1. This question is about energy storage using a chemical cycle

Daily fluctuations in energy usage and in energy generation from renewables lead to a need for energy storage methods. Energy may be stored chemically using the sulfur-iodine cycle. The cycle has also been proposed as a means of producing hydrogen fuel more efficiently than by electrolysis.

At high temperature the sulfur-iodine cycle involves the three gas-phase equilibria:

(1) $I_2(g) + SO_2(g) + 2H_2O(g) \rightleftharpoons H_2SO_4(g) + 2HI(g)$

(2) $2H_2SO_4(g) \rightleftharpoons 2SO_2(g) + 2H_2O(g) + O_2(g)$

(3) $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$

(a) Use the data and the equations at the end of the question to answer the following questions for **reaction (3).**

(i) Calculate the standard enthalpy change at 298 K, $\Delta_r H^{-}(298\text{ K})$.

(ii) Calculate the standard entropy change at 298 K, $\Delta_r S^{\ominus}(298\text{ K})$.

(iii) Calculate the standard Gibbs energy change at 298 K, $\Delta_r G^{\ominus}(298\text{ K})$.

(iv) Calculate the equilibrium constant, K_{298}, at 298 K.

(v) Calculate the equilibrium constant, K_{723}, at 723 K. Assume $\Delta_r H^{\ominus}$ and $\Delta_r S^{-}$ are independent of temperature.

(b) Conditions are chosen so that the three equilibrium reactions above all proceed from left to right. Assuming that the products of **reaction (1)** are all consumed in **reactions (2)** and **(3)**, write an overall equation for the sulfur-iodine cycle.

(c) The standard enthalpy change of reaction at 298 K for **reaction (2)** is +439 kJ mol^{-1}. Use the value of $\Delta_f H^{\ominus}$ (298 K) for $H_2O(g)$ in the table below to calculate the standard enthalpy change of reaction at 298 K for **reaction (1)**.

(d) How much energy, per mol of sulfur atoms at 298 K, is stored with one revolution around the sulfur-iodine cycle?

Data:

	$HI(g)$	$H_2(g)$	$I_2(g)$	$H_2O(g)$
$\Delta_f H^{\ominus}$ (298 K) / kJ mol^{-1}	26.5		62.4	−242
$S^{\ominus}$ (298 K) / J K^{-1} mol^{-1}	207	131	261	189

Useful equations:

$\Delta S^{\ominus} = \Sigma S^{\ominus}(\text{products}) - \Sigma S^{\ominus}(\text{reactants})$

$\Delta G = \Delta H - T\Delta S$

$\Delta G^{\ominus} = -RT \ln K$

Useful constant: $R = 8.314$ J K^{-1} mol^{-1}