A hydrogen economy

Education in Chemistry
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To provide energy for a vehicle hydrogen can be used either in a fuel cell or an internal combustion engine. In this worksheet you will consider the chemistry behind both technologies.

1. a. Calculate the enthalpy change for the combustion of hydrogen:

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O$$

Bond	Bond enthalpy / kJ mol^{-1}
H–H	436
O=O	496
H–O	463

b. i. The enthalpy of combustion of petrol is about 43.5 kJ g^{-1}.

If petrol has a density of 0.80 g cm^{-3}, calculate the amount of energy released by the combustion of 1 dm^3 of petrol.

ii. Calculate the volume of hydrogen that would need to undergo combustion to release the same amount of energy as 1 dm^3 of petrol under standard conditions.

Molar volume of any gas under standard conditions = 24 dm^3

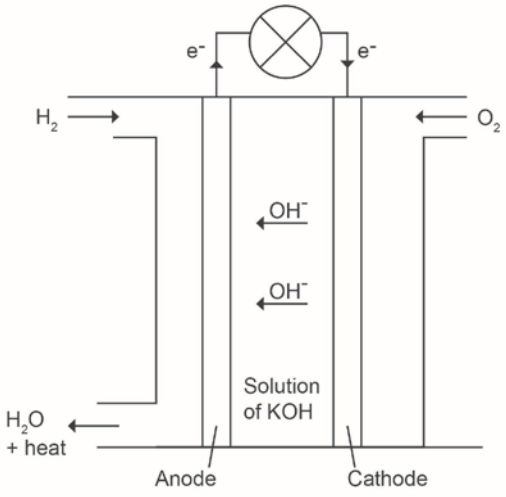
iii. Calculate the volume this amount of gas would occupy if stored at 700 bar of pressure (70000 kPa) and 298K.

Ideal gas constant, R = 8.31 J K^{-1} mol^{-1}

2. An alternative to burning hydrogen as a fuel, is the hydrogen fuel cell. This uses hydrogen and oxygen as ‘fuels’ to produce electricity to drive an electric motor.

Hydrogen–oxygen fuel cells can operate in acidic or in alkaline conditions but commercial cells use porous platinum electrodes in contact with concentrated aqueous potassium hydroxide

Figure 1 shows a hydrogen/oxygen fuel cell operating in alkaline conditions.



a. i. At the anode hydrogen combines with hydroxide ions to produce water and electrons.

Write a half equation for this reaction.

ii. At the cathode oxygen gains electrons and reacts with water to make hydroxide ions.

Write a half equation for this reaction.

iii. Combine the two half equations to determine the overall cell reaction.

b. Complete the standard cell representation for a hydrogen fuel cell operating under alkaline conditions.

$$Pt \mid H_2 \mid H_2O \parallel .....$$

c. Explain why hydrogen fuel cells are more efficient than hydrogen combustion engines.

3. '*Hydrogen fuel cells are better for the environment than petrol combustion engines*.'

Evaluate this statement, providing pros and cons.

Answers

1. a.

Bonds broken		Bonds formed	
1 × H–H	1 × 436	2 × O–H	2 × 463
½ × O=O	½ × 496		
TOTAL IN	**684**	**TOTAL OUT**	**926**

Enthalpy change = 684 – 926 = <u>– 242 kJ mol^{-1}</u>

b. i. 1 g has a volume of 1.25 cm^3 (1 g ÷ 0.80 g cm^{-3}).

43.5 kJ g^{-1} = 43.5 kJ per 1.25 cm^3

1000 cm^3 will therefore release $\frac{43.5\ kJ}{1.25\ cm^3} \times 1000\ cm^3$ = <u>34800 kJ</u>

ii. Amount in moles of hydrogen that must undergo combustion

= 34800 kJ ÷ 242 kJ mol^{-1}

= 143.8 mol

If 1 mole of a gas has a volume of 24 dm^3 under standard conditions then volume of hydrogen needed;

= 143.8 mol × 24 dm^3

= <u>3450 dm^3 (to 3 sig fig)</u>

iii. $V = \frac{nRT}{P} = \frac{143.8\ mol \times 8.31\ J\ K^{-1}mol^{-1} \times 298\ K}{70000000\ Pa}$ = 5.087 × 10^{-3} m^3 = <u>5.09 dm^3 (to 3 sig fig)</u>

2. a. i. $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$

ii. $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

iii. $2H_2 + O_2 \rightarrow 2H_2O$

b. Pt | H_2 | H_2O ‖ O_2 | OH^- | Pt

c. Most of the energy in a hydrogen fuel cell is given out as electricity. Very little heat is evolved. In an internal combustion a lot of energy is lost as heat.

3.

Pros	Cons
Water is the only by-product from the reaction.	CO_2 is released in the production of hydrogen for use in the fuel cell (either from the reaction of methane with steam, or in the production of electricity to produce hydrogen from water).
Fuel cells do not produce pollutants such as NO_x, CO, SO_2 or unburnt hydrocarbons.	Catalysts may be toxic metals.