Fuel cells

4.5.2.2 · Energy changes · revision notes

Chemistry only (not in Combined Science). A fuel cell produces electricity from a fuel, such as hydrogen, and oxygen that are supplied from outside the cell. You need the overall reaction in a hydrogen fuel cell, the half equations at each electrode (Higher tier), and to evaluate hydrogen fuel cells compared with rechargeable cells and batteries.

Key facts

- Fuel cell: fuel and oxygen supplied from outside; the fuel is oxidised electrochemically to produce a potential difference
- Only product: water
- Grade 8+ only Positive electrode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (reduction)
- Fuel cell: refuelled. Battery: recharged.
- Hydrogen fuel cell overall: $2H_2 + O_2 \rightarrow 2H_2O$
- Grade 8+ only Negative electrode: $H_2 \rightarrow 2H^+ + 2e^-$ (oxidation)
- Grade 7+ only Oxidation = loss of electrons; reduction = gain of electrons

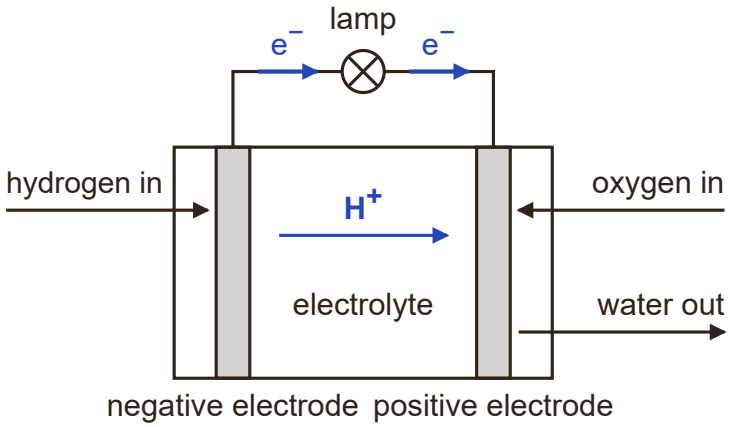
Notes

What a fuel cell is

- A **fuel cell** is supplied with a fuel (e.g. hydrogen) and oxygen or air from an external source.
- The fuel is **oxidised electrochemically** inside the cell to produce a **potential difference**. The fuel does not burn.
- A fuel cell keeps producing electricity for as long as fuel and oxygen are supplied. It is refuelled, not recharged.

The hydrogen fuel cell

- The overall reaction is the oxidation of hydrogen to produce water:
  $2H_2 + O_2 \rightarrow 2H_2O$



Hydrogen and oxygen go in, water comes out, and electrons flow round the external circuit.

- Water is the only product, so the fuel cell releases no carbon dioxide or other pollutants while it is working.
- Negative electrode: hydrogen molecules lose electrons to form hydrogen ions (oxidation).
  $H_2 \rightarrow 2H^+ + 2e^-$ Grade 8+ only
- Positive electrode: oxygen gains electrons and reacts with hydrogen ions to form water (reduction).
  $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ Grade 8+ only
- Electrons flow through the external circuit from the negative electrode to the positive electrode. Hydrogen ions move through the electrolyte to the positive electrode. Grade 8+ only
- If you are told the electrolyte is alkaline, the half equations use hydroxide ions: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$ and $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$. The overall reaction is the same. Grade 9+ only

Fuel cells compared with rechargeable batteries

- Hydrogen fuel cells are a possible alternative to rechargeable cells and batteries, for example in vehicles.
- For fuel cells: they are refuelled in a few minutes, travel further before refuelling, do not lose capacity over time, leave no toxic chemicals to dispose of, and keep working as long as fuel is supplied.
- Against fuel cells: hydrogen is a gas, so it takes up a large volume and is stored under high pressure; it is flammable (explosive when mixed with air); there are few filling stations; and it is often made using fossil fuels.
- For batteries: they can be recharged from the mains. Against batteries: recharging takes a long time, they can only be recharged a limited number of times, they are difficult to dispose of, and the electricity may come from fossil fuels.
- Neither releases carbon dioxide while it is being used, so 'no carbon dioxide' is not a difference between them.

How to answer each type of question

Recall: what goes in and what comes out

1 to 4 marks | Grade 4

1. Inputs: hydrogen and oxygen (or air).
2. Output: water only (and electricity).
3. For the balanced equation, check there are 4 H atoms and 2 O atoms on each side.

Example. (a) Name the **two** substances supplied to a hydrogen fuel cell. (2)
(b) Write a balanced symbol equation for the overall reaction in a hydrogen fuel cell. (2)

Model answer.

(a) hydrogen (1); oxygen or air (1)

(b) correct formulae: $H_2 + O_2 \rightarrow H_2O$ (1); balanced: $2H_2 + O_2 \rightarrow 2H_2O$ (1)

Give advantages and disadvantages

2 marks | Grade 5

1. Read what the fuel cell is being compared with: batteries or petrol engines.
2. Give one clear advantage and one clear disadvantage, each a real difference.
3. Say why each point matters, e.g. 'refuels in minutes, so the car spends less time off the road'.

Example. Give **one** advantage and **one** disadvantage of using hydrogen fuel cells rather than rechargeable batteries to power cars. (2)

Model answer. Advantage: the car can be refuelled in a few minutes, but recharging a battery takes much longer / the fuel cell keeps working as long as hydrogen is supplied (1). Disadvantage: hydrogen is a flammable gas that is difficult to store / there are few hydrogen filling stations / hydrogen is often made using fossil fuels (1).

Evaluate hydrogen fuel cells compared with rechargeable batteries 4 to 6 marks **Grade 5**

1. Use every row of the data, comparing the two side by side with numbers.
2. Add your own knowledge: storage and safety of hydrogen, how the hydrogen or electricity is made, battery disposal.
3. Give points for and against both.
4. End with a conclusion that follows from your points.

Example. A delivery company is choosing between two types of van. Each van drives about 300 km a day.

	Fuel cell van	Battery van
Range	500 km	250 km
Time to refuel or recharge	5 minutes	1 hour
Where it refuels or recharges	hydrogen filling station 40 km from the depot	fast charger at the depot
Other information	–	battery needs replacing after about 8 years

Evaluate the use of a hydrogen fuel cell van compared with a battery van for this company. (6)

Model answer.

The fuel cell van can drive the 300 km a day on one tank, but the battery van (250 km) would have to recharge during the day (1). Refuelling takes only 5 minutes, compared with 1 hour to recharge (1). However, the fuel cell van needs an 80 km round trip to refuel, while the battery van charges at the depot (1). Hydrogen is a flammable gas stored under high pressure, and it is often made from fossil fuels; the electricity for the battery may also come from fossil fuels (1). The battery must be replaced after about 8 years and is difficult to dispose of (1). Neither van releases carbon dioxide while driving. Conclusion: the fuel cell van is better for this company, because it can cover the daily distance without stopping and refuels quickly, even though the filling station is further away (1).

Marked in levels: Level 3 (5 to 6 marks) needs points for both vans, linked to the data, and a justified conclusion.

Write the half equations for a hydrogen fuel cell 2 to 4 marks **Grade 8**

1. Negative electrode: hydrogen loses electrons (oxidation): $H_2 \rightarrow 2H^+ + 2e^-$.
2. Positive electrode: oxygen gains electrons and joins with hydrogen ions (reduction): $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$.
3. Check that both atoms and charges balance in each half equation.
4. To get the overall equation, double the first half equation so both have 4 electrons, add them and cancel the H^+ ions and electrons.

Example. A hydrogen fuel cell has an acidic electrolyte.
(a) Write the half equation for the reaction at the negative electrode. (1)
(b) Write the half equation for the reaction at the positive electrode. (2)
(c) Explain why the reaction at the negative electrode is an oxidation. (1)

Model answer.

(a) $H_2 \rightarrow 2H^+ + 2e^-$ (1)

(b) correct species: $O_2 + H^+ + e^- \rightarrow H_2O$ (1); balanced: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (1)

(c) hydrogen (molecules) lose electrons (1)

Don’t lose marks

- Saying a fuel cell burns hydrogen. The hydrogen is oxidised electrochemically; there is no combustion.
- Saying hydrogen fuel cells produce 'no waste' or 'nothing'. They produce water.
- Saying hydrogen fuel cells cause no pollution at all. Making the hydrogen, or the electricity used to make it, often uses fossil fuels.
- Giving 'no carbon dioxide' as an advantage over batteries. Battery vehicles release no carbon dioxide while in use either.
- Not balancing the charge in half equations, e.g. writing $H_2 \rightarrow H^+ + e^-$.
- Carrying over the electrolysis rule. In electrolysis, oxidation happens at the positive electrode, but in a fuel cell hydrogen is oxidised at the negative electrode.

More tips

Memory tricks

- Fuel cell = refuel; battery = recharge.
- OIL RIG: Oxidation Is Loss of electrons, Reduction Is Gain. Hydrogen loses electrons, so it is oxidised.
- Positive electrode 'four-four-two': $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$.
- The overall equation is the same as for burning hydrogen, but in a fuel cell there is no flame: the reaction produces a potential difference.

Exam technique

- In 'evaluate' questions, check what the fuel cell is compared with. 'Only water is produced' is a strong point against petrol engines, not against batteries.
- Use numbers from the table for both sides, add your own knowledge, and finish with a conclusion that follows from your points.
- In half equations, write electrons as e^- and check that the total charge is the same on both sides.
- Use the key phrase: the fuel is 'oxidised electrochemically' to produce a potential difference.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Name what a hydrogen fuel cell uses**
Hydrogen (the fuel) and oxygen or air are supplied to the cell from outside.

Grade 4 — **State the product of a hydrogen fuel cell**
The only product is water: $2H_2 + O_2 \rightarrow 2H_2O$.

Grade 5 — **Describe how fuel cells produce a potential difference**
The fuel is oxidised electrochemically inside the cell, which produces a potential difference.

Grade 5 — **Give advantages and disadvantages of hydrogen fuel cells**
For example, they are refuelled in minutes, but hydrogen is a flammable gas that is difficult to store.

Grade 5 — **Evaluate fuel cells against rechargeable batteries**
Compare range, refuelling or recharging time, storage, safety, disposal and how the hydrogen or electricity is produced.

Grade 8 — **Write half equations for the hydrogen fuel cell**
Negative electrode: $H_2 \rightarrow 2H^+ + 2e^-$; positive electrode: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$.

Grade 9 — **Explain the electrode reactions using electrons**
Hydrogen loses electrons (is oxidised) at the negative electrode; oxygen gains electrons (is reduced) at the positive electrode.

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