**Q1 This question is about rocket fuels**

The NASA Artemis uses liquid oxygen (LOX) and liquid hydrogen fuel sources. These fuels ensure the rocket mass is low and alongside their large enthalpy change of combustion enable a rocket to overcome gravity.

In 2022 there were a number of failed launch attempts due to a leak in the hydrogen fuel.

In the rocket engine the fuel components are first vaporised before reacting to form water.

**(a)** Write an equation for the reaction between gaseous hydrogen and oxygen.

The bond enthalpy of H–H is 432 kJ mol$^{-1}$ and the average bond enthalpy of O–H is 460 kJ mol$^{-1}$. Assume the enthalpy change for the reaction in part (a) is −241 kJ per mole of hydrogen gas.

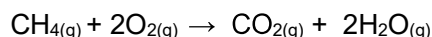**(b)** Calculate the bond enthalpy of the O=O bond in kJ mol$^{-1}$.

The density of liquid hydrogen is 0.071 g cm$^{-3}$.

**(c)** **(i)** Calculate the number of moles of hydrogen molecules in 1 dm$^3$ of liquid hydrogen.

    **(ii)** Calculate the energy released when the gas formed from 1 dm$^3$ of liquid hydrogen is combusted.

SpaceX's aim to colonise Mars leads to the choice of methane as an alternative to hydrogen. Methane can be formed using Mars' natural resources via the Sabatier process as the atmosphere of the planet is made up of 95.3% carbon dioxide by volume. In the Sabatier process methane and water are formed from the reaction of carbon dioxide and hydrogen gas.

**(d)** **(i)** Write an equation for the Sabatier process.

    **(ii)** State the oxidation number of carbon and hydrogen in the reactants and products.

SpaceX has recently developed a new engine, the Raptor, that uses liquid methane and LOX. Energy is required to turn them into the gaseous phase before they react. The enthalpy change of vaporisation of methane is +8.2 kJ mol$^{-1}$ and the enthalpy change of vaporisation of oxygen is +6.8 kJ mol$^{-1}$. The enthalpy change of combustion of methane, shown below, is −890.8 kJ mol$^{-1}$.

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

**(e)** Calculate the enthalpy change of reaction, in kJ, when one mole of **liquid** methane reacts with **liquid** oxygen to form gaseous carbon dioxide and gaseous water.