EngBAM

UNIVERSITY OF BIRMINGHAM | SCHOOL OF CHEMICAL ENGINEERING

5.2.3 Storage and Fuel Cells

Teaching Resource

This resource has been designed to support the delivery of Chemistry content to an A Level Chemistry class. This pack contains a presentation, demonstration videos and a mini-experiment that has been developed by the University of Birmingham School of Chemical Engineering with the aim of inspiring more students to pursue a career in STEM subjects. Linking A Level specification points to University undergraduate content, relevant industry examples and current research projects, it is hoped to further engage students with learning by highlighting how this knowledge is being applied in the industry.

Slides with underlined titles contain information directly relevant to the A Level specification. The other slides contain extension information designed to engage students with the real life application of the specification point.

Lesson Length: Approximately 90-120 minutes

Key Specification Points:
OCR Chemistry A Level A - 5.2.3 Redox and electrode potentials: Storage and fuel cells

- (j) Application of principles of electrode potentials to modern storage cells
  - Details of storage cells and required equations will be provided. Relevant electrode potentials and other data will be supplied.
  - Benefits of electrochemical cells countered by risks of toxicity and fire from Li-based cells.
- (k) Explanation that a fuel cell uses the energy from the reaction of a fuel with oxygen to create a voltage and the change that take place at each electrode.
  - Recall of fuel cells and equations will **not** be required. Relevant electrode potentials and other data will be supplied.

Materials required:

- Copies of the Penny Experiment Lab Sheet
- A digital multimeter

- Per group:
  - At least 5x 1p or 2p coins
  - At least 5x 5p or 10p coins
  - A sheet of cardboard
  - Scissors
  - Clear distilled vinegar
  - A tablespoon
  - A strip of electrical tape
  - Paper towels
  - Salt
  - Bowl

Coin Stack Experiment

This small experiment aims to demonstrate to the students how a chemical cell can be easily made from everyday items. Creating the coin cell demonstrates to students how a cell may actually be formed, compared to the chemical cell diagrams the students are likely to be familiar with. By the end of the activity the students should be comfortable with linking the conventional chemical cell diagram to their coin cell and the students should be able to talk through why the coin cell works. In preparation for the session decide on the number of groups to split the class into. Prepare the equipment listed above so each group has the correct equipment for the experiment. The appropriate risk assessment for this activity is provided. Ensure familiarity with the risk assessment. Slide 8 shows an instructional video on how to complete the experiment and each group should be provided with a lab sheet that has a copy of the instructions. Remind students that the more shiny they can get the coins, the better the experiment will work. The cardboard discs should be damp with the salt-vinegar solution, excess solution should be removed before the disc is added to the stack. Give the students between 10-15 minutes to complete the task, therefore encourage the students to work quickly.

Slide Notes

- Slide 1 - Title Slide
  Emphasise to the class that the slides with underlined titles are relevant to their exams.
- Slide 2 - Introduction to battery storage
  Introduce the idea that energy storage in batteries is based on REDOX chemistry. Underpin the idea that for a battery to work there must be a difference in electrode potential.
- Slide 3 - Standard Electrode Potential
  Define what the standard electrode potential is. Ensure that the students can link back to their previous work on redox reactions.
- Slide 4 - Standard Cell Potentials
  Explain why the equation is set up as it is. Highlight the difference in reaction direction depending on the standard electrode potential.
- Slide 5 - Differences between cell types
  Introduce students to each category of cell. Ask the class in what everyday objects they are likely to find each type of cell. The class may struggle with examples of where fuel cells are used. Fuel cells can be found in modes of transport (mainly trains and cars) and used as backup power for commercial and residential buildings in remote areas.
- Slide 6 - How does a cell work?
  Use the diagram on the presentation to illustrate the information on screen.
- Slide 7 - Coin stack experiment
  Introduce the experiment. The activity aims to show how cells can be created easily from everyday

items. Explain to the class they will be making their own mini batteries in small groups from loose change and vinegar. Show the demonstration video before splitting the class into groups.

- Slide 8 - Demonstration video
- Slide 9 - Coin stack experiment
  Instruct the students to wear safety glasses to protect the eyes against the vinegar. The class can be split into groups and given 10-15 minutes to attempt to make a coin stack cell. This slide should be left up during the experiment as an example of how the coins should be stacked to create the cell. Extra - this activity could be turned into a competition. Challenge the students to be the first group to get a voltage from their cell of at least five elements. After 10-15 minutes clear away the activity before continuing the presentation.
- Slide 10&11 - Primary cells
  Emphasise how the reactions at each electrode are non-reversible, therefore the cell will be non-rechargeable. Refer concepts to the primary cell diagram. Test the students understanding of the half equations.
- Slide 12 - Secondary cells
  Draw attention to the key difference of reversibility between primary and secondary cells. Inform students that Lithium-Ion batteries are the type of batteries they are likely to have in their smartphone.
- Slide 13 - Secondary cells - extension
  The development in battery technology has slowed since the discovery of Lithium-Ion batteries. Scientists are struggling to make any major improvements on the Lithium-Ion battery. A latest development in the technology is flow-cell batteries. The main benefit to this technology is the large storage capacity. This is particularly helpful due to the need for large storage requirements for renewable energy sources. The main drawback is the cost of the materials.
- Slide 14 - Lithium-Ion batteries
  Ask students which type of cell a lithium-ion cell is (A: Secondary cell).
- Slide 15 - Lithium-Ion Batteries
  The main advantage to Lithium-Ion batteries is their low density, high efficiency and storage capacity. This makes them ideal for use in portable device. The advantages outweigh the drawbacks, hence the common utilisation of the technology.
- Slide 16 - End of section
  This is the end of the section on energy storage. Ask the students if they have any questions on what has been covered so far. Ask the students to list all the types of secondary cell listed on slide 10. See how many as a class they can name (A: Lead-acid, Nickel-Cadmium, Nickel-Metal Hydride, Lithium-Ion).
- Slide 17 - Introduction to fuel cells
  Fuel cells often utilise hydrogen as a fuel source, BUT other fuels can be used. The benefit of hydrogen fuel cells in transport over electric vehicles is the lack of recharge time. If hydrogen is used as a fuel, then no CO2 will be produced. High energy efficiency, mention that the efficiency of fuel cells varies between different types. Emphasise to the students that in a hydrogen fuel cell there will be no CO2 emissions. Ask the students where they think hydrogen come from. A: The majority of all commercially available hydrogen comes from the cracking of methane. Therefore, fossil fuels are still being depleted to produce the hydrogen and the problem has not been solved. Hydrogen could be produced through the electrolysis of water. Although this requires electricity, this can be provided by renewable energy sources. Using renewable energy sources to electrolyse during the production of hydrogen is a way to store excess energy produced from renewable energy sources. The hydrogen can be easily stored in a tank and then used to power a fuel cell or can be combusted to produce energy on demand. This helps to solve some of the energy storage issues surrounding renewable energy sources.

- Slide 18 - Drawbacks to hydrogen as a transport fuel
  Cost; high catalyst and manufacturing costs as it is a new technology discourages the public from investment. Infrastructure; people will not buy hydrogen powered vehicles or power supplies if there is not a readily available fuel source (e.g. no hydrogen pumps at the fuel station). Public perception; many members of the public believe that hydrogen is a more dangerous fuel, therefore discouraging them from investing in that technology. Ask the class if they think hydrogen is more dangerous than natural gas. Take a vote to see how many of the class think hydrogen is a more dangerous fuel. Invite and encourage a class discussion but do not answer the question until the demonstration video has been played.

- Slide 19 - Balloon demonstration
  This demonstration video shows three balloons, one filled with butane, another hydrogen and another ethanol being set on fire. This shows what would happen to the fuel in case of an accident (link to a car crash). After watching the video, ask the class if any of them have changed their mind on how dangerous hydrogen is? Retake the vote and see how the number has changed if it has at all.

- Slide 20 - Fuel safety
  This slide demonstrates the areas in which hydrogen is actually safer than butane and ethanol. However, reinforce the point all three fuels are still very dangerous. Emphasise that as hydrogen is so light it will rise, causing less danger compared to conventional fuels which will sink as a result of a density greater than air. Also consider the dangers of storing hydrogen as a compressed gas as well as the low ignition temperature of hydrogen.

- Slide 21 - Safety Question
  Use https://www.mentimeter.com/ to gather the students response to whether hydrogen is more safe to power a car compared to petrol. Menti is an online voting tool that the students can respond to questions using their smartphones.

- Slide 22 - Car Crash Simulation
  Show the students the clip from 0.22-0.43. This shows that during a car crash petrol is more dangerous. This is as the liquid petrol will drip out of the car and if the fuel catches alight then the entire vehicle can quickly become engulfed in flames. Whereas, as hydrogen is less dense than air it will quickly disperse upwards, this will limit the chance of the car catching alight, which is critical if passengers are trapped inside the car.

- Slide 23&24 Acid hydrogen fuel cell
  Take the student through step by step how the fuel cell works with the aid of the diagram. Link it to the previous REDOX chemistry they will have studied. Link the half equations to the diagram.

- Slide 25&26 Alkali hydrogen fuel cell
  Highlight the key difference between an alkali and acid hydrogen fuel cell. The difference in ions and therefore half equations is key to be noted. $H+$ ions are used in an acidic cell with OH- being used in an alkali cell. This should make sense from the students previous studies of acids and bases.

- Slide 27 - Hydrogen fuel cell demonstration kit
  This video shows how a simple hydrogen fuel cell works in real life.

- Slide 28 - What is a PEM fuel cell?
  This slide shows a labeled diagram of a hydrogen fuel cell that could be used in a car. Talk through each bit in the fuel cell.

- Slide 29 - PEM
  Inform the students that this is extra knowledge that they are not required to know for their exams. This is the type of fuel cell which is likely to be used in smaller cars. The catalyst is needed on the electrodes to increase the rate of the REDOX reactions. Highlight that using platinum as a catalyst will be very expensive as it is a precious metal.

- Slide 30 - 5 layer MEA fuel cell
  This exploded diagram of a PEM cell shows the different components that are present within a PEM fuel cell. The middle picture shows an assembled 5 layer membrane electrode assembly fuel cell.
  Gas diffusion layer - a fibrous porous medium to ensure a uniform distribution of gases on the electrode surface as well as the transport of electrons.
  Membrane - conducts protons from anode to cathode.
  Mounted catalyst coating - platinum nanoparticles catalyse the reaction, reducing the required operating temperature of the fuel cell.
  Gasket - used to seal the fuel cell.

- Slide 31 - PEM drawbacks
  Link back to the platinum. State that using a precious metal with large scale manufacturing techniques is not currently economically viable. The scale up of making the membrane needed in the fuel cell is a difficult process. Introduce students to the concept that scale up is not linear.

- Slide 32- PEM solutions
  This slide explains some of the research that the centre for Hydrogen and Fuel Cell Research at the University of Birmingham's School of Chemical Engineering is currently working on to overcome the issues associated with PEM technology. Link to students previous rate of reaction work, increasing the surface area will increase the rate of reaction. Increasing the surface area of the catalyst will increase the rate of reaction, therefore less catalyst will be needed to achieve the same rate of reaction. The use of nanoparticles will allow for the fuel cells to become economically viable. The way that the catalyst is added to the membrane will also effect the efficiency of the cell. Therefore, research into different development techniques and the use of ink dispersing solvents may be able to increase PEM fuel cell performance.

- Slide 33 - Solid oxide fuel cells
  Highlight to students that this is a different type of fuel cell. Uses fossil fuels, but operates at a greater efficiency than combustion methods, thus reducing the amount of emissions released for the same amount of energy produced. The use of nickel catalysts instead of platinum, reduces the cost of the fuel cells, thus making them cheaper. However, the high operating temperature will increase the operating cost of the fuel cell.

- Slide 34 - Fuel cell comparison
  This slide directly compares the PEM and solid oxide fuel cells. The conclusions that students should draw from the comparison is that PEM is more suited to smaller power requirements such as portable devices and city cars, whereas Solid oxide fuel cells are more suited to large methods of public transport and energy distribution.

- Slide 35 - How does a hydrogen car work?
  Talk through the diagram on the slide. The electrical current produced from the fuel cell will drive an electric motor that will power the car. A battery storage system is required to store excess energy if the car is stationary with the fuel cell operating (e.g. while stopped at traffic lights). The car in the diagram was designed and built by the University.

- Slide 36&37 - Hydrogen powered cars
  Ask the students which car they would prefer. Most will probably opt for the sports car that you are able to get for the same price as a standard hydrogen powered car. Highlight this is the issue with current technology that uses are dissuaded from hydrogen powered cars due to the cost and lack of fuelling infrastructure. California seems to be a hot spot for hydrogen powered cars. This could be as a result of high levels of investment into fueling stations.

- Slide 38 - Metal hydrides
  Metal hydrides absorb hydrogen like a sponge. The hydrogen is chemically bonded to the metals inside the capsule. This allows for large volumes of gas to be stored in a small space at a low pressure. Thus, increasing the safety of the fuel storage. However, the increased weight of the extra metals makes this a very heavy and therefore expensive option for use in cars.

- Slide 39 - Hydrogen tank vs Hydride
  This video shows the key differences between the two methods of storing hydrogen.

- Slide 40 - Other hydrogen powered transport options
  Talk about the advantages of using hydrides in a maritime setting as the hyrides can be used to power the boat as well as the boats ballasts (part of the boat for stability). As trains run constantly throughout the day without switching off, solid oxide fuel cells are suited as they don't need to be constantly heated or cooled and they can provide the large power output required. The train in the picture is the UK's first mainline hydrogen train that was developed in partnership with the university.

- Slide 41 - Plenary and questions
  Ask if the students have any questions on the content covered in the lesson. Then ask the students to write down two things they did not know about hydrogen fuel cells before the lesson.