

## 1. This question is about rocket fuels

The Mars Curiosity rover's landing in August 2012 was achieved using variable thrust mono propellant hydrazine rocket thrusters. Hydrazine,  $\text{N}_2\text{H}_4$ , is popular with NASA as it produces no carbon dioxide.

The hydrazine is passed over a suitable catalyst and decomposes to its elements. The rapid production of the hot gaseous elements is what provides the thrust. Ammonia can be formed as an intermediate during the decomposition.



- (a) Write a balanced equation for hydrazine decomposing to ammonia and nitrogen gas.
- (b) Hydrazine may be obtained from the reaction between ammonia and hydrogen peroxide.

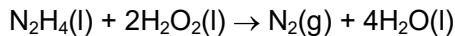


Work out the standard enthalpy change for the decomposition of hydrazine to its elements. The standard enthalpy changes of formation in  $\text{kJ mol}^{-1}$  are:

$\text{NH}_3$ :  $-46.1$ ;  $\text{H}_2\text{O}_2$ :  $-187.8$ ;  $\text{H}_2\text{O}$ :  $-285.8$

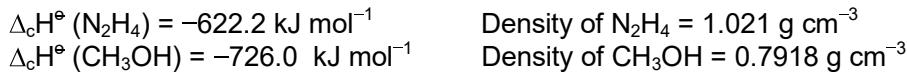
- (c) The first ever rocket-powered fighter plane, the Messerschmitt Me 163, was powered by the reaction between a hydrazine-methanol mixture, known as 'C-Stoff', and hydrogen peroxide ('T-Stoff').

- (i) Hydrogen peroxide reacts with the hydrazine as shown in the equation.



State the oxidation number of nitrogen and oxygen in the reactants and products.

- (ii) Hydrogen peroxide oxidises the methanol to carbon dioxide and water. Write a balanced equation for this reaction.
  - (iii) The fighter plane would hold 225 litres of hydrazine and 862 litres of methanol. Use the following standard enthalpy changes and densities to calculate the heat energy evolved under standard conditions for the combustion of this quantity of rocket fuel. Assume that all the hydrazine and methanol are fully combusted.



- (d) Hydrazine is also commonly combined with dinitrogen tetroxide,  $\text{N}_2\text{O}_4$ , in rocket fuels. This forms a hypergolic mixture, i.e. the reactants ignite spontaneously on contact. NASA used  $\text{N}_2\text{H}_4 / \text{N}_2\text{O}_4$  in many space vehicles and it is likely to be used in next-generation vehicles.
  - (i) Reactions used in rocketry produce chemically stable products (making the reaction exothermic) that are formed as gases (which provide thrust). Suggest the reaction products that are formed in the reaction between  $\text{N}_2\text{H}_4$  and  $\text{N}_2\text{O}_4$ .
  - (ii) Pure  $\text{N}_2\text{O}_4$ , when warmed, initially decomposes not into its elements but instead forms a brown gas. Suggest the identity of this brown gas.
- (e) A derivative of hydrazine with formula  $\text{C}_2\text{H}_8\text{N}_2$  was used in rocket fuels in the Apollo missions. It has two nitrogen atoms that are in different chemical environments and two carbon atoms that are in the same chemical environment. Draw the structure of  $\text{C}_2\text{H}_8\text{N}_2$ .