

## Discussion

- $$\text{CH}_3\text{OH}(\text{l}) + 1\frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$$

$$\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{g})$$

$$\text{C}_3\text{H}_7\text{OH}(\text{l}) + 4\frac{1}{2}\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g})$$
- $$\text{C}_3\text{H}_7\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{CO}(\text{g}) + \text{C}(\text{s}) + 4\text{H}_2\text{O}(\text{g})$$

(one of many possible equations)
- Air has a fixed supply of oxygen (21%). If a fuel has long chains, it needs more oxygen for complete combustion than air can supply. Due to the lack of oxygen, carbon monoxide (CO) and soot (C) will be produced instead of carbon dioxide.
- Propanol seems to produce the most heat energy per gram of fuel.
- As the carbon chain increases, so does the molar heat of combustion by a regular amount.
  - The increase is regular because each alcohol has an extra  $-\text{CH}_2$  group.
  - The average of the two increases is 456.65 kJ/mol. If the molar heat of combustion for propanol is increased by this amount, the estimated amount for butanol is 2020 kJ/mol.

## FOLLOW-UP

- Advantages: it could be produced from a renewable resource; it has non-polluting products of combustion; it has a higher ignition temperature and is therefore safer to transport and store. Disadvantages: production is still too expensive; it gives less energy per gram and fire, costly redesign of car engines is needed if pure ethanol is used; it is hygroscopic and thus may absorb water in wet weather, making the car difficult to start.
- $2\text{C}_2\text{H}_5\text{OH}(\text{l}) + 2\text{H}_2\text{O}(\text{g}) \rightarrow \text{CH}_3\text{CH}_2\text{OH}(\text{g}) + \text{CO}(\text{g})$
  - $\text{CH}_3\text{CH}_2\text{OH}(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightarrow \text{CH}_3\text{CH}_2\text{OH}(\text{g})$  (catalyst is also used)
- Biomass is a future source of methanol and ethanol. Ethanol can be produced from the fermentation of sugars and methanol (wood alcohol) can be produced from the destructive distillation of wood (cellulose).

## Sample risk assessment record

### INVESTIGATION 24: Heat of combustion of alcohols

Assessment team: \_\_\_\_\_

Date: \_\_\_\_\_ Year/group: 12

Ref: *Heinemann Chemistry Practical Manual*

Chemicals used	Conc. (mol/l)	Amount	User code	DG class/haz	Procedure as per Appendix D?	What are the hazards?
ethanol	pure liquid	50 mL	7-12	3	yes	Highly flammable
methanol	pure liquid	<50 mL	11-12	3/6.1 DHS	yes	Highly toxic vapour when ingested causes permanent blindness, highly flammable
1-propanol	pure liquid	<50 mL	7-12	3	yes	Highly flammable, toxic if ingested or inhaled

## Disposal of waste

Reuse all alcohols.

## How are risks controlled?

- wear safety glasses
- use gloves
- wash hands after use
- other (specify): Replace cap on spirit burner to extinguish the flame, keep burners capped

## Assessment of risk:

Risk for this investigation is not significant, provided appropriate control measures are in place as indicated above.

Approved by: \_\_\_\_\_

Date: \_\_\_\_\_

## Investigation 25

### Galvanic cells

#### Rationale

Students are introduced to galvanic cells by constructing a simple Daniell cell and investigating the relationship between voltage and current when the volume of electrolyte is changed. In the second part, students measure the potential difference of a series of different half-cells, while keeping the  $\text{Cu}/\text{Cu}^{2+}$  half-cell as a reference.

#### Syllabus

Perform a first-hand investigation to identify the conditions under which a galvanic cell is produced.  
Perform a first-hand investigation and gather first-hand information to measure the difference in potential of different combinations of metals in an electrolyte solution.

## Background knowledge

Students have a knowledge of the terms oxidation and reduction, and of the activity series of metals. However, before introducing the galvanic cell, you should set up a displacement of metals demonstration or give it as a first-hand investigation (see worksheet on next page), as it is essential that students understand the relationship between the position of a metal in the activity series and the electron-attracting ability of its ions. (The more active metal displaces the less active metal from a solution of its ions.)

## Hints

- Prepare a set of metal displacement reactions, as per the worksheet, using only 3 mL of each 0.1 M solution and a partially immersed metal strip. Let it stand overnight for more definite results. Let students complete the worksheet before attempting the rest of the investigation.
- $\text{Ti}(\text{II})$  chloride could be used instead of nitrate, but it is less soluble.
- The Daniell cell could be also demonstrated using a galvanometer.

# Worksheet: Metal displacement reactions

Test tube	Solution	Metal	Observation
A	copper(II) sulfate	iron	
B	copper(II) sulfate	lead	
C	copper(II) sulfate	zinc	
D	iron(II) sulfate	copper	
E	iron(II) sulfate	lead	
F	iron (II) sulfate	zinc	
G	lead(II) nitrate	copper	
H	lead(II) nitrate	iron	
I	lead(II) nitrate	zinc	
J	zinc sulfate	copper	
K	zinc sulfate	iron	
L	zinc sulfate	lead	

## Questions

- Which of the three metals gave:
  - three reactions
  - two reactions
  - one reaction
  - no reaction
- List the four metals in decreasing order of reactivity.
 

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
- Fill in the missing words.
 

In all the reactions observed, the \_\_\_\_\_ active metal displaces the \_\_\_\_\_ active metal from solution.
- Write a chemical equation for each observed reaction.
 

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_
- Would you expect a replacement reaction to occur between:
  - magnesium and copper(II) sulfate?
  - tin and zinc sulfate?

## Procedure A: DANIELL CELL

### RESULTS

Voltage may differ slightly when the beaker is full and half-full. The current is slightly higher when the beaker is full.

#### Discussion: PROCEDURE A

- a from Zn to Cu  
b oxidation  
c reduction
- $\text{Zn(s)} + \text{Cu}^{2+}(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{Cu(s)}$   
The salt bridge completes the circuit in the cell. The ions in the solution carry charges, so that positive ions (cations) travel towards the cathode and negative ions (anions) travel towards the anode via the salt bridge.
- The voltage of a cell depends on the potential difference of the electrodes, not on the volume of electrolyte. The current depends upon the number of moles of electrons involved in the redox reaction. With a larger volume or more concentrated solution around the electrode, there are more ions to accept electrons and more electrons will be given out at the other electrode.
- As the galvanic cell operates, ions are being used up and the concentration of electrolyte is decreasing, making fewer electrons available in the circuit.

- The copper ion ( $\text{Cu}^{2+}$ ) is the stronger competitor for electrons as copper is less reactive than zinc.

## Procedure B: HALF-CELL POTENTIAL

### RESULTS

All test half-cells are negative. Voltages vary from 0.15 V for tin, to nearly 2 V for magnesium. Different instruments will give different results.

#### Discussion: PROCEDURE B

- a reduction reaction of  $\text{Cu}^{2+}$  ions to solid copper  
b oxidation
- Tin may give a negative result if the measured voltage is lower than 0.34 V.
- All predicted voltages are higher than measured. This is because school laboratory conditions vary from standard conditions. Other factors include dirty electrodes, poor connections, instrument errors, etc.
- As the metals of two half-cells are further apart in the activity series, the galvanic cell shows a higher potential difference. A lower potential difference (lower voltage) is observed when metals are close in the activity series.

## FOLLOW-UP

- a around 0.2 V  
b 0.47 V
- a anode:  $\text{Zn/Zn}^{2+}$ ; cathode:  $\text{Pb/Pb}^{2+}$  as it is less active  
b oxidation in the zinc half-cell (zinc metal loses electrons); reduction in the lead half-cell ( $\text{Pb}^{2+}$  ions reduced to lead solid)  
c 0.63 V
- Lead-acid car battery  
a anode reaction:  $\text{Pb(s)} + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{PbSO}_4(\text{s}) + 2\text{e}^-$   
cathode reaction:  $\text{PbO}_2(\text{s}) + 4\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + 2\text{e}^- \rightarrow \text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O(l)}$   
b  $0.13 + 1.69 = 1.82 \text{ V}$   
c Advantages: rechargeable, long-lasting, cheap to produce  
Disadvantages: heavy, lead pollutes environment
- Watches and calculators have button cells. One type of button cell is a zinc/silver battery  
a Overall reaction for button cell:  $\text{Zn(s)} + \text{Ag}_2\text{O(s)} \rightarrow \text{ZnO(s)} + 2\text{Ag(s)}$   
This reaction is not reversible, while the reaction in the car battery is.  
b The button cell is cost-effective, practical, small and portable. A car battery, while cheap to produce, is very heavy.  
c In our 'throw away' society, a button cell (which cannot be recharged) is more frequently disposed of than a car battery. Both galvanic cells have a major impact on technological advances in our society—their success has sparked further research into more advanced galvanic cells.  
d Car batteries are difficult to dispose of due to the toxic nature of lead and lead(II) oxide. A button cell is easier to dispose of as it is less toxic and much smaller.

## INVESTIGATION 25: Galvanic cells

Assessment team: \_\_\_\_\_ Date: \_\_\_\_\_ Year/group: 12

Ref. Heinemann Chemistry Practical Manual

Chemicals used	Conc. (mol/l)	Amount	User code	DG class/haz	Procedure as per Appendix D?	What are the hazards?
zinc sulfate	1	100 mL	7-12	CW	yes	Slightly toxic if ingested
tin(II) chloride	1	50 mL	7-12	CW	yes	Moderately toxic if ingested
potassium nitrate	0.1	20 mL	7-12	5.1	yes	Forms explosive mixtures with active metals
aluminium nitrate	1	50 mL	7-12	5.1 CW	yes	Moderately toxic if ingested, skin irritant
copper(II) sulfate	1	100 mL	7-12	Not haz CW	yes	Slightly toxic if ingested and by skin contact

## Disposal of waste

Collect all leftover solutions of copper(II) sulfate and zinc sulfate. These should not be washed down the sink. If you cannot reuse them, reprocess as follows: Add a few drops of phenolphthalein indicator to the collected solution until a permanent pink colour is obtained. Place about two tablespoons of solid sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) into the solution to precipitate heavy metal carbonates. Let this settle and decant the clear solution down the sink. When dry, the solid carbonate can be wrapped in paper and disposed of in the garbage bin.

## How are risks controlled?

- wear safety glasses
- use gloves
- wash hands after use

## Assessment of risk:

Risk for this investigation is not significant, provided appropriate control measures are in place as indicated above.

Approved by: \_\_\_\_\_ Date: \_\_\_\_\_

## Investigation 26

## Beetroot: a natural indicator

## Rationale

Students prepare fresh beetroot indicator and test its colour in acidic, neutral and basic solutions. Using pH meters or probes and dataloggers, they measure the transition pH of this natural indicator. Students could also use the same method to test for colour and transition pH of other indicators.

## Syllabus

Perform a first-hand investigation to prepare and test a natural indicator. Identify data and choose resources to gather information about the colour changes of a range of indicators.

## Background knowledge

Students have learned the operational definitions of acids and bases. They should understand what a pH probe measures.

## Hints

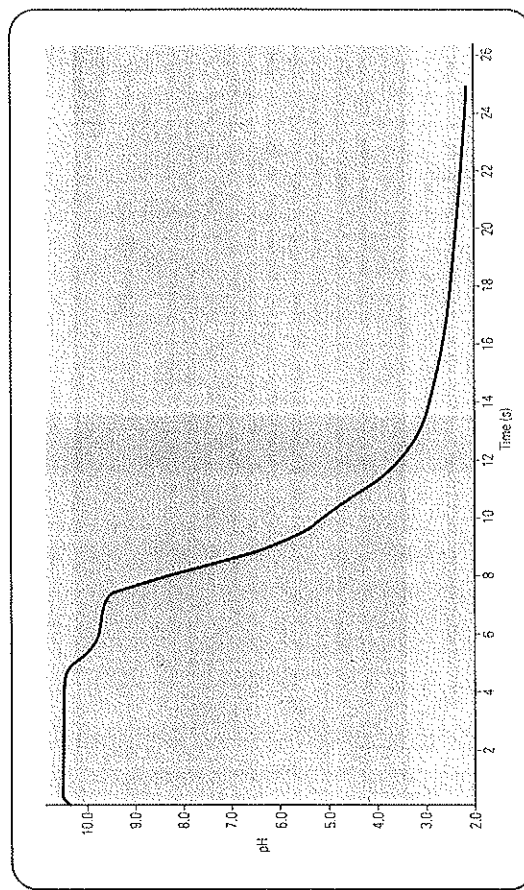
- A pH meter works the same way as a pH probe in a datalogger. The results obtained in this investigation were obtained using pH probes and a datalogger by PASCO Instruments.
- It is advisable to test other indicators, as specified in the syllabus, to give students a better understanding of the chemical uses of indicators in titrations.
- If your school has a datalogger with a pH probe, it should be used to demonstrate titration curves of various strengths of acids and bases, and relate these to the transition pH of selected indicators. This could be done at the later stage, when students are familiar with acid-base titrations and hydrolysis of a salt. A sample of two such titrations, using a datalogger and pH probe, is shown in Figures 1 and 2.
- Figure 1 was obtained using a magnetic stirrer, while Figure 2 was obtained when the solution was stirred with the probe. (For further information on PASCO Instruments, call Walsh & Co Pty Ltd, freecall 1 800 682 155.)

TABLE 1

Indicator	Water	NaCl solution	HCl solution	NaOH solution
beetroot juice	red	slightly lighter red	reddish-blue	yellow

Indicator/pH	Acid colour	Transition colour	Basic colour
beetroot	reddish-blue, 5.7	pale mauve, 11.6	pale yellow, 12.2

FIGURE 1  
Titration of 0.1 M  $\text{Na}_2\text{CO}_3$  with 0.1 M HCl