THE HABER PROCESS

1. a) 1 volume of nitrogen to 3 volumes of hydrogen (or: in the ratio of 1 mole of nitrogen to 3 of hydrogen; or: in equation proportions)

   b) 400 - 450°C

   c) 200 atmospheres (in fact, anything from this up to about 1000 atm would be OK)

   d) iron

   e) The equilibrium mixture of gases is cooled. Because of the very high pressures, the ammonia turns to liquid and can be separated from the unreacted gases which can be recycled.

2. a) the choice of temperature:

   Equilibrium: The production of ammonia is exothermic:

   $$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} \quad \Delta H = -92\ kJ\ mol^{-1}$$

   According to Le Chatelier, if you lower the temperature the system would react by countering this by favouring the exothermic change. That means that a low temperature would give a higher percentage conversion into ammonia.

   Rates: At a low temperature, the formation of ammonia is very slow (or even non-existent). Increasing the temperature increases the rate at which equilibrium is reached. However, a high temperature means a low percentage yield of ammonia.

   Economics: There are no extra factors to consider here. The temperature is chosen as a compromise to give the best possible yield of ammonia reasonably quickly.

   b) the choice of pressure:

   Equilibrium: A high pressure favours the reaction which produces fewer molecules. Fewer molecules produce a lower pressure. This is consistent with Le Chatelier's Principle – countering the change you have made. So in this case, to get the maximum percentage conversion to ammonia you would choose a very high pressure.

   Rates: High pressures bring molecules closer together and so increase collision rates , increasing the rate of reaction.

   Economics: Very high pressures are expensive to produce. They need very strong pipes and containment vessels, and lots of energy to generate. The pressures actually used are a compromise on economic grounds.

c) the use of the catalyst:

Equilibrium: Catalysts have no effect on equilibrium.

Rates: The reaction producing ammonia is very, very slow in the absence of a catalyst.

Economics: Iron is a cheap material and in any case, catalysts aren't used up during a reaction. The costs involving the catalyst are therefore negligible, and the reaction would be much too slow without one.