Lithium-ion cells

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 ($\mathrm{LiCoO_2}$) and the anode is made of graphite (C). 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.

The questions require you to link oxidation, reduction and electrode potentials. You need to apply your understanding of the terminology when describing electrochemical processes. You will also be tasked to write half-equations, calculate an electromotive force (EMF) and construct the lithium-ion cell notation.

Questions

The table shows the standard electrode potentials for two reactions involving lithium ions.

Half equation	E^{θ} (V)
$\mathrm{Li^+ + e^- \rightleftharpoons Li}$	–3.04
$\mathrm{Li^+ + CoO_2 + e^- \rightleftharpoons Li^+[CoO_2]^-}$	+0.56

1. State the oxidation state of cobalt in:

(a) $\mathrm{Li^+[CoO_2]^-}$
(b) $\mathrm{CoO_2}$

2.

(a) Define standard electrode potential.
(b) What are the standard conditions?
(c) Why are standard conditions important?

For the following questions, consider the lithium-ion cell during discharge.

3. Use the E^{θ} data to identify reactions that occur at the electrodes. Write the half-equations for both the positive and negative electrodes.

Hint: what does a highly negative E^{θ} value imply? You need to identify the species that is more easily oxidised.

4. At which electrode does reduction occur? Explain your reasoning using cobalt.

5. Is it better to use the terms positive/negative electrode or anode/cathode? Explain your ideas by completing the table using the following equations and phrases:

☐ $Li^+ + CoO_2 + e^- \leftrightharpoons Li^+[CoO_2]^-$

☐ $Li^+ + e^- \leftrightharpoons Li$

☐ Lithium ion is reduced

☐ Cathode

☐ Oxidation at anode (AN OX)

☐ Anode

☐ $Li^+[CoO_2]^- \leftrightharpoons Li^+ + CoO_2 + e^-$

☐ $Li \leftrightharpoons Li^+ + e^-$

☐ Anode

☐ Lithium is oxidised

☐ Cathode

☐ Reduction at cathode (RED CAT)

Hint: it is important to know the difference between a galvanic cell and an electrolytic cell. Which process always occurs at the cathode?

Cell	Positive electrode	Negative electrode
Galvanic cell (discharge) Electrical energy is generated		
Electrolytic cell (charging) Electrical energy is used to drive reaction	Cobalt ion is oxidised Oxidation at anode (AN OX)	Lithium ion is reduced Reduction at cathode (RED CAT)

6. Calculate the overall EMF (E^{θ}) of the cell during discharge.

7. Why is the electrolyte a mixture of lithium ions in an organic solvent?

8. Construct the cell notation for the lithium-ion cell.