Lithium-ion cells

This resource accompanies the article **Better batteries** in *Education in Chemistry* which can be viewed at rsc.li/3FaHfUg and delves into the research developments in battery science.

Learning objectives

1. Use oxidation numbers to identify oxidation and reduction.
2. Write half-equations to demonstrate reactions occurring in lithium-ion cells.
3. Calculate E^{θ} values using data.
4. Use terminology correctly to explain processes happening in lithium-ion cells.

Introduction

Electrochemical cells have important commercial applications as portable electricity supplies to power electronic devices such as mobile phones, tablets and laptops. Rachid Yazami and John B Goodenough played a key role in the development of rechargeable batteries such as lithium-ion cells. The cathode in a lithium-ion cell is made of lithium cobalt oxide ($LiCoO_2$) and the anode is made of graphite (C). Oxidation always occurs at the anode (AN OX) and reduction at the cathode (RED CAT). The batteries can be charged and discharged. This relies on the movement of lithium ions in the electrolyte through a semipermeable barrier and electrons in an external circuit. Over time, the battery performance decreases from repeated insertion of lithium ions into the graphite structure.

How to use the resource

The questions may be used at the end of the topic, either in class or as homework, to reinforce understanding of electrochemical cells and identify misconceptions.

Questions 1, 2, 4, and 6 test recall of definitions, task learners to work out oxidation numbers and perform simple calculations.

Questions 3, 7 and 8 require learners to apply their knowledge to deduce half-equations at the relevant electrodes, make links to the electrochemical series and construct the lithium-ion cell notation.

Question 5 enables you to check learners' understanding of terminology and correct any misconceptions around the use of keywords and process in electrochemistry.

Answers

1.

(a) +3
(b) +4

2.

(a) The standard electrode potential (E^{θ}) of a half-cell is the voltage measured under standard conditions when the cell is connected to a standard hydrogen electrode (SHE).
(b) Standard conditions are 100 kPa, 298 K and an ion concentration of 1.0 $\mathrm{mol\ dm^3}$.
(c) We use standard conditions to help us compare values. Equilibrium reactions are affected by changing conditions. Changing the temperature and concentration of ions will affect the position of equilibria and, in turn, affect the E^{θ} of the cell.

3. Positive electrode: $\mathrm{Li^+ + CoO_2 + e^- \leftrightharpoons Li^+[CoO_2]^-}$
E^{θ} is more positive so the reaction proceeds in the forward direction.

Negative electrode: $\mathrm{Li \leftrightharpoons Li^+ + e^-}$
E^{θ} is more negative so the reaction proceeds in the reverse direction.

Oxidation always occurs at the anode (AN OX). Reduction occurs at the cathode (RED CAT). The more negative E^{θ} species loses electrons; it is more easily oxidised. Electrons are lost to the electrode making the electrode more negative.

The half-equations show that lithium can only lose electrons to the graphite electrode. Therefore, graphite is the negative electrode (anode). Lithium ions react with the lithium cobalt oxide electrode, causing a reduction reaction at the positive electrode (cathode).

4. Reduction occurs at the positive electrode. Reduction is a gain of electrons (OILRIG). The cobalt ion has been reduced from +4 to +3.

5. It is simpler to use positive/negative electrode.
Key things to remember:

- Reduction occurs at the cathode (RED CAT).
- Oxidation is loss of electrons (OILRIG); oxidation always occurs at the anode.
- Electrons flow from the anode to the cathode.

The table summarises the differences between galvanic and electrolytic cells when assigning cathode and anode.

Cell	Positive electrode	Negative electrode
Galvanic cell (discharge) Electrical energy is generated	$\mathbf{Li^+ + CoO_2 + e^- \leftrightharpoons Li^+[CoO_2]^-}$ **Cobalt is reduced** **Reduction at cathode (RED CAT)** **Cathode**	$\mathbf{Li \leftrightharpoons Li^+ + e^-}$ **Lithium is oxidised** **Oxidation at anode (AN OX)** **Anode**
Electrolytic cell (charging) Electrical energy is used to drive reaction	$\mathbf{Li^+[CoO_2]^- \leftrightharpoons Li^+ + CoO_2 + e^-}$ Cobalt ion is oxidised Oxidation at anode (AN OX) **Anode**	$\mathbf{Li^+ + e^- \leftrightharpoons Li}$ Lithium ion is reduced Reduction at cathode (RED CAT) **Cathode**

6.

$$E^{\theta}{}_{overall} = E^{\theta}{}_{red} - E^{\theta}{}_{ox}$$
$$= -3.04 - (+0.56)$$
$$= -3.60\ \mathrm{V}$$

show formula
show substitution
include unit and sign

7. Lithium reacts vigorously with water, so an organic solvent is used.

8. $\mathrm{Li}\ |\ \mathrm{Li^+}\ ||\ \mathrm{Li^+, CoO_2}\ |\ \mathrm{LiCoO_2}$
ROOR: **R**educed species I **O**xidised species I I **O**xidised species I **R**educed species