(c) The equilibrium system will not shift. Both the forward and reverse rates are increased by the same factor as the solid surface area increases. *(Adding more sodium carbonate does not change its concentration, since pure substances in the solid state have concentrations that are essentially fixed, i.e., the number of moles per unit volume of each substance is a constant.)*

(d) The equilibrium system will shift to the left. Decreasing the volume of the vessel compresses the $CO_2(g)$ and thereby increases its concentration, which increases the reverse reaction rate, while the forward reaction rate is not changed.

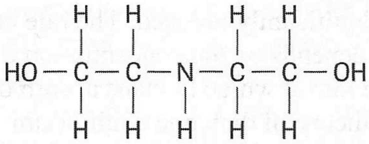
(e) The equilibrium system will shift to the right. Decreasing the concentration of $Cl^-(aq)$ decreases the reverse reaction rate, while the forward reaction rate is not changed. *(Added $AgNO_3(s)$ will dissolve, introducing $Ag^+(aq)$, which will react with $Cl^-(aq)$ to form $AgCl(s)$.)*

(f) The equilibrium system will not shift. Increasing the vessel volume allows all the gases in the system to expand and thereby decreases their concentrations. Since the concentration of each gas is changed by the same factor and the forward and reverse reactions involve the same number of moles of gases, both the forward and the reverse reaction rates are decreased equally.

(g) The equilibrium system will shift to the right. Adding soluble $Fe(NO_3)_3(s)$ increases the concentration of $Fe^{3+}(aq)$, which increases the forward reaction rate, while the reverse reaction rate is not changed.

37. The forward reaction is favoured (i.e., increased) by the changes in (b) and (c). *(These are the only exothermic changes.)*

38. (a) The structural formula for diethanolamine is:



(b) Since the forward reaction is exothermic (negative $\Delta_r H$), keeping the temperature low will favour the forward reaction in both equilibria; the system will shift right to try to compensate for the removal of heat. High pressure ensures that more hydrogen sulfide remains dissolved, favouring the forward progress of the solubility equilibrium for $H_2S(g)$.

39. To regenerate the scrubber solution, reverse the conditions. Heat the reaction vessel to shift both equilibria to the left, and decrease the pressure to encourage the most H_2S to come out of the solution.

40. $CO_2(g) + H_2O(l) \leftrightarrows H_2CO_3(aq)$ (negative $\Delta_r H$)

41. $H_2CO_3(aq) + (C_2H_4OH)_2NH(aq) \leftrightarrows (C_2H_4OH)_2NH_2^+(aq) + HCO_3^-(aq)$ (negative $\Delta_r H$)

Because this equation is very similar to the one representing the removal of $H_2S(g)$, the process conditions for removing $H_2S(g)$—heating the reaction vessel—should work to remove $CO_2(g)$ as well.

Extension

42. In an industrial amine "scrubber" system:
1. Sour gas enters the contactor tower and rises through the descending amine solution.
2. Purified gas flows from the top of the tower.
3. The amine solution, carrying absorbed acid gases, leaves the tower for the heat exchanger or optional flash tank.
4. Rich amine is heated by hot, regenerated lean amine in the heat exchanger.

5. Rich amine is further heated in the regeneration still column, by heat supplied from the reboiler. The steam rising through the still liberates H_2S and CO_2, regenerating the amine. The equilibrium shifts to favour the reverse reaction.
6. Steam and acid gases, separated from the rich amine, are condensed and cooled, respectively, in the reflux condenser.
7. Condensed steam is separated in the reflux accumulator and is then returned to the still. Acid gases may be vented or directed to a sulfur recovery system.
8. Hot, regenerated lean amine is cooled in a solvent aerial cooler and circulated to the contactor tower, completing the cycle.

Both the dissolving of the hydrogen sulfide gas and its reaction with diethanolamine are equilibrium processes. The conditions are manipulated to first maximize the quantity of hydrogen sulfide that is removed from the gas mixture, and then to regenerate the hydrogen sulfide after it has been separated from the gas mixture. Chemical equilibrium is crucial to this scrubber system. If the main steps were not equilibrium processes, then it would not be possible to shift the equilibrium in the desired direction. The same description applies to the removal of carbon dioxide.

Refineries in Alberta that use this process to reduce sulfur content include Shell (Fort Saskatchewan), PetroCanada (Edmonton), and Imperial Oil (Edmonton).

43. The tungsten and iodine reaction to produce tungsten(II) iodide is exothermic. A high temperature of the system forces the equilibrium to shift to the left, depositing metallic tungsten on the filament. This deposition reverses the tendency of the tungsten to be lost gradually from the filament. The presence of the halogen (iodine) helps to establish an equilibrium that, at high temperature, restores the filament.
44. At high altitude, the concentration of oxygen in air is significantly reduced. The rate at which oxygen will dissolve (react with hemoglobin) in blood depends on the concentration of gaseous oxygen in the lungs. Thus, at high altitudes the rate at which humans absorb oxygen from the air they breathe is considerably reduced. The theory of dynamic equilibrium explains that the rate of dissolving of oxygen is reduced, while the rate of oxygen escaping from solution is unchanged, by a decrease in concentration of gaseous oxygen. Le Châtelier's principle leads to the conclusion that more oxygen will escape from solution in blood as the equilibrium shifts to counteract the decreased gaseous oxygen concentration in the air. People who are born and live their lives at high altitudes tend to have larger than average lung capacities, so that the amount of oxygen absorbed is increased by increasing the total amount that is inhaled with each breath.