The heat is on: heating food and drinks with chemical energy

Have you ever longed for a hot drink or meal but had no fire or stove to hand? **Marlene Rau** presents two activities from the *Lebensnaher Chemie-unterricht* portal that use chemical reactions to heat food – and to introduce the topic of exothermic reactions.

Image courtesy of Martin Müller / pixelio

Heater meals

Heater meals – originally developed for military use – are ready-made self-heating meal packs. They can be heated in many ways – by pressing a button on the packaging, unwrapping and shaking the pack, or pouring the contents of one bag into another and waiting for a few minutes – all of which use exothermic chemical reactions. These meals can be used to motivate students to study such reactions relatively safely and without the use of a burner. Plus there is the added value of discussing the negative ecological aspects of disposable meals.

For the following experiment, we use the Crosse & Blackwell heater-meal system, which relies on the reaction of magnesium and salt water to produce hydrogen:

$$Mg\ (s) + 2H_2O\ (l) \rightarrow Mg^{2+}\ (aq) + H_2\ (g)\uparrow + 2OH^-\ (aq)$$

s: solid; l: liquid; g: gaseous; aq: in solution; the vertical arrow indicates that gas is released.

This reaction is very slow, due to passivation, so to speed it up, iron and salt are added. Passivation is the process by which a material is made less reactive, usually by the deposition of a layer of oxide on its surface: if you place a strip of magnesium into cold water, its surface will oxidise to magnesium hydroxide ($Mg(OH)_2$), and this coating will prevent further reaction.

Therefore, in the heater meal, iron is added to the magnesium, leading to the production of a local cell – small-scale corrosion that happens where two metals of different reactivity are in contact under humid conditions – which speeds up the exothermic reaction. Because the electron potential of magnesium is lower than that of iron (the less reactive metal), electrons will pass from the magnesium to the iron, and only from there into the water. Although magnesium cations (Mg^{2+}) and hydroxide anions (OH^-) continue to be formed, they are separated by the iron and cannot combine to form magnesium hydroxide. As a result, the magnesium does not become passivated by a coating of magnesium

Images courtesy of Gregor von Borstel

The heater-meal pack: the meal (silver bag), heater bag into which the meal is placed (orange), salt-water bag (see-through), magnesium/iron mixture (white bag, taken out of the orange bag), spoon

hydroxide, which would lower the reactivity.

Because the differently charged magnesium and hydroxide ions are mobile, in pure water they would soon form magnesium hydroxide, the charge would be equilibrated and the reaction would slow down again. To prevent this, sodium chloride is added to the water, so that the sodium (Na^+) and chloride (Cl^-) ions from the salt can move to the magnesium and hydroxide ions instead, equilibrating the charge.

The experiment can be used to introduce and discuss the topics of electron transfer, local cell, passivation, sacrificial anodes, corrosion and the composition of water (covalent bonds, polarity and oxidation numbers). It takes about 45 minutes plus discussion time and has been successfully tested with 14-year-olds to study electron transfer reactions and corrosion, as well as with older students to work on electrochemistry.

Materials

Demonstration materials

- A magnesium strip
- Cold (unheated) saturated sodium chloride solution (salt water)
- Phenolphthalein solution
- A Crosse & Blackwell heater-meal pack (available from a range of suppliers)[w1]
- A heat-resistant glass
- A laboratory thermometer

Materials per group

- An empty tea bag
- A small amount (a few grains, covering the tip of a spatula) of the magnesium / iron powder mixture taken from a Crosse & Blackwell heater-meal pack. Mixing magnesium and iron powder yourself tends not to work since it is already partly oxidised. The powder mixture in the heater meal packs is vacuum-sealed.
- A 50 ml syringe
- 10 ml saturated sodium chloride solution
- A 20 ml syringe
- A three-way stopcock
- A small beaker
- A plastic tube fitting on the valves of the stopcock (about 10 cm long)
- A bowl filled with water
- A burning candle
- A test tube
- Phenolphthalein solution <1% per weight

REVIEW

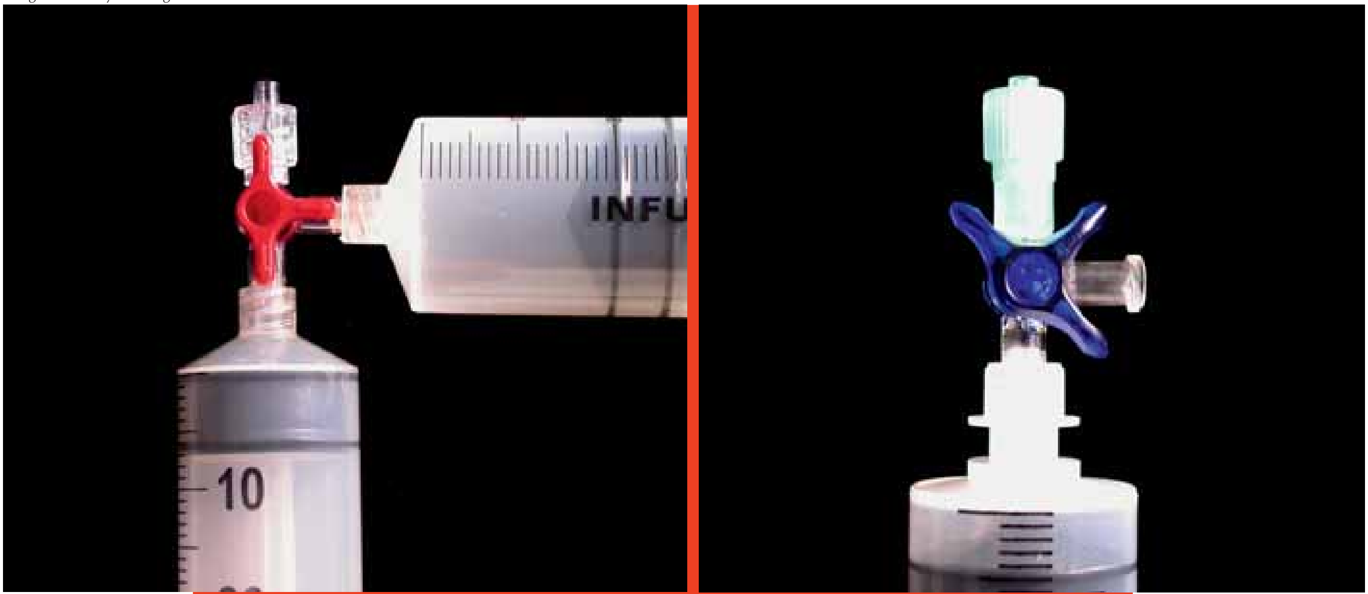
- **Chemistry**
- **General science**
- **Energy**
- **Ages 8-19**

This article allows students to discover the link between classroom science and the real world. With experiments that have a wow factor – often missing from practical lessons – students can develop and build skills and knowledge.

The main subject addressed is chemistry, but the teacher could adapt the lesson to include discussions of energy from other subjects, for example keeping warm, survival in cold climates, and treatment of sports injuries. The experiments could also be used to trigger a discussion of how science works.

Nick Parmar, UK

Images courtesy of Gregor von Borstel



A closed and an open three-way stopcock

The plastic materials required for the experiment can be ordered as part of the ChemZ[w2] kits, which were developed in collaboration with the *Lebensnaher Chemieunterricht* (LNCU)[w3] project, but are also available from most medical and chemical lab suppliers.

Procedure

1. Show a film about the heater meal[w4].
2. Show the heater meal to the students.
3. Pour the contents of the heater-meal pack into a heat-resistant glass with a thermometer and observe the reaction – it heats up and bubbles are produced.

   Note: if you use the contents of only two of the four packages of magnesium / iron mixture, you can save the contents of the other two for the students' experiments – it will be sufficient for about 20 student groups. Even with only two of the packages for the demonstration, the heater meal will reach a temperature of 100 °C after about one minute.
4. Discuss: why does this work? What is happening? What kind of gas is produced?
5. Explain the reaction of magnesium – ignore the iron and salt for the moment.
6. Demonstrate that a magnesium strip shows a weak reaction with cold saturated salt solution (which is what is added in the heater meal): a few gas bubbles are visible, and adding a droplet of phenolphthalein solution gives a light pink colour.
7. Before starting, demonstrate how to perform the oxy-hydrogen test: hold the top of a test tube close to a flame, allowing the gas in the tube to combust. There are two possible positive results:
   a) If the tube contains both hydrogen and oxygen, the hydrogen will combust with a 'squeaky pop'. Under normal lab conditions, this is the usual result, as the tube will also contain oxygen from the air.
   b) If the tube is completely filled with hydrogen, there will be no sound, but the gas combusts with colourless flame and the resulting water will fog the test tube. Furthermore, the exothermic reaction will heat the tube. Students often mistake this for a negative result (no hydrogen).
8. Place the students into groups of three to perform the heater-meal experiment. Because of the resulting heat, the reaction speeds up, so should only be performed on a small scale (as suggested).

   At the local cell, magnesium hydroxide is produced. If desired, this can be detected using phenolphthalein (see below).
9. Hand out the worksheet (see page 49 or download it from the *Science in School* website[w5]) describing how to carry out the heater-meal experiment. The students will now be ready to start.

Student worksheet

Safety note: Wear safety goggles. The reaction creates highly flammable gas – be careful. See also the general safety note on the *Science in School* website (www.scienceinschool.org/safety) and on page 65.

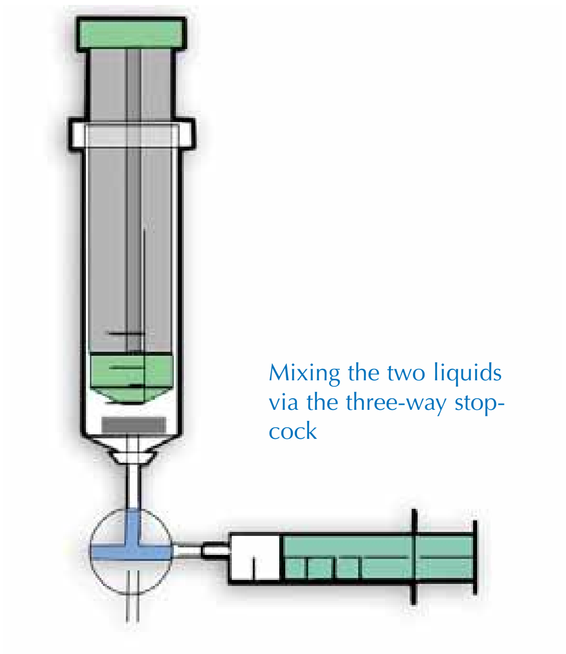
1. Put the metal powder mixture into an empty tea bag and stuff this into a 50 ml syringe (without the tea bag, the powder could block the syringe). Press out the air.
2. Fill the 20 ml syringe with salt water and connect it to the large syringe using a three-way stopcock.
3. Turn the stopcock's valve to let the two materials flow together in the closed system.

   As the reaction proceeds, gas will collect in one of the syringes.
4. As soon as more than 25 ml of gas has collected, open the stopcock and let the salt water flow out, collecting it in a beaker.

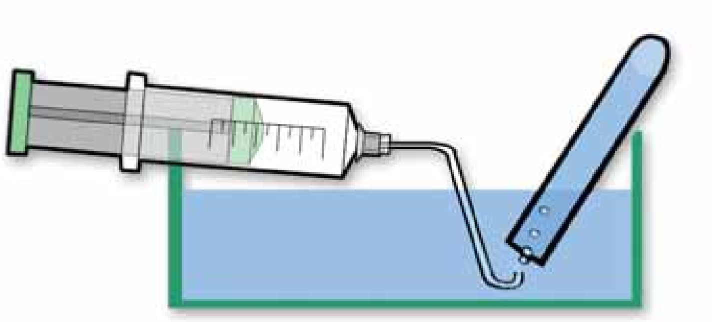
   Safety note: because of the resulting heat, the reaction speeds up (chain reaction). Keep a careful eye on it, to make sure you let the water out of the syringe before the gas that is produced pushes the piston out of the syringe.
5. Once you have released the water, close the valve to keep the gas in the syringe, and attach the plastic tube to the valve. If gas continues to be produced, leave the valve open.
6. Press the piston of the syringe to push the gas into a test tube through a pneumatic trough (use the plastic tube, bowl of water and test tube as in the diagram).
7. Perform the test for hydrogen by holding the mouth of the test tube in a flame (see diagram below), making sure you hold the top of the tube close enough to the flame. The test should be positive.

Optional: add one droplet of phenolphthalein solution to the water you collected in the beaker. What happens? Why?

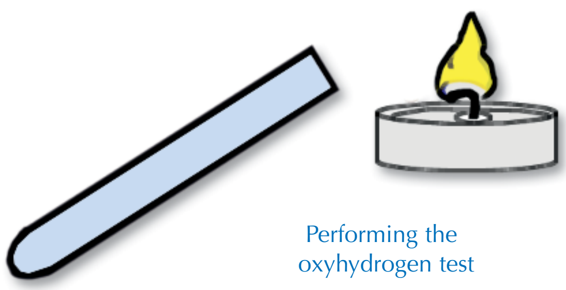
Health and safety note: the remaining liquids can be disposed of in the sink. Clean the plastic materials with water and leave them to dry.



Mixing the two liquids via the three-way stop-cock



Collecting the gas



Performing the oxyhydrogen test

Images courtesy of Gregor von Borstel

Discussion

Other reactions commonly used in heater meals include the oxidisation of iron, the reaction of anhydrous calcium chloride with water (see below) or, for cooling, the reaction of ammonium nitrate fertiliser with water.

Further experiments such as making your own heat and cold packs, or determining the oxygen content in the air with the aid of the iron oxidation reaction used in heat packs, are described on the LNCU website[w3].

This activity can also form part of a lesson in which the students develop a script for a TV science programme to answer a viewer's question on the function of heater meals. The English version of this worksheet is available on the *Science in School* website[w5], the German one on the LNCU website[w3].

A quick cup of hot coffee

In this activity, students heat coffee using anhydrous calcium chloride and water. The activity works well as part of a teaching unit on dissolving salts in water, to introduce the energetic aspects of this process. Students should already be familiar with ionic and covalent bonds. The activity works well with groups of three students aged 14 and over.

One possibility is to discuss lattice energy, using as an example from everyday life cold packs that rely on an endothermic reaction triggered by bending a metal plate. The following activity can then be used to introduce the notion of hydration energy and to demonstrate that the reaction by which some salts dissolve is an exothermic reaction.

The activity is relatively safe – the most dangerous aspect is the possibility of breaking glass by not handling it carefully.

Materials per group

- About 10 g anhydrous calcium chloride
- Different sizes of beakers
- Water
- Styrofoam / polystyrene (use reasonably large pieces as smaller pieces are a nuisance when they become charged and 'stick' everywhere)
- Two laboratory thermometers
- Soluble coffee powder
- Further items to awaken the students' imagination, such as rubber bands, foil, batteries, etc.

Student worksheet

1. Using the materials provided, how can you achieve the highest possible temperature change when making coffee?

   You have 5 minutes to discuss your experimental approach in the group. Before you put your plan into action, check the safety (not the feasibility) of it with your teacher.

   You then have 10 minutes to perform the experiment. If you want to change your procedure part way through, check with your teacher.

2. Before you start, record the starting temperature of the air and the coffee, and note the amount of coffee (in ml) you are making.

3. During the experiment, measure the air and coffee temperatures and note down the maximum temperature you achieve.

Safety note: Wear safety goggles; do not drink the coffee.

BACKGROUND

The source of the activities: *Lebensnaher Chemieunterricht*

In 2003, four German chemistry teachers joined forces to create a web portal to share their best teaching ideas: *Lebensnaher Chemieunterricht*[w3] (LNCU, chemistry lessons relevant to everyday life). Their collection has grown steadily, and they offer a wide selection of activities for all age ranges from primary to upper-secondary school, linking to major curricular topics in chemistry, such as the periodic table, titration, and air and water, plus biology and physics activities for the youngest students.

Their German-language materials are freely available as downloadable PDFs and Word® documents, with both instructions for teachers and worksheets for students. In addition, the website offers a range of videos on the activities and a list of more (German and English) websites with teaching ideas and relevant materials for the science classroom.

Potential approaches

Two problems the students often face are adding too little calcium chloride to the water (the more they use, the more heat will be produced) and forgetting to insulate their beakers.

A common solution to the task is to improvise a small water bath by placing water and calcium chloride in a large beaker, and fixing styrofoam around the beaker with sticky tape. The coffee can then be heated in a smaller beaker in the improvised water bath.

The best result within the context of the LNCU project (see box) was achieved by filling a small beaker with water and placing it in a larger beaker with a layer of styrofoam in-between for insulation. The students then placed the calcium chloride, to which they had added very little water, in a small film canister. Attaching a string to it and a stone for weight, they let it hang into the water. The temperature of 50 ml of coffee changed from 20 to 44 °C in less than a minute.

Heating coffee with calcium chloride

Image courtesy of Gregor von Borstel

Discussion

Discuss the apparent contradiction between the behaviour of cold packs in previous experiments and the experiment you have just performed – in this case, the solution process is not endothermic. In the cold packs, more energy is required to destroy the salt's molecular lattice (lattice energy) than is released when water molecules surround the ions (hydration energy). The required energy is drawn from the surroundings, so the solution cools down. In the coffee experiment, in contrast, the hydration energy is higher than the lattice energy, so the process as a whole is exothermic. Hydration and lattice energy are fixed characteristics of an individual salt.

Further experiment

To follow this up, the students could try to achieve the lowest possible temperature using anhydrous calcium chloride, sodium chloride and ice. They may be surprised to find that the addition of anhydrous calcium chloride to ice (rather than water) does not increase the temperature. This is because the hydrogen bonds in the ice crystals first have to be broken, which requires energy, so that the full process is endothermic.

Web references

w1 – To order Crosse & Blackwell heater meals online, see: www.heatermeals.co.uk, www.aapnespis.no or www.dauerbrot.de

w2 - The ChemZ kits were developed in close collaboration with the LNCU project, and offer a range of plastic materials normally used in medicine for use in school labs. For more information and to order materials, see: www.chemz.de

w3 – The LNCU project is run by German chemistry teachers Andy Bindl, Andreas Böhm, Gregor von Borstel and Manfred Eusterholz. For more information (in German) and to access all materials, see: www.lncu.de

w4 – Videos of the heater meals (albeit an older version in which the packs were in deep plates rather than today's aluminium sachets) are available on the Dauerbrot website (www.dauerbrot.de) or via the direct link: http://tinyurl.com/6ewkvhw

as well as here www.aapnespis.no/Norsport1_0/show.htm

You can also find a photo demonstration of how the heater meals are prepared here: www.mlaltd.co.uk/store

w5 – To download the English worksheets of the main heater-meal and the heater-meal science TV show activities, see: www.scienceinschool.org/2011/issue18/lncu#resources

Resources

For some microscale chemistry experiments using disposable materials, from kindergarten to secondary-school level (in English and German), see: www.micrecol.de

If you find the idea of microscale chemistry experiments appealing, you may also like:

Kalogirou E, Nicas E (2010) Microscale chemistry: experiments for schools. *Science in School* **16**: 27-32. www.scienceinschool.org/2010/issue16/microscale

If you enjoyed reading this article, why not take a look at the full list of chemistry articles published in *Science in School*? See: www.scienceinschool.org/chemistry

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To learn how to use this code, see page 1.