This resource was developed as part of the HyAcademy.eu project.

Hydrogen: Properties, Thermodynamics and Electrochemistry

Bertz Associates

HyAcademy.EU

creative commons

UK Research and Innovation

Clean Hydrogen Partnership

Co-funded by the European Union

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

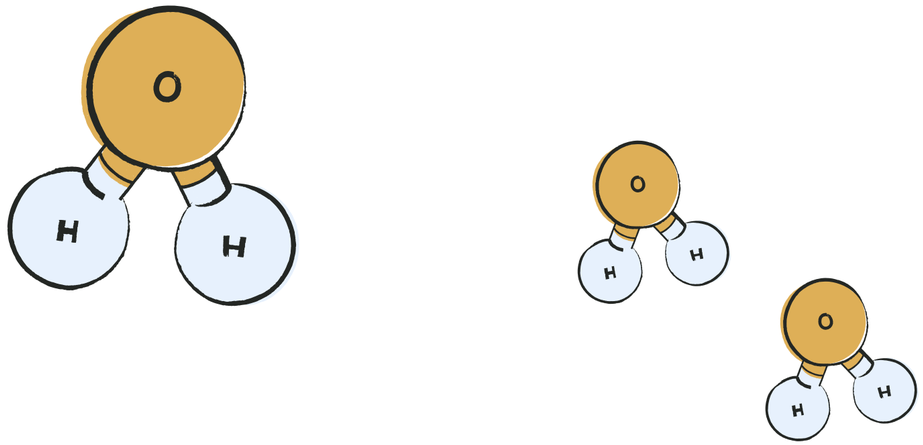
Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

The European Hydrogen Academy and Net-Zero Hydrogen Academy are supported by the Clean Hydrogen Partnership and its members under Grant Agreement No: 101137988, by UK Research and Innovation (UKRI), and the Swiss Confederation Secretariat for Education, Research and Innovation (SERI)

What are the Key Properties?

Hydrogen is the lightest element in the universe because it is the first element in the periodic table; as a gas it has the properties:

- Colourless
- Tasteless
- Odourless
- Low density
- Low solubility
- Highly reactive
- Highly flammable in air



Thermal and Energy Properties

- The boiling point of hydrogen is -253°C (20K)
- The melting point of hydrogen is -259°C (14K)
- So hydrogen is usually a gas on Earth
- Hydrogen can be used as a fuel, as when it combusts (reacts with oxygen), water is produced
- Hydrogen as a fuel has:
  - A low amount of energy per unit volume
  - A high amount of energy per unit weight
- These difference between these ‘energy densities’ is very important for understanding hydrogen’s fuel potential

Hydrogen as a Liquid

- In some applications, such as rocket fuel, liquid hydrogen is used instead of gaseous hydrogen
- Liquid hydrogen has a much greater energy density per unit volume than gaseous hydrogen so would be a better fuel
- Liquid hydrogen is expensive to produce so is not widely used
- To make liquid hydrogen:
  - Hydrogen is compressed, causing it to heat up (think $pV = nRT$)
  - Hydrogen is cooled to a low temperature
  - Hydrogen then expands, causing the temperature to drop further until it's liquid hydrogen

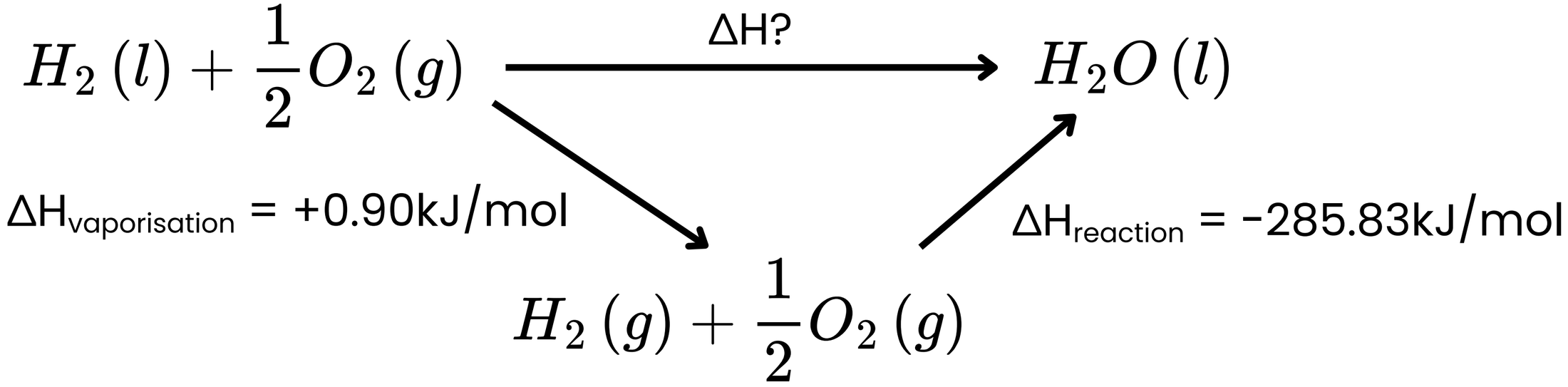
Hydrogen Hess Cycles

- Hess's Law - the enthalpy change for a chemical reaction is independent of the route taken
- Let's take find the enthalpy change when liquid hydrogen and gaseous oxygen react to produce water
- The enthalpy of formation for water is valuable information for this, which is the enthalpy change when gaseous hydrogen and oxygen react to produce water

$$H_2\,(l) + \frac{1}{2}O_2\,(g) \rightarrow H_2O\,(l) \quad \Delta H = ?$$

$$H_2\,(g) + \frac{1}{2}O_2\,(g) \rightarrow H_2O\,(l) \quad \Delta H = -285.83 kJ/mol$$

Hydrogen Hess Cycles



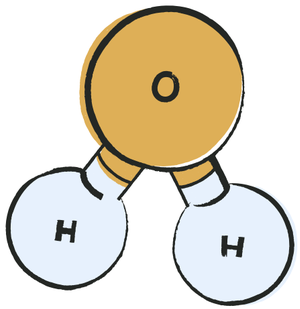
- To calculate the enthalpy change, we use the indirect path, so hydrogen is first vaporised (we add the enthalpy of vaporisation)

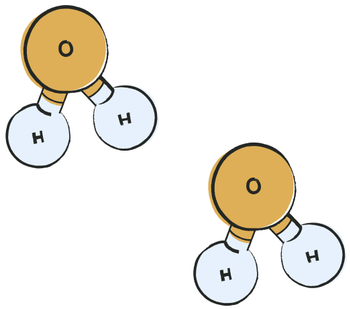
  ΔH = ΔH$_{vaporisation}$ + ΔH$_{reaction}$ = (+0.90) + (-285.83) = -284.93kJ/mol

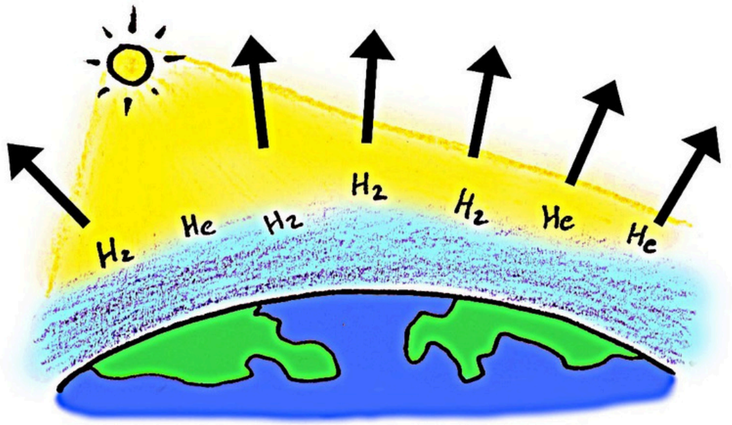
- The reaction enthalpy is therefore -284.93kJ/mol, so it is exothermic

Where is all the Hydrogen?

- There is a good reason why we don’t have lots of hydrogen floating around our atmosphere:
  - Hydrogen is light so it easily escapes Earth’s gravity into space
  - Hydrogen is very reactive so it spontaneously reacts with other elements, such as oxygen, in the atmosphere
- Let’s think about what spontaneous means here…







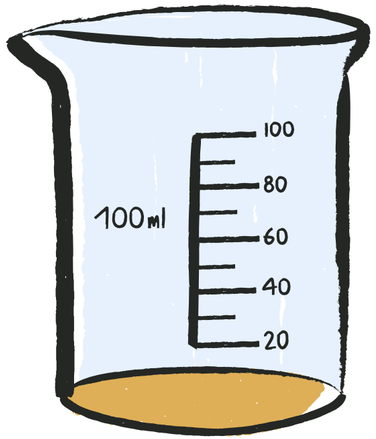
Source: youtube.com\minuteearth

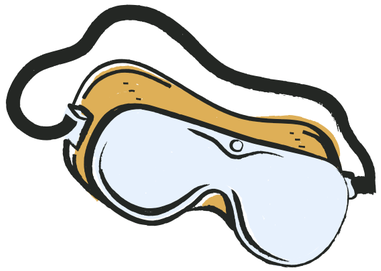
Where is all the Hydrogen?

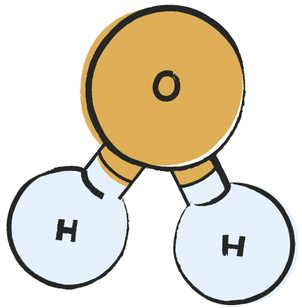
- Let's take the reaction from earlier: $H_2\left(g\right) + \frac{1}{2}O_2\left(g\right) \rightarrow H_2O\left(l\right)$
- Every reaction can be thought of as an equilibrium between reactants and products: $H_2\left(g\right) + \frac{1}{2}O_2\left(g\right) \rightleftharpoons H_2O\left(l\right)$
- If a reaction strongly tends towards either the reactants or products, it typically represented as a one-way reaction
- The Gibbs Free Energy can be calculated, and the more negative it is, the more spontaneous the reaction
- The Gibbs Free Energy for the above reaction is -237.13kJ/mol at 25°C, so it is highly spontaneous

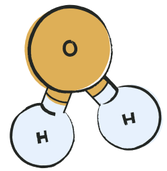
Hydrogen Electrochemistry

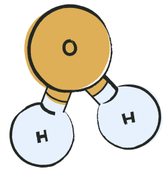
- Non-spontaneous reactions can occur, although they require an energy input
- This is seen when splitting water: $H_2O\,(l) \rightarrow H_2\,(g) + \frac{1}{2}O_2\,(g)$
- Therefore, water is often split using an electrolyser, to provide the additional energy required







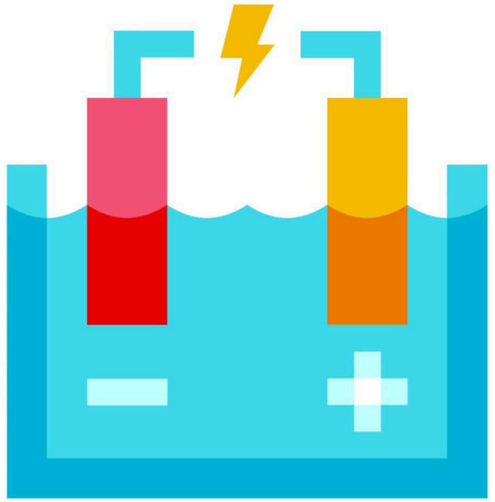




Hydrogen Electrochemistry

- The theoretical voltage required for water electrolysis is found to be 1.23V at a temperature of 25°C
- However, as this value is theoretical, the actual voltage required will be greater when we take into consideration the type of electrolyser, efficiencies and other physical limitations
- Practically, a voltage of around 1.5-2.0V is necessary

Source: liketreesplanted.com


Source: icons8.com

What Have we Learnt Today?

- The key physical and chemical properties of hydrogen ✅
- The thermal and energy properties of hydrogen ✅
- How liquid hydrogen can be used as a direct fuel ✅
- What Hess Cycles are and some examples using hydrogen ✅
- What a spontaneous reaction (Gibbs Free Energy) is and some examples using hydrogen ✅
- How a non-spontaneous reaction can occur, using hydrogen production in an electrolyser as an example ✅

Overall we've discovered how properties, thermodynamics and electrochemistry are related, using hydrogen as an example ✅

What’s Next?

- Complete the worksheet to reinforce what you have learnt today!

This resource was developed as part of the HyAcademy.eu project.

Thank You!

Project funded by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

Co-funded by the European Union

The European Hydrogen Academy and Net-Zero Hydrogen Academy are supported by the Clean Hydrogen Partnership and its members under Grant Agreement No: 101137988, by UK Research and Innovation (UKRI), and the Swiss Confederation Secretariat for Education, Research and Innovation (SERI)