{NH}_2] = 0.00500 \text{ to a reasonable approximation}$$

$$[\text{H}^+] = \frac{2.40 \times 10^{-5}}{0.00500} \times \frac{1.00 \times 10^{-14}}{[\text{H}^+]}$$

$$[\text{H}^+]^2 = \frac{2.40 \times 10^{-5} \times 1.00 \times 10^{-14}}{0.00500}$$

$$= 4.80 \times 10^{-17}$$

$$[\text{H}^+] = 6.928 \times 10^{-9} \text{ mol dm}^{-3}$$

pH = 8.16

(b) (ii)  $\text{pH} = 7 + \frac{1}{2}pK_a + \frac{1}{2}\log_{10}c = 7 + \frac{1}{2} \times 4.62 + \frac{1}{2}\log_{10}0.00500 = 8.16$

19. Equilibrium concentrations are:  
 $[\text{C}_2\text{H}_5\text{COOH}] = 0.500 \text{ mol dm}^{-3}$ ;  $[\text{C}_2\text{H}_5\text{COO}^-] = 1.00 \text{ mol dm}^{-3}$ .  

$$K_a = \frac{[\text{C}_2\text{H}_5\text{COO}^-][\text{H}^+]}{[\text{C}_2\text{H}_5\text{COOH}]}$$

$$1.35 \times 10^{-5} = \frac{1.00 \times [\text{H}^+]}{0.500}$$

$$[\text{H}^+] = \frac{1.35 \times 10^{-5} \times 0.500}{1.00} = 6.75 \times 10^{-6} \text{ mol dm}^{-3}$$

pH = 5.17

20. RFM ethanoic acid = 60; RFM sodium ethanoate = 82.  
 Moles ethanoic acid in  $100 \text{ cm}^3 = 12.0/60 = 0.200$   
 Moles sodium ethanoate in  $100 \text{ cm}^3 = 4.10/82 = 0.0500$   
 $[\text{CH}_3\text{COOH}] = 2.00 \text{ mol dm}^{-3}$ ;  $[\text{CH}_3\text{COONa}] = 0.500 \text{ mol dm}^{-3}$ .

$$K_a = \frac{[\text{CH}_3\text{COO}^-][\text{H}^+]}{[\text{CH}_3\text{COOH}]}$$

$$1.74 \times 10^{-5} = \frac{0.500 \times [\text{H}^+]}{2.00}$$

$$[\text{H}^+] = \frac{1.74 \times 10^{-5} \times 2.00}{0.500} = 6.96 \times 10^{-5} \text{ mol dm}^{-3}$$

pH = 4.16

21. The methanoic acid has been diluted from  $20$  to  $100 \text{ cm}^3$  – by a factor of 5. The new concentration is therefore  $0.100/5 = 0.0200 \text{ mol dm}^{-3}$ .  
 The sodium methanoate has been diluted from  $80$  to  $100 \text{ cm}^3$ . Its concentration is now  $4/5$  of the original =  $0.0400 \text{ mol dm}^{-3}$ .

$$K_a = \frac{[\text{HCOO}^-][\text{H}^+]}{[\text{HCOOH}]}$$

$$1.78 \times 10^{-4} = \frac{0.0400 \times [\text{H}^+]}{0.0200}$$

$$[\text{H}^+] = \frac{1.78 \times 10^{-4} \times 0.0200}{0.0400} = 8.90 \times 10^{-5} \text{ mol dm}^{-3}$$

pH = 4.05

22. (a) "Unlogging"  $pK_a$  gives  $K_a = 1.51 \times 10^{-5} \text{ mol dm}^{-3}$

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

$$1.51 \times 10^{-5} = \frac{[\text{H}^+] \times 0.300}{0.500}$$

$$[\text{H}^+] = \frac{1.51 \times 10^{-5} \times 0.500}{0.300} = 2.517 \times 10^{-5} \text{ mol dm}^{-3}$$

pH = 4.60

- (b) Moles of  $\text{H}^+$  added =  $\frac{2.00}{1000} \times 5.00 = 0.0100$

This uses up  $0.0100 \text{ mol}$  of  $\text{A}^-$  ions and produces an extra  $0.0100 \text{ mol}$  of HA.

$$[\text{A}^-] = 0.290 \text{ mol dm}^{-3}$$
;  $[\text{HA}] = 0.510 \text{ mol dm}^{-3}$ .

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

$$1.51 \times 10^{-5} = \frac{[\text{H}^+] \times 0.290}{0.510}$$

$$[\text{H}^+] = \frac{1.51 \times 10^{-5} \times 0.510}{0.290} = 2.656 \times 10^{-5} \text{ mol dm}^{-3}$$

pH = 4.58

➤ If you prefer to do this differently, see page 209.

$$(c) \text{ Moles of OH}^- \text{ added} = \frac{2.00}{1000} \times 5.00 = 0.0100$$

This uses up 0.0100 mol of HA and produces an extra 0.0100 mol of A<sup>-</sup> ions.

$$[\text{HA}] = 0.490 \text{ mol dm}^{-3}; [\text{A}^-] = 0.310 \text{ mol dm}^{-3}$$

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

$$1.51 \times 10^{-5} = \frac{[\text{H}^+] \times 0.310}{0.490}$$

$$[\text{H}^+] = \frac{1.51 \times 10^{-5} \times 0.490}{0.310} = 2.387 \times 10^{-5} \text{ mol dm}^{-3}$$

$$\text{pH} = 4.62$$

23. "Unlogging" the pH gives  $[\text{H}^+] = 3.16 \times 10^{-4} \text{ mol dm}^{-3}$

$$K_a = \frac{[\text{HCOO}^-][\text{H}^+]}{[\text{HCOOH}]}$$

$$1.78 \times 10^{-4} = \frac{[\text{HCOO}^-] \times 3.16 \times 10^{-4}}{[\text{HCOOH}]}$$

$$\frac{[\text{HCOO}^-]}{[\text{HCOOH}]} = \frac{1.78 \times 10^{-4}}{3.16 \times 10^{-4}} = \frac{0.563}{1}$$

Since both solutions have the same concentration, they can be mixed in this ratio by volume.

24. (a) "Unlogging"  $\text{p}K_a$  gives  $K_a = 2.29 \times 10^{-11} \text{ mol dm}^{-3}$

On mixing, each solution is diluted by a factor of 2.

$$[\text{B}] = 0.500 \text{ mol dm}^{-3}; [\text{BH}^+] = [\text{BH}^+\text{Cl}^-] = 0.500 \text{ mol dm}^{-3}$$

$$K_a = \frac{[\text{B}][\text{H}^+]}{[\text{BH}^+]} = 2.29 \times 10^{-11}$$

$$[\text{H}^+] = \frac{2.29 \times 10^{-11} \times [\text{BH}^+]}{[\text{B}]} = \frac{2.29 \times 10^{-11} \times 0.500}{0.500} = 2.29 \times 10^{-11}$$

$$\text{pH} = 10.6$$

$$(b) (i) \text{ Moles of H}^+ \text{ added} = \frac{4.00}{1000} \times 5.00 = 0.0200$$

This uses up 0.0200 mol of B and produces an extra 0.0200 mol of BH<sup>+</sup>.

$$[\text{B}] = 0.480 \text{ mol dm}^{-3}; [\text{BH}^+] = 0.520 \text{ mol dm}^{-3}$$

$$K_a = \frac{[\text{B}][\text{H}^+]}{[\text{BH}^+]} = 2.29 \times 10^{-11}$$

$$[\text{H}^+] = \frac{2.29 \times 10^{-11} \times [\text{BH}^+]}{[\text{B}]} = \frac{2.29 \times 10^{-11} \times 0.520}{0.480} = 2.481 \times 10^{-11}$$

$$\text{pH} = 10.6$$

➤ The solution originally contained  $0.500 \text{ mol dm}^{-3}$  of each component, because the solutions were diluted by a factor of 2 on mixing.

$$(b) (ii) \text{ Moles of OH}^- \text{ added} = \frac{4.00}{1000} \times 5.00 = 0.0200$$

This uses up 0.0200 mol of BH<sup>+</sup> and produces an extra 0.0200 mol of B.

$$[\text{BH}^+] = 0.480 \text{ mol dm}^{-3}; [\text{B}] = 0.520 \text{ mol dm}^{-3}$$

$$K_a = \frac{[\text{B}][\text{H}^+]}{[\text{BH}^+]} = 2.29 \times 10^{-11}$$

$$[\text{H}^+] = \frac{2.29 \times 10^{-11} \times [\text{BH}^+]}{[\text{B}]} = \frac{2.29 \times 10^{-11} \times 0.480}{0.520} = 2.114 \times 10^{-11}$$

$$\text{pH} = 10.7$$

(c) "Unlogging" the pH gives  $[\text{H}^+] = 3.16 \times 10^{-11} \text{ mol dm}^{-3}$ .

$$K_a = \frac{[\text{B}][\text{H}^+]}{[\text{BH}^+]} = 2.29 \times 10^{-11}$$

$$\frac{[\text{B}]}{[\text{BH}^+]} = \frac{2.29 \times 10^{-11}}{3.16 \times 10^{-11}} = \frac{0.725}{1}$$

Because the concentrations of the two solutions are the same, they can be mixed in this ratio by volume.

$$25. (a) (i) 2.59 \quad (ii) 0.07 \quad (iii) 11.1$$

$$(b) (i) 0.0123 \text{ mol dm}^{-3} \quad (ii) 3.98 \times 10^{-7} \text{ mol dm}^{-3} \\ (iii) 5.01 \times 10^{-15} \text{ mol dm}^{-3}$$

$$26. (a) 0.30 \quad (b) 1.40$$

$$27. (a) 0.0631 \text{ mol dm}^{-3} \quad (b) 0.50 \text{ mol dm}^{-3} \quad (c) 0.5 \text{ mol dm}^{-3}$$

$$28. 7.08$$

$$29. (a) 13 \quad (b) 12.3$$

$$30. (a) 2.00 \text{ mol dm}^{-3} \quad (b) 5.00 \times 10^{-4} \text{ mol dm}^{-3}$$

$$31. (a) 0.70 \quad (b) 13.8 \quad (c) 7.00$$

$$32. (a) 3.23 \quad (b) 3.41 \quad (c) 1.58$$

$$33. 4.63$$

$$34. (a) \text{ Assuming you haven't made any approximations, } \text{p}K_a = 3.23 \quad (b) 9.30$$

$$35. 5.00$$

$$36. 4.0$$

$$37. (a) 11.6 \quad (b) 12.1 \quad (c) 10.3$$

$$38. 9.38$$

39. (a) 4.86 (b) 4.23 (c) 8.95 (d) 10.6  
 40. (a) 4.76 (b) 4.75 (c) 4.77  
 41. (a) Mix sodium ethanoate and ethanoic acid solutions in the ratio 0.550:1.  
 (b) Mix ammonium chloride and ammonia solutions in the ratio 0.562:1.

### Chapter 9

1.  $\text{AgBr}_{(s)} \rightleftharpoons \text{Ag}^+_{(aq)} + \text{Br}^-_{(aq)}$   
 Each mole of silver bromide that dissolves gives 1 mole of each ion in solution.  
 $[\text{Ag}^+_{(aq)}] = 8.8 \times 10^{-7} \text{ mol dm}^{-3}$   
 $[\text{Br}^-_{(aq)}] = 8.8 \times 10^{-7} \text{ mol dm}^{-3}$   
 $K_{sp} = [\text{Ag}^+][\text{Br}^-] = (8.8 \times 10^{-7})^2 = 7.7 \times 10^{-13} \text{ mol}^2 \text{ dm}^{-6}$
2. RFM of  $\text{MgCO}_3 = 84$   
 Solubility =  $0.27/84 \text{ mol dm}^{-3} = 3.21 \times 10^{-3} \text{ mol dm}^{-3}$   
 $\text{MgCO}_{3(s)} \rightleftharpoons \text{Mg}^{2+}_{(aq)} + \text{CO}_3^{2-}_{(aq)}$   
 Each mole of magnesium carbonate that dissolves gives 1 mole of each ion in solution.  
 $[\text{Mg}^{2+}_{(aq)}] = 3.21 \times 10^{-3} \text{ mol dm}^{-3}$   
 $[\text{CO}_3^{2-}_{(aq)}] = 3.21 \times 10^{-3} \text{ mol dm}^{-3}$   
 $K_{sp} = [\text{Mg}^{2+}][\text{CO}_3^{2-}] = (3.21 \times 10^{-3})^2 = 1.0 \times 10^{-5} \text{ mol}^2 \text{ dm}^{-6}$
3.  $\text{Al}(\text{OH})_{3(s)} \rightleftharpoons \text{Al}^{3+}_{(aq)} + 3\text{OH}^-_{(aq)}$   
 Each mole of aluminium hydroxide which dissolves gives 1 mole of  $\text{Al}^{3+}_{(aq)}$  and 3 moles of  $\text{OH}^-_{(aq)}$  in solution.  
 $[\text{Al}^{3+}_{(aq)}] = 2.5 \times 10^{-9} \text{ mol dm}^{-3}$   
 $[\text{OH}^-_{(aq)}] = 3 \times 2.5 \times 10^{-9} = 7.5 \times 10^{-9} \text{ mol dm}^{-3}$   
 $K_{sp} = [\text{Al}^{3+}][\text{OH}^-]^3 = 2.5 \times 10^{-9} \times (7.5 \times 10^{-9})^3 = 1.1 \times 10^{-33} \text{ mol}^4 \text{ dm}^{-12}$
4. RFM of  $\text{PbI}_2 = 461$   
 Solubility =  $0.29/461 \text{ mol dm}^{-3} = 6.29 \times 10^{-4} \text{ mol dm}^{-3}$   
 $\text{PbI}_{2(s)} \rightleftharpoons \text{Pb}^{2+}_{(aq)} + 2\text{I}^-_{(aq)}$   
 Each mole of lead(II) iodide which dissolves gives 1 mole of  $\text{Pb}^{2+}_{(aq)}$  and 2 moles of  $\text{I}^-_{(aq)}$  in solution.  
 $[\text{Pb}^{2+}_{(aq)}] = 6.29 \times 10^{-4} \text{ mol dm}^{-3}$   
 $[\text{I}^-] = 2 \times 6.29 \times 10^{-4} = 1.258 \times 10^{-3} \text{ mol dm}^{-3}$   
 $K_{sp} = [\text{Pb}^{2+}][\text{I}^-]^2$   
 $= 6.29 \times 10^{-4} \times (1.258 \times 10^{-3})^2$   
 $= 1.0 \times 10^{-9} \text{ mol}^3 \text{ dm}^{-9}$

➤ Your calculator will give you an answer of 9.95 (etc.)  $\times 10^{-10}$ . This rounds to  $1.0 \times 10^{-9}$  to 2 significant figures.

5.  $\text{Ag}_2\text{SO}_{4(s)} \rightleftharpoons 2\text{Ag}^+_{(aq)} + \text{SO}_4^{2-}_{(aq)}$   
 Each mole of silver(I) sulphate which dissolves gives 2 moles of  $\text{Ag}^+_{(aq)}$  and 1 mole of  $\text{SO}_4^{2-}_{(aq)}$ .  
 $[\text{Ag}^+_{(aq)}] = 2 \times 0.016 = 0.032 \text{ mol dm}^{-3}$   
 $[\text{SO}_4^{2-}_{(aq)}] = 0.016 \text{ mol dm}^{-3}$   
 $K_{sp} = [\text{Ag}^+]^2[\text{SO}_4^{2-}]$   
 $= (0.032)^2 \times 0.016$   
 $= 1.6 \times 10^{-5} \text{ mol}^3 \text{ dm}^{-9}$
6. (a)  $\text{BaCO}_{3(s)} \rightleftharpoons \text{Ba}^{2+}_{(aq)} + \text{CO}_3^{2-}_{(aq)}$   
 (i) Let the solubility of barium carbonate be " $s$ "  $\text{mol dm}^{-3}$ .  
 Each mole of barium carbonate that dissolves gives 1 mole of each ion in solution.  
 $[\text{Ba}^{2+}_{(aq)}] = s \text{ mol dm}^{-3}$   
 $[\text{CO}_3^{2-}_{(aq)}] = s \text{ mol dm}^{-3}$   
 $K_{sp} = [\text{Ba}^{2+}][\text{CO}_3^{2-}]$   
 $5.1 \times 10^{-9} = s^2$   
 $s = 7.1(4) \times 10^{-5} \text{ mol dm}^{-3}$   
 (ii) 1 mole of  $\text{BaCO}_3$  weighs 197 g.  
 Solubility =  $7.14 \times 10^{-5} \times 197 \text{ g dm}^{-3} = 0.014 \text{ g dm}^{-3}$
- (b)  $\text{Ca}(\text{OH})_{2(s)} \rightleftharpoons \text{Ca}^{2+}_{(aq)} + 2\text{OH}^-_{(aq)}$   
 (i) Let the solubility of calcium hydroxide be " $s$ "  $\text{mol dm}^{-3}$ .  
 Each mole of calcium hydroxide that dissolves gives 1 mole of  $\text{Ca}^{2+}_{(aq)}$  and 2 moles of  $\text{OH}^-_{(aq)}$  in solution.  
 $[\text{Ca}^{2+}_{(aq)}] = s \text{ mol dm}^{-3}$   
 $[\text{OH}^-_{(aq)}] = 2s \text{ mol dm}^{-3}$   
 $K_{sp} = [\text{Ca}^{2+}][\text{OH}^-]^2$   
 $5.5 \times 10^{-6} = s \times (2s)^2$   
 $4s^3 = 5.5 \times 10^{-6}$   
 $s = 0.011(1) \text{ mol dm}^{-3}$   
 (ii) 1 mole of  $\text{Ca}(\text{OH})_2$  weighs 74 g.  
 Solubility =  $0.0111 \times 74 \text{ g dm}^{-3} = 0.82 \text{ g dm}^{-3}$
- (c)  $\text{Al}(\text{OH})_{3(s)} \rightleftharpoons \text{Al}^{3+}_{(aq)} + 3\text{OH}^-_{(aq)}$   
 (i) Let the solubility of aluminium hydroxide be " $s$ "  $\text{mol dm}^{-3}$ .  
 Each mole of aluminium hydroxide that dissolves gives 1 mole of  $\text{Al}^{3+}_{(aq)}$  and 3 moles of  $\text{OH}^-_{(aq)}$  in solution.  
 $[\text{Al}^{3+}_{(aq)}] = s \text{ mol dm}^{-3}$   
 $[\text{OH}^-_{(aq)}] = 3s \text{ mol dm}^{-3}$

➤ Your answer should only be quoted to 2 significant figures because this is the accuracy of the solubility product. However, if you carry on with the calculation using this 2 sig fig result you could introduce rounding errors into your final answer. The easiest way is to quote your first answer to 2 sig figs, but use the number which is still on your calculator to complete the calculation.

$$K_{sp} = [\text{Al}^{3+}][\text{OH}^-]^3$$

$$1.0 \times 10^{-33} = s \times (3s)^3$$

$$27s^4 = 1.0 \times 10^{-33}$$

$$s = 2.5 \times 10^{-9} \text{ mol dm}^{-3} \quad (2.47 \times 10^{-9} \text{ mol dm}^{-3})$$

(ii) 1 mole of  $\text{Al}(\text{OH})_3$  weighs 78 g.

$$\text{Solubility} = 2.47 \times 10^{-9} \times 78 \text{ g dm}^{-3} = 1.9 \times 10^{-7} \text{ g dm}^{-3}$$

(d)  $\text{Sb}_2\text{S}_3(s) \rightleftharpoons 2\text{Sb}^{3+}_{(aq)} + 3\text{S}^{2-}_{(aq)}$

(i) Let the solubility of antimony(III) sulphide be " $s$ "  $\text{mol dm}^{-3}$ . Each mole of antimony(III) sulphide that dissolves gives 2 moles of  $\text{Sb}^{3+}_{(aq)}$  and 3 moles of  $\text{S}^{2-}_{(aq)}$  in solution.

$$[\text{Sb}^{3+}_{(aq)}] = 2s \text{ mol dm}^{-3}$$

$$[\text{S}^{2-}_{(aq)}] = 3s \text{ mol dm}^{-3}$$

$$K_{sp} = [\text{Sb}^{3+}]^2[\text{S}^{2-}]^3$$

$$1.7 \times 10^{-93} = (2s)^2 \times (3s)^3$$

$$4s^2 \times 27s^3 = 1.7 \times 10^{-93}$$

$$108s^5 = 1.7 \times 10^{-93}$$

$$s = 1.1 \times 10^{-19} \text{ mol dm}^{-3} \quad (1.09 \times 10^{-19} \text{ mol dm}^{-3})$$

(ii) 1 mole of  $\text{Sb}_2\text{S}_3$  weighs 340 g.

$$\text{Solubility} = 1.09 \times 10^{-19} \times 340 \text{ g dm}^{-3} = 3.7 \times 10^{-17} \text{ g dm}^{-3}$$

7. Let the solubility of lead(II) sulphate be " $s$ "  $\text{mol dm}^{-3}$ .

Each mole of lead(II) sulphate produces 1 mole of  $\text{Pb}^{2+}_{(aq)}$  ions in solution.

$$[\text{Pb}^{2+}_{(aq)}] = s \text{ mol dm}^{-3}$$

Virtually all the sulphate ions will be coming from the sodium sulphate solution.

$$[\text{SO}_4^{2-}_{(aq)}] = 0.10 \text{ mol dm}^{-3}$$

$$K_{sp} = [\text{Pb}^{2+}][\text{SO}_4^{2-}]$$

$$1.6 \times 10^{-8} = s \times 0.10$$

$$s = 1.6 \times 10^{-7} \text{ mol dm}^{-3}$$

8.  $\text{Ag}_2\text{SO}_4(s) \rightleftharpoons 2\text{Ag}^+_{(aq)} + \text{SO}_4^{2-}_{(aq)}$

Let the solubility of silver(I) sulphate be " $s$ "  $\text{mol dm}^{-3}$ .

Each mole of silver(I) sulphate which dissolves gives 2 moles of  $\text{Ag}^+_{(aq)}$  and 1 mole of  $\text{SO}_4^{2-}_{(aq)}$ .

(a)  $[\text{Ag}^+_{(aq)}] = 2s \text{ mol dm}^{-3}$

$$[\text{SO}_4^{2-}_{(aq)}] = s \text{ mol dm}^{-3}$$

$$K_{sp} = [\text{Ag}^+]^2[\text{SO}_4^{2-}]$$

$$1.6 \times 10^{-5} = (2s)^2 \times s$$

$$4s^3 = 1.6 \times 10^{-5}$$

$$s = 0.016 \text{ mol dm}^{-3}$$

(b) Virtually all the silver ions will be coming from the silver(I) nitrate solution.

$$[\text{Ag}^+_{(aq)}] = 0.10 \text{ mol dm}^{-3}$$

The concentration of the sulphate ions will be the same as the dissolved silver(I) sulphate.

$$[\text{SO}_4^{2-}_{(aq)}] = s \text{ mol dm}^{-3}$$

$$K_{sp} = [\text{Ag}^+]^2[\text{SO}_4^{2-}]$$

$$1.6 \times 10^{-5} = (0.10)^2 \times s$$

$$s = 1.6 \times 10^{-3} \text{ mol dm}^{-3}$$

(c) As in part (a) the silver ion concentration will be twice that of the dissolved silver(I) sulphate.

$$[\text{Ag}^+_{(aq)}] = 2s \text{ mol dm}^{-3}$$

Virtually all the sulphate ions will be coming from the sulphuric acid.

$$[\text{SO}_4^{2-}_{(aq)}] = 0.50 \text{ mol dm}^{-3}$$

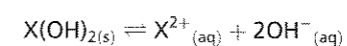
$$K_{sp} = [\text{Ag}^+]^2[\text{SO}_4^{2-}]$$

$$1.6 \times 10^{-5} = (2s)^2 \times 0.50$$

$$4s^2 \times 0.50 = 1.6 \times 10^{-5}$$

$$s = 2.8 \times 10^{-3} \text{ mol dm}^{-3}$$

9. In every case, you need to consider the solubility of  $\text{X}(\text{OH})_2$ :



$$K_{sp} = [\text{X}^{2+}][\text{OH}^-]^2$$

With ammonia solution,  $[\text{OH}^-_{(aq)}] = 2.1 \times 10^{-3} \text{ mol dm}^{-3}$ , because the original ammonia is diluted by a factor of 2 when the two solutions are mixed.

$[\text{X}^{2+}_{(aq)}]$  is also half of what it was originally for the same reason.

$$[\text{X}^{2+}_{(aq)}] = 0.050 \text{ mol dm}^{-3}$$

Multiplying these ion concentrations together in the same way as the solubility product expression gives:

$$0.050 \times (2.1 \times 10^{-3})^2 = 2.2 \times 10^{-7} \text{ mol}^3 \text{ dm}^{-9}$$

If this number is bigger than the solubility product you will get a precipitate as the excess ions are removed from solution. If this number is smaller than the solubility product, equilibrium has not been reached and so no precipitate will form. Comparing the numbers given, only magnesium hydroxide will form a precipitate.

With sodium hydroxide solution,  $[\text{OH}^-_{(aq)}] = 0.50 \text{ mol dm}^{-3}$ , because the original solution is diluted by a factor of 2 when the two solutions are mixed.

Once again,  $[\text{X}^{2+}_{(aq)}] = 0.050 \text{ mol dm}^{-3}$

Multiplying these ion concentrations together in the same way as the solubility product expression gives:

$$0.050 \times (0.50)^2 = 0.0125 \text{ mol}^3 \text{ dm}^{-9}$$

This number is bigger than all the solubility product values, and so you will get a precipitate in each case.

10. The ethoxyethane contains 0.80 g of X in 25 cm<sup>3</sup>:  
 concentration of X in ethoxyethane =  $\frac{0.80}{25} = 0.032 \text{ g cm}^{-3}$   
 The water contains (1.0 - 0.80) g in 100 cm<sup>3</sup>:  
 concentration of X in water =  $\frac{0.20}{100} = 0.0020 \text{ g cm}^{-3}$   
 $K_c = \frac{\text{concentration of X in ethoxyethane}}{\text{concentration of X in water}} = \frac{0.032}{0.0020} = 16$

11. (a) Aqueous layer:  
 Number of moles of HCl =  $\frac{26.0}{1000} \times 1.00$   
 = 0.0260  
 The equation shows that the ammonia and HCl react 1:1.  
 Number of moles of NH<sub>3</sub> = 0.0260 (in 25.0 cm<sup>3</sup>)  
 $[\text{NH}_3] = \frac{1000}{25.0} \times 0.0260$   
 = 1.04 mol dm<sup>-3</sup>
- (b) CHCl<sub>3</sub> layer:  
 Number of moles of HCl =  $\frac{8.40}{1000} \times 0.0500 = 4.20 \times 10^{-4}$   
 The equation shows that the ammonia and HCl react 1:1.  
 Number of moles of NH<sub>3</sub> = 4.20 × 10<sup>-4</sup> (in 10.0 cm<sup>3</sup>)  
 $[\text{NH}_3] = \frac{1000}{10.0} \times 4.20 \times 10^{-4} = 0.0420 \text{ mol dm}^{-3}$

(c) The partition coefficient:

$$K_c = \frac{[\text{NH}_3 \text{ in H}_2\text{O}]}{[\text{NH}_3 \text{ in CHCl}_3]} = \frac{1.04}{0.0420} = 24.8$$

12.  $\frac{\text{concentration of X in ether}}{\text{concentration of X in water}} = \frac{20.0}{1}$   
 $\frac{\text{mass of X in ether/volume of ether}}{\text{mass of X in water/volume of water}} = \frac{20.0}{1}$   
 $\frac{\text{mass of X in ether}}{\text{volume of ether}} \times \frac{\text{volume of water}}{\text{mass of X in water}} = \frac{20.0}{1}$

(a) Substituting volumes:

$$\frac{\text{mass of X in ether}}{30.0} \times \frac{200}{\text{mass of X in water}} = \frac{20.0}{1}$$

$$\frac{\text{mass of X in ether}}{\text{mass of X in water}} = \frac{600}{200} = \frac{3}{1}$$

Of every 4 parts of X, 1 part remains in the water and 3 parts transfer to the ether.

$$\text{Mass remaining in the water} = 1/4 \times 3.00 \text{ g} = 0.75 \text{ g}$$

(b) Substituting volumes for one extraction:

$$\frac{\text{mass of X in ether}}{15.0} \times \frac{200}{\text{mass of X in water}} = \frac{20.0}{1}$$

$$\frac{\text{mass of X in ether}}{\text{mass of X in water}} = \frac{300}{200} = \frac{3}{2}$$

For every 5 parts of X, 2 parts remain in the water after each extraction.

$$\text{Mass remaining after 1 extraction} = 2/5 \times 3.00 \text{ g}$$

$$\text{Mass remaining after 2 extractions} = 2/5 \times 2/5 \times 3.00 \text{ g} = 0.48 \text{ g}$$

(c) Substituting volumes for one extraction:

$$\frac{\text{mass of X in ether}}{10.0} \times \frac{200}{\text{mass of X in water}} = \frac{20.0}{1}$$

$$\frac{\text{mass of X in ether}}{\text{mass of X in water}} = \frac{200}{200} = \frac{1}{1}$$

This time, half of X remains in the water after each extraction.

$$\text{Mass remaining after 1 extraction} = 1/2 \times 3.00 \text{ g}$$

$$\text{Mass remaining after 2 extractions} = 1/2 \times 1/2 \times 3.00 \text{ g}$$

$$\text{Mass remaining after 3 extractions} = 1/2 \times 1/2 \times 1/2 \times 3.00 \text{ g} = 0.375 \text{ g}$$

13. 1 volume of water dissolves 0.25 volumes of ethene if the partial pressure of ethene is 1 atm. At a pressure of 2.0 atm, 1 volume of water will dissolve 2.0 × 0.25 volumes of ethene = 0.50 volumes  
 100 cm<sup>3</sup> of water will dissolve 0.50 × 100 cm<sup>3</sup> of ethene = 50 cm<sup>3</sup>.

14. Mole fractions of both CO and CO<sub>2</sub> are 0.50.

$$\text{Partial pressures of both} = 0.50 \times 0.80 \text{ atm} = 0.40 \text{ atm.}$$

If the partial pressure of CO was 1 atm, 1 dm<sup>3</sup> of water would dissolve 0.035 dm<sup>3</sup> of CO.

At the lower partial pressure of 0.40 atm, it will dissolve 0.40 × 0.035 dm<sup>3</sup> = 0.014 dm<sup>3</sup>.

If the partial pressure of CO<sub>2</sub> was 1 atm, 1 dm<sup>3</sup> of water would dissolve 1.71 dm<sup>3</sup> of CO<sub>2</sub>.

At the lower partial pressure of 0.40 atm, it will dissolve 0.40 × 1.71 dm<sup>3</sup> = 0.68 dm<sup>3</sup>.

➤ Only 2 significant figures.

15. (a) Mole fractions: N<sub>2</sub>: 0.78      O<sub>2</sub>: 0.21      Ar: 0.0093  
 Partial pressures: N<sub>2</sub>: 0.78 × 0.97      O<sub>2</sub>: 0.21 × 0.97      Ar: 0.0093 × 0.97  
 = 0.757 atm      = 0.204 atm      = 9.02 × 10<sup>-3</sup> atm  
 Volumes dissolved in 1.0 m<sup>3</sup>:  
 N<sub>2</sub>: 0.757 × 0.024 = 0.018 m<sup>3</sup> (0.0182 m<sup>3</sup> for use in part (b))  
 O<sub>2</sub>: 0.204 × 0.049 = 0.010 m<sup>3</sup> (0.0100 m<sup>3</sup> for use in part (b))  
 Ar: 9.02 × 10<sup>-3</sup> × 0.056 = 5.1 × 10<sup>-4</sup> m<sup>3</sup> (5.05 × 10<sup>-4</sup> m<sup>3</sup> for use in part (b))

- (b) Total volume of dissolved gases =  $0.0182 + 0.0100 + 5.05 \times 10^{-4} \text{ m}^3$   
 $= 0.0287 \text{ m}^3$   
 %  $\text{N}_2 = 0.0182/0.0287 \times 100 = 63\%$   
 %  $\text{O}_2 = 0.0100/0.0287 \times 100 = 35\%$   
 %  $\text{Ar} = (5.05 \times 10^{-4})/0.0287 \times 100 = 1.8\%$
16. (a)  $4.8 \times 10^{-10} \text{ mol}^2 \text{ dm}^{-6}$  (b)  $1.8 \times 10^{-10} \text{ mol}^2 \text{ dm}^{-6}$   
 (c)  $5.3 \times 10^{-6} \text{ mol}^3 \text{ dm}^{-9}$  (d)  $1.3 \times 10^{-21} \text{ mol}^4 \text{ dm}^{-12}$
17. (a)  $3.2 \times 10^{-3} \text{ mol dm}^{-3}$  (b)  $2.4 \times 10^{-16} \text{ g dm}^{-3}$   
 (c)  $1.2 \times 10^{-6} \text{ mol dm}^{-3}$  (d)  $2.9 \times 10^{-15} \text{ g dm}^{-3}$
18.  $3.2 \times 10^{-6} \text{ mol dm}^{-3}$
19.  $7.9 \times 10^{-14} \text{ mol dm}^{-3}$
20.  $8.9 \times 10^{-3} \text{ mol dm}^{-3}$
21. Yes.  $[\text{Ag}^+][\text{Cl}^-]$  on mixing is  $2.5 \times 10^{-7}$ , which is greater than the solubility product.
22. No.  $[\text{Mg}^{2+}][\text{CO}_3^{2-}]$  on mixing is  $8 \times 10^{-6}$ , which is less than the solubility product.
23. 75
24. (a) In ether,  $[\text{HA}] = 0.16 \text{ mol dm}^{-3}$ ; in water,  $[\text{HA}] = 0.080 \text{ mol dm}^{-3}$  (b) 2.0
25. (a) 2.00 g (b) 0.625 g
26. (a)  $1.9 \text{ cm}^3$  (b)  $0.86 \text{ cm}^3$
27. 98%
28. (a)  $1.9 \text{ dm}^3$  (b)  $5.1 \times 10^{-4} \text{ dm}^3$

## Chapter 10

1. In each of these questions,  
 $E^\ominus_{\text{cell}} = E^\ominus$  of right hand electrode  $- E^\ominus$  of left hand electrode
- (a)  $E^\ominus_{\text{cell}} = -0.40 - (-1.66) = +1.26 \text{ volts}$   
 (b)  $E^\ominus_{\text{cell}} = +0.34 - (+0.80) = -0.46 \text{ volts}$   
 (c)  $E^\ominus_{\text{cell}} = +1.36 - (+0.77) = +0.59 \text{ volts}$

2. In each of these questions,  
 $E^\ominus_{\text{cell}} = E^\ominus$  of right hand electrode  $- E^\ominus$  of left hand electrode
- (a)  $-0.49 = e - (-0.25)$   $e = -0.74 \text{ volts}$   
 (b)  $-2.11 = -2.37 - e$   $e = -0.26 \text{ volts}$   
 (c)  $+0.79 = -0.40 - e$   $e = -1.19 \text{ volts}$
3. (a) The two equilibria involved are:  
 $\text{Co}^{2+}_{(\text{aq})} + 2e^- \rightleftharpoons \text{Co}_{(\text{s})}$   $E^\ominus = -0.28 \text{ volts}$   
 $\text{Al}^{3+}_{(\text{aq})} + 3e^- \rightleftharpoons \text{Al}_{(\text{s})}$   $E^\ominus = -1.66 \text{ volts}$
- Either the more negative equilibrium will move to the left; the more positive (less negative) to the right. Since you are starting from Al and  $\text{Co}^{2+}$ , those movements are possible and so the reaction is feasible.
- Or calculate  $E^\ominus_{\text{cell}}$  for the cell with the equilibrium you want to move to the right as the right hand electrode. You want the cobalt equilibrium to move right:  
 $E^\ominus_{\text{cell}} = -0.28 - (-1.66) \text{ volts} = +1.38 \text{ volts}$   
 A positive answer shows the reaction is feasible.
- (b) The two equilibria involved are:  
 $\text{Na}^{+}_{(\text{aq})} + e^- \rightleftharpoons \text{Na}_{(\text{s})}$   $E^\ominus = -2.71 \text{ volts}$   
 $\text{Mg}^{2+}_{(\text{aq})} + 2e^- \rightleftharpoons \text{Mg}_{(\text{s})}$   $E^\ominus = -2.37 \text{ volts}$
- Either the more negative equilibrium will move to the left; the more positive (less negative) to the right. Since you are starting from  $\text{Na}^+$  and Mg, no movements are possible and so the reaction is not feasible.
- Or calculate  $E^\ominus_{\text{cell}}$  for the cell with the equilibrium you want to move to the right as the right hand electrode. You want the sodium equilibrium to move right:  
 $E^\ominus_{\text{cell}} = -2.71 - (-2.37) \text{ volts} = -0.34 \text{ volts}$   
 A negative answer shows the reaction is not feasible.
- (c) The two equilibria involved are:  
 $\text{Br}_{2(\text{l})} + 2e^- \rightleftharpoons 2\text{Br}^{-}_{(\text{aq})}$   $E^\ominus = +1.07 \text{ volts}$   
 $\text{Cl}_{2(\text{g})} + 2e^- \rightleftharpoons 2\text{Cl}^{-}_{(\text{aq})}$   $E^\ominus = +1.36 \text{ volts}$
- Either the more negative (less positive) equilibrium will move to the left; the more positive to the right. Since you are starting from  $\text{Br}^-$  and  $\text{Cl}_2$ , movement is possible and so the reaction is feasible.
- Or calculate  $E^\ominus_{\text{cell}}$  for the cell with the equilibrium you want to move to the right as the right hand electrode. You want the chlorine equilibrium to move right:  
 $E^\ominus_{\text{cell}} = +1.36 - (+1.07) \text{ volts} = +0.29 \text{ volts}$   
 A positive answer shows the reaction is feasible.
- (d) The two equilibria involved are:  
 $\text{Fe}^{3+}_{(\text{aq})} + e^- \rightleftharpoons \text{Fe}^{2+}_{(\text{aq})}$   $E^\ominus = +0.77 \text{ volts}$   
 $\text{Cl}_{2(\text{g})} + 2e^- \rightleftharpoons 2\text{Cl}^{-}_{(\text{aq})}$   $E^\ominus = +1.36 \text{ volts}$



Either: the more negative (less positive) equilibrium will move to the left; the more positive to the right. Since you are starting from  $\text{Fe}^{2+}$  and  $\text{Cl}_2$ , movement is possible and so the reaction is feasible.

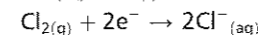
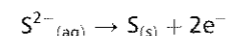
Or calculate  $E^\ominus_{\text{cell}}$  for the cell with the equilibrium you want to move to the right as the right hand electrode. You want the chlorine equilibrium to move right:

$$E^\ominus_{\text{cell}} = +1.36 - (+0.77) \text{ volts} = +0.59 \text{ volts}$$

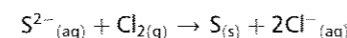
A positive answer shows the reaction is feasible.

4. Work out the feasibility using either of the methods above.

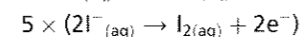
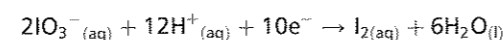
(a) Feasible. (The more positive equilibrium moves to the right, the negative one to the left, which is what you need to happen.)



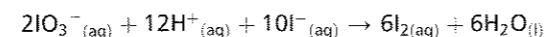
Combining:



(b) Feasible. (The more positive equilibrium moves to the right, the less positive (more negative) one to the left, which is what you need to happen.)



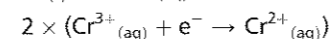
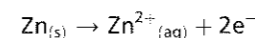
Combining:



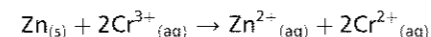
(Note that this should ideally be divided by 2 to simplify it.)

(c) Not feasible. (You want the silver equilibrium to move to the left, which needs it to have the more negative  $E^\ominus$  value.)

(d) Feasible. (The zinc equilibrium is more negative and so will move to the left, while the chromium equilibrium moves right – which is what you want.)



Combining:

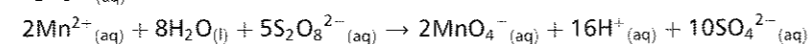


5. (a) -1.10 volts (b) +1.18 volts (c) -2.11 volts

6. (a) -1.66 volts (b) -0.25 volts

7. (a) feasible (b) not feasible (c) not feasible (d) feasible

8.  $\text{S}_2\text{O}_8^{2-}_{(\text{aq})}$



9. Yes:  $\text{Cr}^{2+}_{(\text{aq})} + \text{V}^{3+}_{(\text{aq})} \rightarrow \text{Cr}^{3+}_{(\text{aq})} + \text{V}^{2+}_{(\text{aq})}$

10. Yes:  $3\text{Fe}^{2+}_{(\text{aq})} + \text{NO}_3^-_{(\text{aq})} + 4\text{H}^+_{(\text{aq})} \rightarrow 3\text{Fe}^{3+}_{(\text{aq})} + \text{NO}_{(\text{g})} + 2\text{H}_2\text{O}_{(\text{l})}$

11. No

12. Blue

## Chapter 11

- Decrease. (System becomes less disordered as 3 moles of assorted gases form 2 moles of liquid.)
  - Increase. (Increase in disorder mainly due to gas being produced.)
  - Decrease. (Less disorder mainly due to loss of gas.)
  - Increase. (Increase in disorder mainly due to gas and liquid being produced from solids.)
- |                      |                              |  |
|----------------------|------------------------------|--|
| Entropy of products  | $= (2 \times 152.1) + 205.0$ | $= 509.2 \text{ JK}^{-1} \text{ mol}^{-1}$ |
| Entropy of reactants | $= (2 \times 133.1)$         | $= 266.2 \text{ JK}^{-1} \text{ mol}^{-1}$ |
| Entropy change       | $= 509.2 - 266.2$            | $= +243 \text{ JK}^{-1} \text{ mol}^{-1}$  |
  - |                      |  |   |
|----------------------|--|---|
| Entropy of products  | $= 146.4 \text{ JK}^{-1} \text{ mol}^{-1}$ |   |
| Entropy of reactants | $= (3 \times 27.3) + (2 \times 205.0)$     | $= 491.9 \text{ JK}^{-1} \text{ mol}^{-1}$  |
| Entropy change       | $= 146.4 - 491.9$                          | $= -345.5 \text{ JK}^{-1} \text{ mol}^{-1}$ |
  - |                      |  |   |
|----------------------|--|---|
| Entropy of products  | $= 106.7 + (2 \times 192.3) + (2 \times 69.9)$ | $= 631.1 \text{ JK}^{-1} \text{ mol}^{-1}$  |
| Entropy of reactants | $= 220.1 + 83.4$                               | $= 303.5 \text{ JK}^{-1} \text{ mol}^{-1}$  |
| Entropy change       | $= 631.1 - 303.5$                              | $= +327.6 \text{ JK}^{-1} \text{ mol}^{-1}$ |
- $$\Delta S_{\text{surroundings}} = \frac{-\Delta H}{T} = \frac{-(-65\,000)}{298} = +218.1 \text{ JK}^{-1} \text{ mol}^{-1}$$
  - |                            |   |  |
|----------------------------|---|--|
| Entropy of products        | $= 83.4 \text{ JK}^{-1} \text{ mol}^{-1}$ |  |
| Entropy of reactants       | $= 39.7 + 69.9$                           | $= 109.6 \text{ JK}^{-1} \text{ mol}^{-1}$ |
| $\Delta S_{\text{system}}$ | $= 83.4 - 109.6$                          | $= -26.2 \text{ JK}^{-1} \text{ mol}^{-1}$ |
  - $$\Delta S_{\text{total}} = \Delta S_{\text{surroundings}} + \Delta S_{\text{system}} = +218.1 - 26.2 = +191.9 \text{ JK}^{-1} \text{ mol}^{-1}$$

A positive  $\Delta S_{\text{total}}$  shows the reaction is feasible.
- 

$$\Delta H + 2(-286) = -450$$

$$\Delta H = +122 \text{ kJ mol}^{-1}$$

$$(b) \Delta S_{\text{surroundings}} = \frac{-\Delta H}{T} = \frac{-122\,000}{373} = -327.1 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$(c) \text{Entropy of products} = 75.0 + 130.6 = 205.6 \text{ J K}^{-1} \text{ mol}^{-1}$$

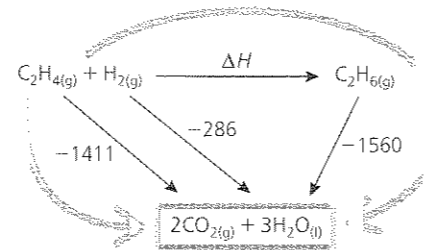
$$\text{Entropy of reactants} = 33.2 + (2 \times 69.9) = 173.0 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\Delta S_{\text{system}} = 205.6 - 173.0 = +32.6 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$(d) \Delta S_{\text{total}} = \Delta S_{\text{surroundings}} + \Delta S_{\text{system}} = -327.1 + 32.6 = -294.5 \text{ J K}^{-1} \text{ mol}^{-1}$$

A negative  $\Delta S_{\text{total}}$  shows the reaction is not feasible.

5. (a)



$$\Delta H - 1560 = -1411 - 286$$

$$\Delta H = -137 \text{ kJ mol}^{-1}$$

$$(b) \Delta S_{\text{surroundings}} = \frac{-\Delta H}{T} = \frac{-(-137\,000)}{273} = +501.8 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$(c) \text{Entropy of products} = 229.5 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\text{Entropy of reactants} = 219.5 + 130.6 = 350.1 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\Delta S_{\text{system}} = 229.5 - 350.1 = -120.6 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$(d) \Delta S_{\text{total}} = \Delta S_{\text{surroundings}} + \Delta S_{\text{system}} = +501.8 - 120.6 = +381.2 \text{ J K}^{-1} \text{ mol}^{-1}$$

A positive  $\Delta S_{\text{total}}$  shows the reaction is feasible.

$$6. (a) \Delta S_{\text{surroundings}} = \frac{-\Delta H}{T} = \frac{-173\,000}{850} = -203.5 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\Delta S_{\text{total}} = \Delta S_{\text{surroundings}} + \Delta S_{\text{system}} = -203.5 + 175.9 = -27.6 \text{ J K}^{-1} \text{ mol}^{-1}$$

A negative  $\Delta S_{\text{total}}$  shows the reaction is not feasible.

$$(b) \Delta S_{\text{surroundings}} = \frac{-\Delta H}{T} = \frac{-173\,000}{1050} = -164.8 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\Delta S_{\text{total}} = \Delta S_{\text{surroundings}} + \Delta S_{\text{system}} = -164.8 + 175.9 = +11.1 \text{ J K}^{-1} \text{ mol}^{-1}$$

A positive  $\Delta S_{\text{total}}$  shows the reaction is feasible.

$$7. \Delta G = \Delta H - T\Delta S$$

$$= -144 - (500 \times 0.2269) \text{ (Remember to convert } \Delta S \text{ into kJ K}^{-1} \text{ mol}^{-1}\text{)}$$

$$= -257 \text{ kJ mol}^{-1}$$

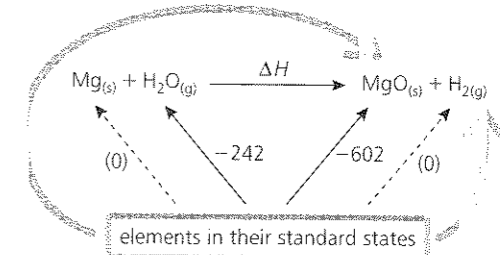
A negative  $\Delta G$  shows the reaction is feasible.

$$8. (a) \Delta G = \Delta H - T\Delta S = +237 - (1000 \times 0.1899) = +47.1 \text{ kJ mol}^{-1}$$

A positive  $\Delta G$  shows the reaction is not feasible.

► If  $237 < 0.1899T$   
 $237/0.1899 < T$   
 $1250 < T$   
 which is the same as saying  
 $T > 1250$

9.



$$\Delta H - 242 = -602 \text{ kJ mol}^{-1}$$

$$\Delta H = -360 \text{ kJ mol}^{-1}$$

$$\text{Entropy of products} = 26.9 + 130.6 = 157.5 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\text{Entropy of reactants} = 32.7 + 188.7 = 221.4 \text{ J K}^{-1} \text{ mol}^{-1}$$

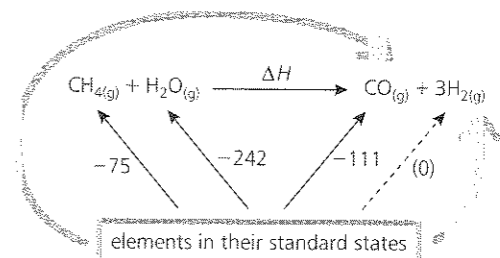
$$\Delta S_{\text{system}} = 157.5 - 221.4 = -63.9 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\Delta G = \Delta H - T\Delta S$$

$$= -360 - 373 \times (-0.0639) \text{ (Remember to convert } \Delta S \text{ into kJ K}^{-1} \text{ mol}^{-1}\text{)}$$

$$= -336 \text{ kJ mol}^{-1}$$

10.



$$\Delta H - 75 - 242 = -111$$

$$\Delta H = +206 \text{ kJ mol}^{-1}$$

$$\text{Entropy of products} = 197.6 + (3 \times 130.6) = 589.4 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\text{Entropy of reactants} = 186.2 + 188.7 = 374.9 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\Delta S_{\text{system}} = 589.4 - 374.9 = +214.5 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\Delta G = \Delta H - T\Delta S$$

$$= +206 - (1200 \times 0.2145) \text{ (Remember to convert } \Delta S \text{ into kJ K}^{-1} \text{ mol}^{-1}\text{)}$$

$$= -51.4 \text{ kJ mol}^{-1}$$

The negative value shows the reaction is feasible.

To be feasible,  $\Delta G < 0$

$$\text{Therefore, } \Delta H - T\Delta S < 0$$

$$206 - 0.2145T < 0$$

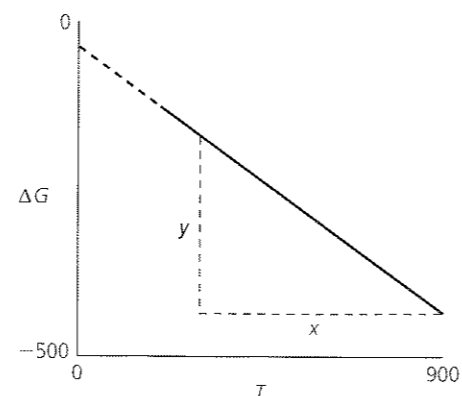
$$206 < 0.2145T$$

$$T > 960 \text{ K}$$

► See the help box above if you have problems.

11. (a)  $\Delta S$  is positive (mainly because of gas produced).  $-T\Delta S$  is therefore negative. At low temperatures,  $\Delta G$  is positive because of the positive  $\Delta H$ . At higher temperatures the negative  $-T\Delta S$  eventually outweighs  $\Delta H$ , and so  $\Delta H - T\Delta S$  becomes negative: C.
- (b)  $\Delta S$  is negative (3 moles of gas going to 2).  $-T\Delta S$  is therefore positive. At low temperatures,  $\Delta G$  is negative because of the negative  $\Delta H$ . At higher temperatures the positive  $-T\Delta S$  eventually outweighs  $\Delta H$ , and so  $\Delta H - T\Delta S$  becomes positive: D.
- (c)  $\Delta S$  is positive (mainly because of gas produced).  $-T\Delta S$  is therefore negative.  $\Delta H$  is also negative.  $\Delta H - T\Delta S$  will be negative at all temperatures: A.
- (d)  $\Delta S$  is negative (products are much more ordered).  $-T\Delta S$  is therefore positive.  $\Delta H$  is also positive.  $\Delta H - T\Delta S$  will be positive at all temperatures: B.

12.



$$\Delta G = \Delta H - T\Delta S$$

When  $T = 0$ ,  $\Delta G = \Delta H$ . Extrapolating the line to  $T = 0$  gives  $\Delta H = -36 \text{ kJ mol}^{-1}$ .

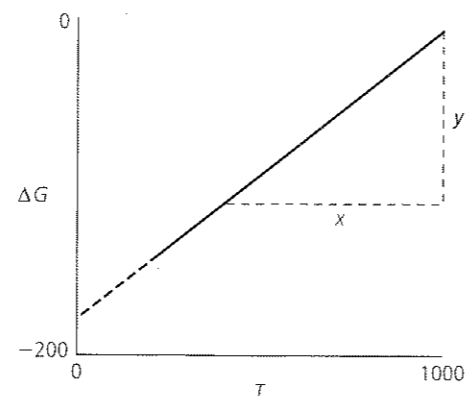
Slope of line =  $-\Delta S$ . Measure the slope as  $-y/x$ . It is a negative slope because  $\Delta G$  decreases with temperature.

$$\text{Slope} = -0.446 \text{ kJ mol}^{-1} \text{ K}^{-1}$$

$$-\Delta S = -0.446 \text{ kJ mol}^{-1} \text{ K}^{-1}$$

$$\Delta S = +0.446 \text{ kJ mol}^{-1} \text{ K}^{-1} \text{ (or } +446 \text{ J K}^{-1} \text{ mol}^{-1}\text{)}$$

13.



► Don't forget to convert  $^{\circ}\text{C}$  to K, and kJ to J.

$$14. \Delta S_{\text{system}} = \frac{\Delta H}{T} = \frac{+30\,000}{354} = +84.7 \text{ J K}^{-1} \text{ mol}^{-1}$$

15. (a) increase (b) decrease  
(c) decrease (d) increase
16. (a)  $+125.6 \text{ J K}^{-1} \text{ mol}^{-1}$  (b)  $-212.4 \text{ J K}^{-1} \text{ mol}^{-1}$   
(c)  $-330.2 \text{ J K}^{-1} \text{ mol}^{-1}$  (d)  $+494 \text{ J K}^{-1} \text{ mol}^{-1}$
17. (a) (i)  $-141 \text{ J K}^{-1} \text{ mol}^{-1}$  (ii)  $-159 \text{ J K}^{-1} \text{ mol}^{-1}$ , therefore not feasible.  
(b) (i)  $-157 \text{ J K}^{-1} \text{ mol}^{-1}$  (ii)  $+73 \text{ J K}^{-1} \text{ mol}^{-1}$ , therefore feasible.
18. (a)  $-214 \text{ kJ mol}^{-1}$  (b)  $+648 \text{ J K}^{-1} \text{ mol}^{-1}$  (c)  $-360.4 \text{ J K}^{-1} \text{ mol}^{-1}$   
(d)  $+287.6 \text{ J K}^{-1} \text{ mol}^{-1}$ , therefore feasible.
19. (a)  $+65 \text{ kJ mol}^{-1}$  (b)  $+14 \text{ J K}^{-1} \text{ mol}^{-1}$  (c)  $-65 \text{ J K}^{-1} \text{ mol}^{-1}$   
(d)  $-51 \text{ J K}^{-1} \text{ mol}^{-1}$ , therefore not feasible.
20. (a) (i)  $+8.88 \text{ kJ mol}^{-1}$ , therefore not feasible  
(ii)  $-17.7 \text{ kJ mol}^{-1}$ , therefore feasible  
(b) 467 K
21. (a)  $\text{MgCO}_3$ :  $\Delta H = +100 \text{ kJ mol}^{-1}$ ;  $\Delta S = +174.8 \text{ J K}^{-1} \text{ mol}^{-1}$ ;  
 $\Delta G = -57.3 \text{ kJ mol}^{-1}$   
 $\text{BaCO}_3$ :  $\Delta H = +268 \text{ kJ mol}^{-1}$ ;  $\Delta S = +171.9 \text{ J K}^{-1} \text{ mol}^{-1}$ ;  
 $\Delta G = +113 \text{ kJ mol}^{-1}$   
Only  $\text{MgCO}_3$  decomposes at 900 K.
- (b)  $\text{MgCO}_3$  572 K;  $\text{BaCO}_3$  1560 K
22. (a) A (b) D (c) C (d) B
23. (a)  $+220 \text{ kJ mol}^{-1}$  (b)  $+187 \text{ J K}^{-1} \text{ mol}^{-1}$  (c) 1180 K
24. (a)  $+9.8 \text{ J K}^{-1} \text{ mol}^{-1}$  (b)  $+94 \text{ J K}^{-1} \text{ mol}^{-1}$