The reaction of aluminium with copper salts

Description

Powdered aluminium and solid hydrated copper(II) sulfate do not react even on adding a little water, due to the unreactive oxide layer on the aluminium.

However, powdered aluminium and solid copper(II) chloride do react vigorously on adding a little water.

Topic

Displacement reactions of metals.

Timing

Less than five minutes.

Level

Pre-16.

Apparatus

- One 250 cm^3 beaker for each experiment
- Wash bottle containing water

Chemicals

- 3 g of solid copper(II) sulfate-5-water (copper sulfate) (harmful)
- 3 g of solid copper(II) chloride-2-water (copper chloride) (toxic)
- 3 g of powdered aluminium (highly flammable; contact with water releases a flammable gas - hydrogen)
- A few grams of powdered zinc (flammable; contact with water releases a flammable gas - hydrogen) (for the extension)

Method

Cover the base of a 250 cm^3 beaker with 3 g of solid copper(II) sulfate. Add a similar amount of aluminium powder. Then add enough water from the wash bottle to cover the solids, and swirl the mixture. No reaction occurs.

Cover the base of a 250 cm^3 beaker with 3 g of solid copper(II) chloride. Add a similar amount of aluminium powder. Then add enough water from the wash bottle to cover the solids. A vigorous exothermic reaction occurs (there is no need to swirl the mixture).

Teaching tips

Remind students of the relative positions of copper and aluminium in the reactivity series. Also point out to them the fact that aluminium has an oxide layer coating its surface because it is reactive and reacts rapidly with oxygen in the air. Thus, in the case of copper(II) sulfate they do not see the reaction between aluminium and the copper salt. However, copper(II) chloride solution can remove the oxide layer and thus demonstrates the true reactivity of aluminium with copper ions.

With students for whom the full explanation might be felt to be too complex, teachers might prefer to demonstrate only the reaction of aluminium powder and copper(II) chloride.

Extensions

The reaction between zinc powder and copper(II) sulfate solution can be demonstrated in the same way. This reaction takes place because the oxide layer present on the surface of zinc is less tenacious that that on aluminium. This reaction is exothermic but much less vigorous than that between aluminium and copper chloride. It has been used as the heat source for self-heating cans of soup.

Magnesium powder (or ribbon) or iron filings can also be used as the metal instead of aluminium in these displacement reactions.

Further details

An interesting variation of the reaction between aluminium and copper chloride using the aluminium in the form of a soft drinks can is described in L R Summerlin and J L Ealy Jr, *Chemical Demonstrations a sourcebook for teachers,* Washington DC: American Chemical Society ,1988, pp152-153. Here a scratch is made around the circumference of the inside of an aluminium drink can. This removes the protective lacquer applied to the can. Copper(II) chloride solution (1 mol dm^{-3}) is then poured into the can and reacts with the aluminium exposed by the scratch. This leaves the upper and lower halves of the can held together only by the paint on the outside and these can be pulled apart easily.

Another experiment in which the true reactivity of aluminium is demonstrated in T. Lister, *Classic Chemistry Demonstrations*, London: Royal Society of Chemistry, 1995, pp 39-40. Here the oxide layer is removed from the aluminium by using sodium hydroxide and mercury(II) chloride.

Theory

Even though aluminium is much higher than copper in the reactivity series, no reaction takes place with copper(II) sulfate because of the oxide layer present on the surface of the aluminium. This is quite tenacious and resists removal. If scratched, it rapidly reforms, as the newly exposed aluminium reacts rapidly with oxygen from the air. This oxide layer is the reason that aluminium can be used unpainted for garage doors, window frames *etc*.

One explanation for the vigorous reaction with copper(II) chloride is that the chloride ions act as good ligands and form a complex with Al^{3+} ions of the type $AlCl_4^-$ which helps to remove the oxide layer, thus exposing the unprotected aluminium to aqueous Cu^{2+} ions leading to the displacement reaction:

$2Al(s) + 3CuCl_2(aq)$? $2AlCl_3(aq) + 2Cu(s)$

or ionically:

$2Al(s) + 3Cu^{2+}(aq)$? $2Al^{3+}(aq) + 2Cu(s)$

Safety

- Wear eye protection.
- Protect the audience with a safety screen.
- Your employer’s risk assessment should be consulted before carrying out this activity. This activity is *unlikely to be* covered by model (general) risk

assessments used in UK schools. CLEAPSS has prepared a special risk assessment (below) that is likely to be acceptable to most employers. It is, however, the responsibility of the teacher carrying out the activity to check that this risk assessment is in fact acceptable to their employer. Bear in mind also that this may need some modification to suit local conditions.

Acknowledgement

This demonstration was developed by Dr Colin Chambers, formerly of Bolton Grammar School.

Model risk assessment

The model risk assessment below has been provided by CLEAPSS.

CLEAPSS SCHOOL SCIENCE SERVICE

Risk Assessment (to meet the COSHH and/or the Management of Health and Safety at Work Regulations)

Applicant: Royal Society of Chemistry

School/LEA: This risk assessment is likely to be acceptable to most education employers in England, Wales and Northern Ireland.

Operation: The reaction of aluminium with copper salts

This risk assessment applies to the procedure as described in the accompanying RSC document as outlined below.

Details of operation

About 3 g of solid copper(II) sulfate-5-water is added to a dry 250-ml beaker. About 3 g of aluminium powder is added. Enough water is added from a wash bottle to cover the solids and the mixture is swirled. No reaction occurs.

About 3 g of solid copper(II) chloride-2-water is added to a dry 250-ml beaker. About 3 g of aluminium powder is added. Enough water is added from a wash bottle to cover the solids and the mixture is swirled. A vigorous exothermic reaction occurs (there is no need to swirl the mixture)

Similar activities may also be undertaken using zinc or magnesium powder in place of aluminium powder.

Substance(s) possibly hazardous to health:	(a) Aluminium (b) Copper(II) sulfate-5-water (c) Copper(II) chloride-2-water (d) Hydrogen chloride gas (formed as a by-product) (e) Magnesium powder (f) Zinc powder
Classification under CHIP3 Regulations 2002	(a) Aluminium is flammable and contact with water can liberate extremely flammable gases. (b) Copper(II) sulfate-5-water is harmful if swallowed, irritating to eyes and skin and very toxic to aquatic organisms; it may cause long term adverse effects in the aquatic environment. (c) Copper(II) chloride-2-water is not classified by the CHIP regulations and suppliers may provide conflicting information. (d) Hydrogen chloride gas (formed as a by-product) is toxic by inhalation and causes severe burns (corrosive). (e) Magnesium is highly flammable and contact with water can liberate extremely flammable gases. (f) Zinc is flammable and contact with water can liberate extremely flammable gases.

Particular risks:	(a) The reaction between copper(II) chloride and aluminium is highly exothermic. (b) The steam produced was slightly acidic due to the formation of a little hydrogen chloride. (c) If the reaction is put to one side for disposal later on, the addition of more water by the teacher or technician can initiate further violent reactions. (d) The reactions between copper(II) salts and magnesium are highly exothermic.
Maximum exposure limits:	(a) -
Occupational exposure standards: (mg m^{-3})	(a) For hydrogen chloride 2 (LTEL), 8 (STEL)

Risk assessment

- The substances involved in this reaction are covered by CLEAPSS Hazcards: aluminium, *Hazcard* 1; copper salts *Hazcard* 27; hydrogen chloride, *Hazcard* 49; magnesium, *Hazcard* 59 and zinc, *Hazcard* 107.
- Although these reactions in these activities are not covered by CLEAPSS School Science Service *Hazcards*, the risk is no greater and may be less than a number of other reactions which are covered, eg aluminium reacting with iodine.
- Traces of hydrogen chloride can be detected by smell just above the beaker and there is enough to affect indicator paper. However, the quantities are small and a fume cupboard is not required.
- Under no circumstances should silver salts be substituted for copper salts.
- The bench should be protected from the risk of the beaker breaking or the contents boiling over. However, the latter should not happen using the quantities specified.
- The demonstrator should wear eye protection to BS EN 166 3 (eg goggles or face shield).
- The students should stand at least 3 m from the demonstration and wear eye protection.
- Once the demonstration is over, fill the beaker half full with water and allow it to cool down. The liquid can be decanted and the solid placed in the waste bin.

Assessor:

Dr T P Borrows, MA, PhD, CChem, FRSC *Director*

If further clarification is required, contact:

The School Science Service, Brunel University, Uxbridge UB8 3PH

Tel: 01895 251496

Notes

COSHH stands for Control of Substances Hazardous to Health. The regulations require that an assessment of risk should be made before substances hazardous to health are handled.

The substances covered are the reactants, the products and any intermediate or side products that are very toxic, toxic, harmful corrosive or irritant. Just because a substance carries no hazard label does not mean that it is completely safe.

The Management of Health and Safety at Work Regulations require a similar risk assessment for substances with other hazard classifications or activities involving hazardous procedures.

MEL stands for the Maximum Exposure Limit. On no account should the level of vapour exceed this value and as far as reasonably practicable the employer should see that exposure is kept as low as possible.

OES stands for Occupation Exposure Standard. Exposure should be either at the standard or preferably below. These values represent good practice. There are 2 limits. LTEL stands for long term exposure limit and is averaged over an 8 hour time weighted average (TWA) period. STEL is the short term exposure value and is averaged over a 15 minute TWA period. It is the value more relevant to schools. If a STEL is not specifically prescribed then the STEL for that substance is 3 times the LTEL value.