products will increase. Rate will increase but no equilibrium shift.

9.

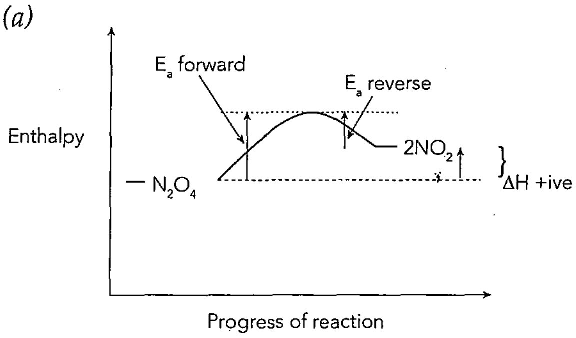
(i) *Pressure will increase as there are more particles. Yield and rate will remain constant as particle spacing remains the same.*

(ii) *For pressure to remain constant volume must increase therefore both rates decrease, but yield will increase as equilibrium shifts right.*

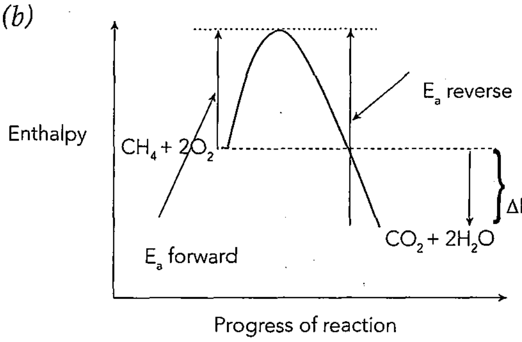
10. *Pressure will be reduced as volume increases. Yield will reduce as equilibrium shifts left and so $[SO_2]$ will increase but upto a lower level than before – hence rate will be lower.*

11.

(a)



(b)



Set 3 Changing Temperatures

1. *Pressure will decrease but equilibrium shifts to the right as exothermic and yield must increase. Forward rate will decrease as temperature is reduced and equilibrium shifts to the right because reverse rate decreases more than the forward rate.*
2. *Pressure must increase with temperature. Yield must decrease for exothermic reactions as equilibrium shifts to the left. Rate must increase with higher temperature.*

3.

(i) *Pressure must increase with temperature as K increases for endothermic reactions ($K = [CO_2]$).*
Yield will increase as equilibrium shifts to the right. Rate always increases with temperature.

(ii) *Mass of $CaCO_3$ will be reduced as equilibrium shifts to the right.*

(iii) $K = [CO_2]$.

4.

(i) *Pressure must increase with temperature. Yield must increase with temperature for the endothermic reaction. Rate must increase with temperature.*

(ii) *More iodine would be produced so colour becomes darker.*

5. *Pressure must increase with temperature. Yield must increase with temperature for an endothermic reaction. Rate must increase with temperature.*

6.

(i) *Exothermic equilibrium shifts to the left so mass of AgCl decreases. Forward rate must increase with higher temperature but reverse rate increases more.*

(ii) *Rate of forward reaction would decrease as the equilibrium shifts to the left. AgCl decreases.*

7.

(i) *Pressure must increase with temperature. Yield must decrease with temperature for an exothermic reaction. Forward rate must increase with higher temperature but reverse rate increases more so the equilibrium shifts to the left.*

(ii) *Mass and volume of bromine would increase.*

8.

(i) *Pressure must increase with temperature. Yield must increase with temperature for an endothermic reaction. Rate must increase with higher temperature.*

(ii) *Mass of ZnO would decrease as the equilibrium shifts to the right.*

9. *Pressure must increase with temperature. Yield must increase with temperature for an endothermic reaction. Rate must increase with higher temperature.*

10.

(i) *$[Cl_2]$ would decrease as the equilibrium shifts to the left.*

(ii) *$FeCl_2$ is a solid and so its concentration cannot change but mass would increase.*

(iii) *The mass of iron would decrease as the equilibrium shifts to the right.*

(iv) *Pressure must decrease with a temperature drop as Cl_2 molecules collide less.*

(v) *Total enthalpy change would be -342 + -57 = -399 kJ.*

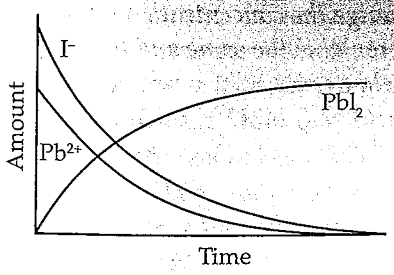
Set 4 Equilibrium

1. c, 2. b, 3. b, 4. a, 5. d, 6.a, 7. c, 8. d, 9. d, 10. e, 11. e, 12. a

Answers to longer questions

1. (a) $Pb^{2+}(aq) + 2I^{-}(aq) \rightarrow PbI_2(s)$

(b)



(c) *The amount of the precipitate formed, its colour or intensity of the yellow colour, or any other observable changes have ceased.*

(d) *This could only be shown using tagged radioactive isotope mixed with normal iodine. It could be shown that the proportion of the radioactive isotopic iodine continues changing during the equilibrium even though the amounts remain constant.*

2.

(a) N_2, H_2, *and* NH_3 *are present at equilibrium.*

(b) *Final concentrations:* $[N_2] = 1.60$ mol L^{-1}, $[H_2] = 1.00$ mol L^{-1}, $[NH_3] = 0.40$ mol L^{-1}

(c) *Concentrations after 3 minutes:* $[N_2] = 1.65$ mol L^{-1}, $[H_2] = 1.10$ mol L^{-1}, $[NH_3] = 0.25$ mol L^{-1}

(d) *About 2 minutes after the reaction commences.*

(e). *At the seventh minute after the reaction commences.*

(f) *Same as given for b) above.*

3.,

(a) *Increase the temperature of the reaction mixture.*
Increase the pressure in gaseous reactions.
Increase the concentrations of the reactants.
Increase the surface area of any solids which are reacting.
Use a catalyst

(b) $Cr_2O_7^{2-}(aq) + H_2O(l) \rightleftharpoons 2CrO_4^{2-}(aq) + 2H^+(aq)$
(i) *Reaction would move to the right and colour would turn more yellow.*
(ii) *Reaction would move to the left and colour would turn more orange.*
(iii) *All ion concentrations would become less initially, then by LCP reaction would move to the right to increase the concentration of ions.*

(c) *When the bottle is opened* CO_2 *gas is lost from the left side of the equation, so, by LCP, the reaction will move right to replace it.*

(d) (i) *In an open container the* CO_2 *is lost and so by LCP reaction moves right to produce more. Eventually all the* $CaCO_3$ *will have decomposed.*
(ii) *In a sealed container the* CO_2 *cannot escape and an equilibrium is reached where the forward rate = reverse rate and the mass of* $CaCO_3$ *will become constant.*

4.

(a) *A decrease in pressure will shift the equilibrium to the left, forming more of the reactants from the products.*

(b) *A decrease in pressure has no effect because the number of gaseous moles are equal on both sides.*

(c) *A decrease in pressure will shift the equilibrium to the right (towards greater number of gaseous moles), forming more products from the reactants.*

(d) *A decrease in pressure will shift the equilibrium to the right (towards a greater number of gaseous moles), forming more products.*

5.

(a) *Raising the temperature will shift the equilibrium to the left, forming more reactants as this is an exothermic reaction.*

(b) *Raising the temperature will shift the equilibrium to the left, forming more reactants as this is an exothermic reaction.*

(c) *Raising the temperature will shift the equilibrium to the right, forming more products as this is an endothermic reaction.*

6. *The opposite effect to what is stated in question 5 will occur in each case.*

7.

(a) $K = [Ca^{2+}][OH^-]^2$

(b) $K = \dfrac{[NH_3]^2}{[N_2][H]^3}$

(c) $K = \dfrac{[NO_2]^2}{[NO]^2[O_2]}$

(d) $K = \dfrac{[Mn^{2+}]^2[Fe^{3+}]^5}{[MnO_4^-]^2[Fe^{2+}]^5[H^+]^6}$

(e) $K = \dfrac{[Mn^{2+}]^2[CO_2]^{10}}{[MnO_4^-]^2[H_2C_2O_4]^5[H^+]^6}$

8.

(a) $K = \dfrac{[Co(H_2O)_6]^{2+}[Cl^-]^4}{[CoCl_4^-]^2}$

(b) *If you sprinkle some NaCl solution, the increased concentration of chloride ions will shift the equilibrium to the left and the solution will become blue.*

(c) *After microwaving the papers the blue paper will remain blue and the pink one will turn blue. The shift in equilibrium is to the left as water is removed from the paper.*

9.

Change made	Change in rate	Change in yield
Increase in pressure	No change	No Change
Increase in temperature	Increase	Decrease
Add some NaCl solid	Increase	Increase
Divide the solution into 100 mL portions to increase the state of subdivision	No change	No change (not changing concentrations)

10.

(a) *At the beginning of the reaction, SO_2, Cl_2, and SO_2Cl_2 are all present.* *($SO_2 = 0.05$ M, $Cl_2 = 0.068$M, $SO_2Cl_2 = 0.05$ M)*

(b) $K = \dfrac{[SO_2][Cl_2]}{[SO_2Cl_2]}$

(c) *Chlorine was pumped into the system.* *The increased concentration of one of the products shifts the equilibrium to the left. Chlorine starts reacting with SO_2, producing SO_2Cl_2. Therefore $[SO_2]$ begins to decrease and $[SO_2Cl_2]$ begins to increase.*

(d) *At t = 9 mins.*

(e) *Volume of vessel is reduced so all concentrations decrease.*

11.

(a) *i) After $BaCl_2$ solution is added, the concentration of Ba^{2+} ions increases. Equilibrium shifts to the left.* *More $Ba(OH)_2$ is produced. The solution becomes cloudy initially, then becoming whiter.*
ii) Addition of $Ba(OH)_2$ solid does not eventually produce any effect as K must stay constant.

(b) *i) NaOH solution reacts and will dissolve acidic CO_2 gas. The equilibrium will shift to the right to produce more CO_2. More $CaCO_3$ will decompose.*
ii) This is an endothermic reaction. Decrease in temperature will shift the equilibrium to the left, forming more $CaCO_3$. CO_2 gas is reduced because K reduces.
iii) The reaction moving to the right to produce some more CO_2, as some of this gas dissolves in the added water.
iv) A decrease in pressure will drive the reaction to the side of more number of gaseous moles. Equilibrium will shift to the right. More CO_2 will be produced but the concentration will remain the same so that K can stay the same. $K = [CO_2]$. $CaCO_3$ decreases.

(c) *i) When the volume of the system is increased, the reaction moves in the direction of greater number of gaseous moles (left). More reactants are produced and the system gets cooler as a result.*
ii) Introduction of an inert gas does not change the concentration of the gases and so K remains the same and there is no change in yield or rate.

12. $Cr_2O_7^{2-}(aq) + 2H^+(aq) + 3SO_2(g)$ *Orange*
$\rightleftharpoons 2Cr^{3+}(aq) + H_2O(l) + 3SO_4^{2-}(aq)$ *Green*

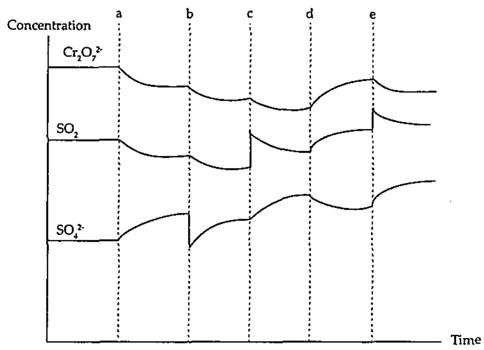
(a) *When a solution of HCl is added to the mixture, $[H^+]$ increases. The equilibrium shifts to the right. More Cr^{3+} and SO_4^{2-} are produced and the mixture becomes greener..*

(b) *The added Ba^{2+} ions will react with SO_4^{2-} ions to produce $BaSO_4(s)$ and decrease its concentration. Equilibrium will shift to the right in order to produce more SO_4^{2-} ion. The mixture becomes more greenish.*

(c) *The reaction will then move to the right according to LCP to partially increase the concentrations again and so the colour will become greener.*

(d) *The added OH^- ions will react with the H^+ ions in the mixture to produce H_2O, thus decreasing its concentration. Equilibrium will shift to the left producing more reactants. The solution will become more orange.*

(e) *Increased concentration of the reactant SO_2 will shift the equilibrium to the right leading to the production of more Cr^{3+} and the other products. The solution will become greener.*



13.

Tube No.	Change imposed	Shift in equilibrium	Explanation
A	5 mL of water added	None	All ions are diluted but no increase. Both rates reduced.
B	A few drops of Br added	Left	Concentration of Br increases so reaction moves left by LCP to decrease Br concentration
C	A few drops of $AgNO_3(aq)$ added	Right	Ag^+ ion reacts with the Br ion to form a precipitate of AgBr and removes Br^-. So reaction moves right by LCP to increase Br concentration.

14.

(i) *The reaction has reached equilibrium.*

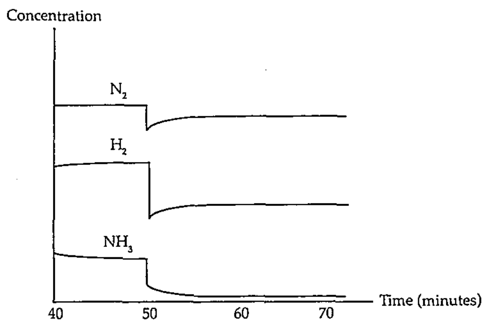
(ii) *For every N_2 molecule used in the reaction 3 H_2 molecules are use up so the H_2 will decrease 3 times faster than the N_2.*

(iii) *More N_2 was introduced into the vessel.*

(iv) *Forward reaction rate and reverse reaction rate will have increased but forward rate increases more than the reverse rate.*

(v) *With more nitrogen present, the particles are closer and so there will be more collisions per second and the forward rate will go up producing more product. With more product, the reverse collision rate will then rise.*

(vi)



15.

(a) $CO_2(g) \rightleftharpoons CO_2(aq)$

(b) *Increasing oceanic temperatures would cause the equilibrium to shift in the reverse direction so more $CO_2(g)$ would be produced.*

(c) $CO_2(aq) + H_2O(l) \overset{1}{\rightleftharpoons} H^+(aq) + HCO_3^-(aq) \overset{2}{\rightleftharpoons} 2H^+(aq) + CO_3^{2-}(aq)$

As carbon dioxide dissolves into the ocean LCP predicts that equilibrium 1 shifts in the forward direction to partially counteract the imposed change and the concentration of hydrogen ions and hydrogencarbonate ions increases. In turn, LCP predicts that equilibrium 2 will shift in the forward direction, further increasing the concentration of hydrogen ions. The pH decreases and acidity increases.

(d) *Increasing the CO_2 concentration increases the collisions between CO_2 and H_2O molecules and so the rate of the forward reaction 1 increases relative to the rate of its reverse reaction. This in turn increases to collisions between hydrogen ions and hydrogencarbonate ions and so the rate of the forward reaction 2 increases relative to the rate of its reverse reaction. More hydrogen ions contribute to increased acidity.*

(e) *Increasing hydrogen ion concentration causes the equilibrium 2 above to shift in the reverse direction in order to partially counteract the imposed change. This causes the carbonate ion concentration to decrease.*

(f) $CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2O(l) + CO_2(g)$

Chapter 2.
Acids and Bases

Set 1 Brønsted-Lowry Acids and Bases

1.

(a)

(i) $2HCl(aq) + Mg(s) \rightarrow MgCl_2(aq) + H_2(g)$

$2H^+(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + H_2(g)$

(ii) $H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

(iii) $2HNO_3(aq) + CaO(s) \rightarrow Ca(NO_3)_2(aq) + H_2O(l)$

$2H^+(aq) + CaO(s) \rightarrow Ca^{2+}(aq) + H_2O(l)$

(iv) $2HBr(aq) + K_2CO_3(aq) \rightarrow 2KBr(aq) + H_2O(l) + CO_2(g)$

$2H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$

(b) *Davy identified acids as substances that contain hydrogen that could be replaced by metals. In equation (i) and (iii) the metal has replaced the hydrogen in the acid to produce the salt.*

(c) *Magnesium metal is not considered a 'Davy' base because when it reacts with an acid it does produce a salt, but not water. In our terms, the reaction is not a neutralisation.*

2.

(a) *Weak Arrhenius acid, since it does produce hydrogen ions in water but does not ionise completely.*

$H_3PO_4(aq) \rightleftharpoons H^+(aq) + H_2PO_4^-(aq)$

(b) *Weak Arrhenius base, since it does produce hydroxide ions in water but does not onise completely.*

$NH_3(g) + H_2O(l) \rightleftharpoons + NH_4^+(aq) + OH^-(aq)$

(c) *Weak Arrhenius acid, since it does produce hydrogen ions in water but does not ionise completely.*

$HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$

(d) *Strong Arrhenius base, since it dissociates completely to produce OH^- ions in solution.*

$LiOH(s) \rightarrow Li^+(aq) + OH^-(aq)$

(e) *Strong Arrhenius acid, since its first ionisation occurs completely.*

$H_2SO_4(aq) \rightarrow H^+(aq) + HSO_4^-(aq)$

3. (i) Acid = H_2O, Base is CN^-

(ii) Acid = CH_3COOH, Base = S^{2-}

(iii) Acid = HS^-, Base = CO_3^{2-}

4. (i) H_2O/ OH^-, HCN/ CN^-

(ii) CH_3COOH/ CH_3COO^-,

(iii) HS^-/ S^{2-}, HCO_3^-/ CO_3^{2-}

5. *Theoretically the HCl solution should give the same number of H^+ ions as the H_2SO_4 as the latter is diprotic and the acids are both strong. However, not both of the hydrogens from the H_2SO_4 are fully ionised in solution. One is a strong ionisation and the second is weak so for HCl, moles of H^+ is $0.2 \times 1 = 0.2$*