STUDENT WORKBOOK

CHEMISTRY FeSTiVAlS

CHEMISTRY FOR GOOD CHALLENGE

MAKING A MICROBIAL FUEL CELL

NAME:

SCHOOL:

Salters' Institute

LEARNING OUTCOMES

1. **Find out what a microbial fuel cell is and how it works.**
2. **Discover the process of alcohol fermentation and how redox reactions are involved in this process.**
3. **Demonstrate that a voltage can be produced using microbes.**

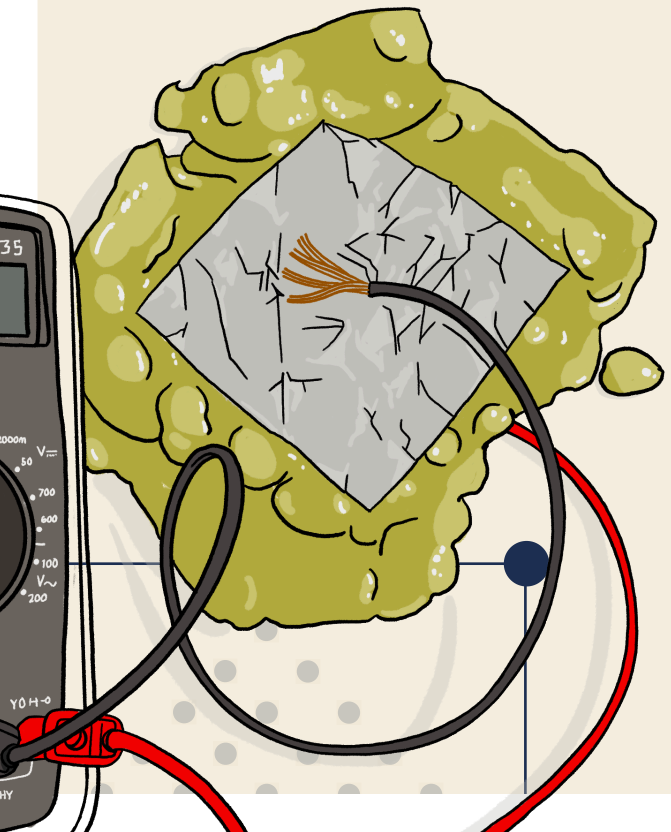
Information

Fuel cells produce energy using redox reactions. A microbial fuel cell (MFC) is a type of fuel cell that uses living microorganisms such as yeast, algae or bacteria to produce electrical energy from chemical energy.

The first microbial fuel cells were investigated in 1911 by a scientist called Michal Cresse Potter, who used brewers' yeast in his experiments [1]. Today MFCs are used to generate energy for low power applications where batteries would be impractical. MFCs have also been used to harvest energy from waste water treatment plants.

Most microbial fuel cells have a limited operational range of environmental conditions; typically between 20 – 40°C and a pH between 5 and 7. This is due to the optimal growth conditions for the microbes used within the fuel cells).

Yeast are special microbes capable of the process of fermentation. In anaerobic conditions (where no oxygen is present) yeast use a process known as fermentation to produce the energy required for growth. In fermentation, yeast breaks down sugars to produce ethanol and carbon dioxide. This biochemical reaction is widely utilised in baking and brewing. During fermentation, yeast can produce electrons.



Remember

Oxidation is the term used to describe the loss of electrons from a substance, whilst reduction is the term used to describe the gain of electrons by a substance.

In most biochemical systems, both oxidation and reduction reactions happen at the same time. When both oxidation and reduction reactions take place at the same time, this is called a redox reaction.

In the first reaction, the sucrose is broken down into glucose and fructose by invertase, an enzyme occurring in yeast:

sucrose + water + $\xrightarrow{\textit{invertase}}$ glucose

$C_{12}H_{22}O_{11} + H_2O + \xrightarrow{\textit{invertase}} 2\ C_6H_{12}O_6$

Glucose is oxidised, losing electrons in the process. A molecule in the yeast, called NAD$^+$, then gains the electrons and is reduced. During this redox process, ethanol and carbon dioxide are formed.

The overall equation for the fermentation of glucose by yeast is:

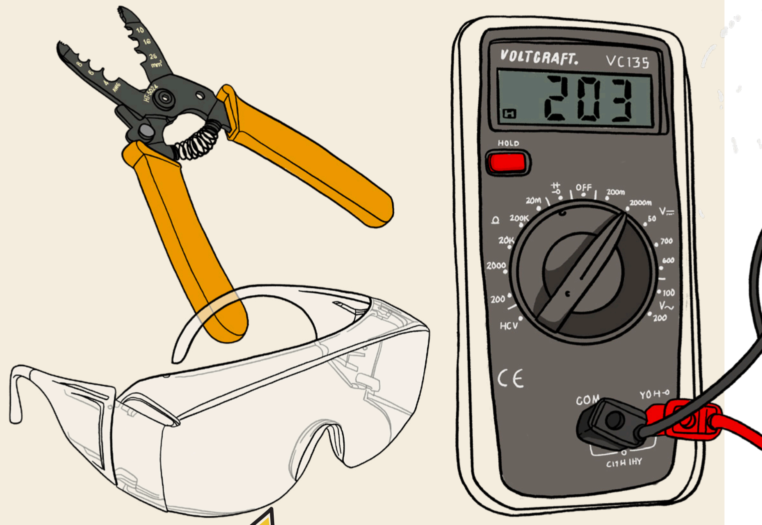
glucose → ethanol + carbon dioxide

$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$

In this experiment, by encasing the yeast in jelly an anaerobic environment is created. The jelly is rich in sugar (sucrose). The jelly also contains citric acid, which will act as the electrolyte in this MFC. An electrolyte is a substance which conducts electricity and connects the positive and negative electrodes (i.e. red and black wires). As electrons are produced, they can be diverted through the MFC before the NAD+ is reduced. The kitchen foil electrodes collect the voltage produced in the fuel cell, which then runs through the leads to the multimeter and back into the jelly, where the reaction continues until the reactants are used up.

YOU WILL NEED

- **Block of jelly (containing sugar), any flavour**
- **Dried baking yeast**
- **Kitchen foil**
- **Catering wrap / cling film**
- **Container that will hold 600ml liquid with a liquid depth of 5 – 8cm**
- **1L measuring jug**
- **200ml beaker**
- **200ml measuring cylinder**
- **Balance and weighing boat**
- **Stirring rod**
- **Thermometer**
- **2 paper plates**
- **Blunt / table Knife**
- **Multimeter or Voltmeter**
- **2 leads – one black, one red**
- **Wire strippers**
- **Timer / watch**
- **Scissors**
- **Ruler**
- **Sellotape**
- **Kettle**
- **Access to a fridge**



Safety

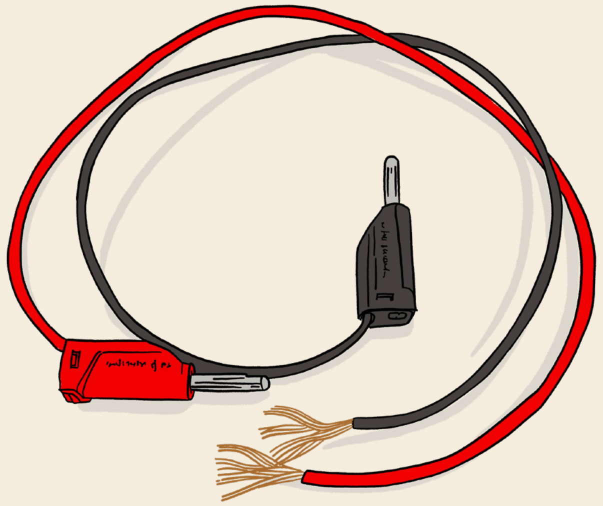
- **Take care handling hot sugary liquids. Wear eye protection whilst making the jelly. Alternatively, your teacher might prepare this for you and give it to you when slightly cooled.**
- **Take care with scissors and wire cutters. Ask for help if required.**
- **Do not eat anything made in a science experiment.**
- **Wash your hands after this experiment.**

ACTIVITY 1

Making a yeast-jelly microbial fuel cell

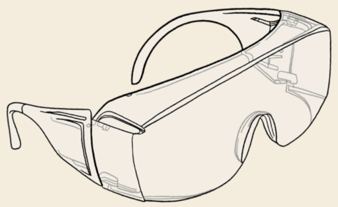
Instructions

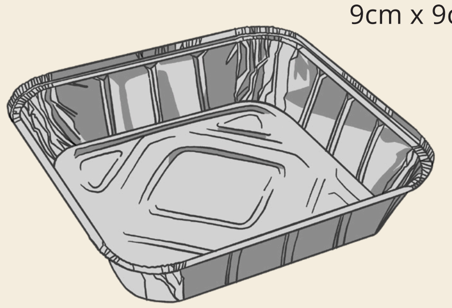
1. Using the scissors, cut just below the plug on one end of the black lead. Using the wire strippers, remove 2cm of the plastic coating from the cut end of the lead to reveal the copper wire. Gently fan the wires out to make a wide contact at the end of the lead. Repeat with the red 4mm lead. They should now look like the illustration below.



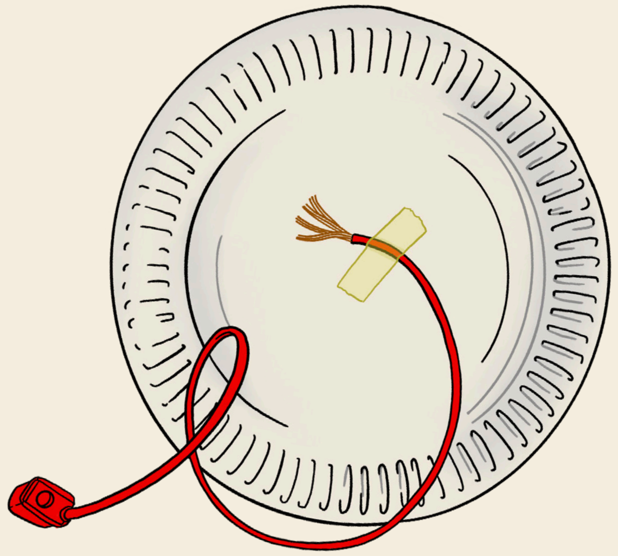
Preparing the leads to make the electrodes.

2. Cut two 7cm x 7cm squares of kitchen foil. Using Sellotape, tape the copper wire fan from the black lead onto the middle of one side of the first square of kitchen foil and the red to the other. These will be your electrodes.

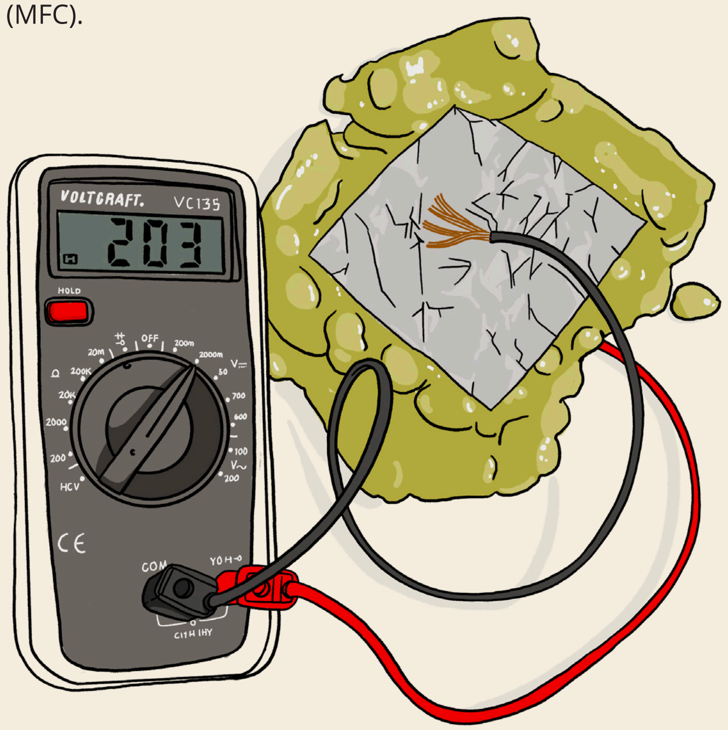




3. Add 5g of dried yeast to the beaker. Add 100ml of cold tap water. Stir gently with a stirring rod until the yeast forms a smooth mixture. Leave for 15 minutes for the yeast to become active.
4. Tear up the jelly block into small cubes and add to the measuring jug.
5. Put on your eye protection for this step. Add 250ml of boiling water from a kettle to the measuring jug containing the jelly pieces. Stir using a stirring rod until the jelly is completely dissolved. Add a further 250ml cold tap water to the jug and stir to mix.
6. Add the thermometer to the jug of hot jelly and let it cool until the liquid reaches 38°C.
7. Add yeast mixture from step 3 to the jelly mixture. Stir to mix thoroughly.
8. Line the food container with cling film. Pour the jelly / yeast mixture into the food container and place in a science preparation fridge (not a fridge used for food preparation or storage) and leave to set for approximately 2 – 3 hours.
9. When the jelly is set, place a paper plate over the container, invert the jelly and gently peel off the cling film to reveal a slab of yeast jelly. Use the knife to cut a 9cm x 9cm square of jelly.



10. Place the red electrode onto the second paper plate, with the sellotaped wire touching the plate and the kitchen foil upwards. Connect the plug end of the red electrode to the voltage port on the multimeter.
11. Carefully transfer the 9cm x 9cm yeast jelly square onto the prepared red electrode.
12. Place the black electrode on top of the jelly, with the kitchen foil in good contact with the jelly surface and the taped copper wire on the top. Connect the plug end of the black electrode to the COM port on the multimeter. This should now look like illustration below. You have now made a microbial fuel cell (MFC).
13. Immediately turn on the multimeter and take a reading of the voltage (in mV). Record the reading in the results in the table on the next page, then start your timer. Leave your microbial fuel cell in a warm room.
14. Using the multimeter, take readings of the voltage every at least 15 minutes over a period of 1.5 hours. Gently pressing the electrode down into the jelly surface helps ensure a good contact before taking each reading. Record the readings in the results table on the next page. Plotting a graph of the change in voltage over time may help you answer some of the questions below.



Connecting the Microbial Fuel Cell to the multimeter.

Time (minutes)	Voltage Reading (mV)
0 minutes	
15 minutes	
30 minutes	
45 minutes	
60 minutes	
75 minutes	
90 minutes	

Questions arising from the experiment

1) Why does the jelly become 'puffy' after several hours at room temperature?

2) Can you explain how the voltage changes over time with reference to the fermentation reactions of the yeast in the jelly?

3) Are there any limitations on the environmental conditions where a yeast-jelly fuel cell might be used or what it might be used for?

CHALLENGE

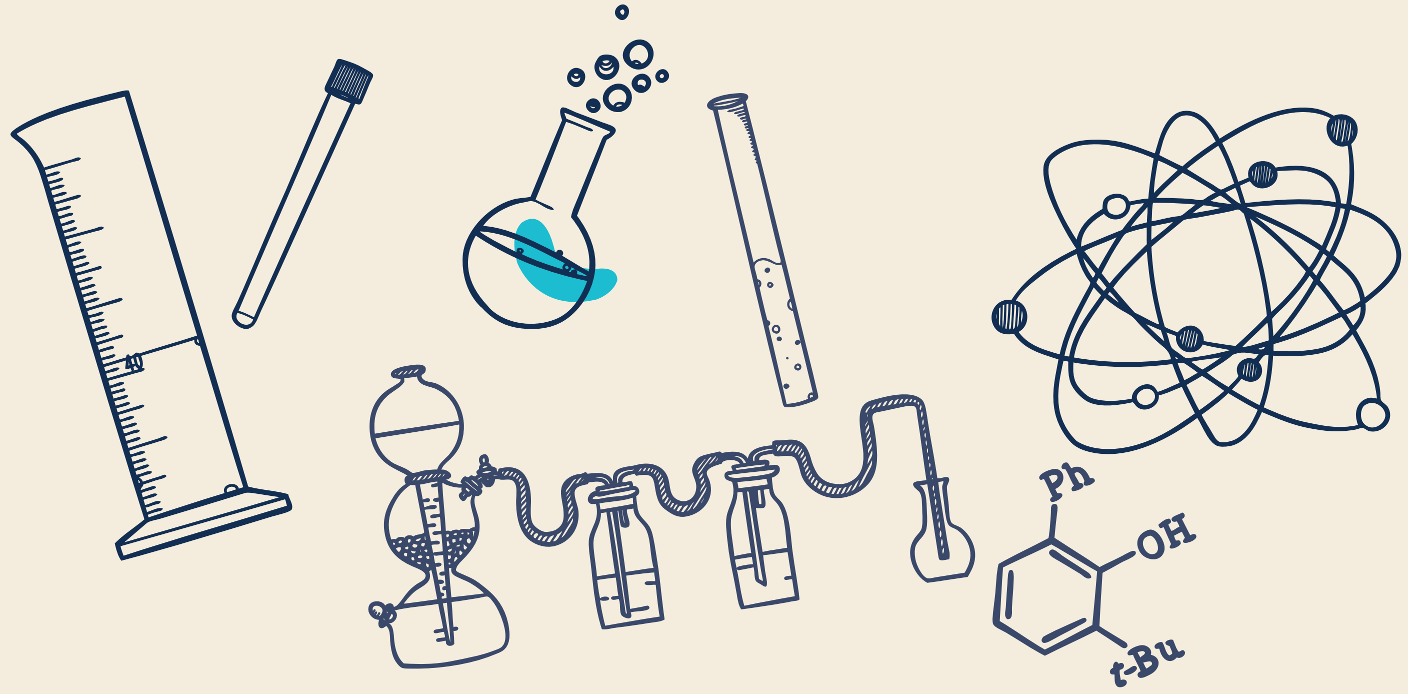
Try adapting this experiment to produce the highest voltage output possible. You could try altering the: volume of jelly, size of electrodes, running temperature, sugar content of the jelly (use sugar free jelly granules and add sugar separately), yeast content of the jelly, or even connecting several yeast / jelly MFCs together!

What's next?

Now that you have tried out this experiment why not check out how you can use your results to help you come up with ideas fto build sustainable cities and communities for the future. Head to **festivalsofchemistry.org** to find out more!

Did you know

Recently it has been disovered that some microorganisms, such as cable bacteria, can conduct electricity!



[1] Potter, M. C. (1911). 'Electrical Effects Accompanying the Decomposition of Organic Compounds'. Proceedings of the Royal Society B: Biological Sciences. 84 (571): 260–76.

This article can be found at:

https://royalsocietypublishing.org/doi/pdf/10.1098/rspb.1911.0073

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