Past-paper walk-through

Cell Potential Under Nonstandard Conditions ▪ 9.10

eXercise

Questions in this set

- 2015 Q1

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.
[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

Question 1

Half Reaction	E at pH 11 and 298 K (V)
$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$	$+0.34$
$ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$	-1.31
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$	-1.60
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$	-2.78

(a)(i) Early forms of metal-air cells used zinc as the anode. Zinc oxide is produced as the cell operates according to the overall equation below.

$$2Zn(s) + O_2(g) \rightarrow 2ZnO(s)$$

Using the data in the table above, calculate the cell potential for the zinc-air cell.

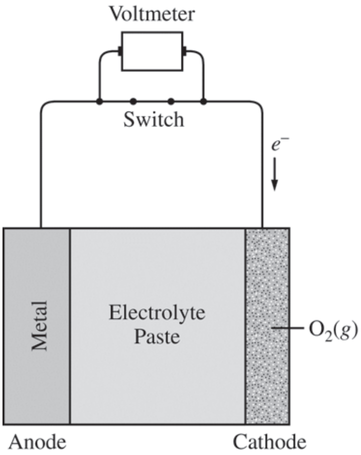
(a)(ii) The electrolyte paste contains OH^- ions. On the diagram of the cell above, draw an arrow to indicate the direction of migration of OH^- ions through the electrolyte as the cell operates.

Question 1

schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal a
given in the table below.

Half Reaction	E at pH 11 and 298 K (V)
$O_2(g) + 2\,H_2O(l) + 4\,e^- \rightarrow 4\,OH^-(aq)$	+0.34
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	–1.31
$Na_2O(s) + H_2O(l) + 2\,e^- \rightarrow 2\,Na(s) + 2\,OH^-(aq)$	–1.60
$CaO(s) + H_2O(l) + 2\,e^- \rightarrow Ca(s) + 2\,OH^-(aq)$	–2.78

Question 1


Voltmeter
Switch
e^-
Metal
Electrolyte
Paste
$O_2(g)$
Anode
Cathode

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.
[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

| Half Reaction | E at pH 11 and 298 K (V) | |—|—| | $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$ |
$+0.34$ | | $ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$ | -1.31 | |
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$ | -1.60 | |
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$ | -2.78 |

Question 1

(b)(i) A fresh zinc-air cell is weighed on an analytical balance before being placed in a hearing aid for use. As the cell operates, does the mass of the cell increase, decrease, or remain the same?

(b)(ii) Justify your answer to part (b)(i) in terms of the equation for the overall cell reaction.

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

Half Reaction	E at pH 11 and 298 K (V)
$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$	$+0.34$
$ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$	-1.31
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$	-1.60
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$	-2.78

Question 1

(c)(i) The zinc-air cell is taken to the top of a mountain where the air pressure is lower. Will the cell potential be higher, lower, or the same as the cell potential at the lower elevation?

(c)(ii) Justify your answer to part (c)(i) based on the equation for the overall cell reaction and the information above.

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

Half Reaction	E at pH 11 and 298 K (V)
$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$	$+0.34$
$ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$	-1.31
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$	-1.60
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$	-2.78

Question 1

(d) Metal-air cells need to be lightweight for many applications. In order to transfer more electrons with a smaller mass, Na and Ca are investigated as potential anodes. A 1.0 g anode of which of these metals would transfer more electrons, assuming that the anode is totally consumed during the lifetime of a cell? Justify your answer with calculations.

Question 1

2015 ▪ Q1

Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

[Schematic diagram of a metal-air cell: a "Voltmeter" box connected via a "Switch" to two electrode leads. An arrow labeled e^- points down into the right electrode. The cell body is divided into three vertical regions labeled (left to right) "Metal", "Electrolyte Paste", and a stippled region with an arrow pointing to it labeled $O_2(g)$. The bottom of the left region is labeled "Anode" and the bottom of the right region is labeled "Cathode".]

Half Reaction	E at pH 11 and 298 K (V)
$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$	$+0.34$
$ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2OH^-(aq)$	-1.31
$Na_2O(s) + H_2O(l) + 2e^- \rightarrow 2Na(s) + 2OH^-(aq)$	-1.60
$CaO(s) + H_2O(l) + 2e^- \rightarrow Ca(s) + 2OH^-(aq)$	-2.78

Question 1

(e)(i) The only common oxide of zinc has the formula ZnO. Write the electron configuration for a Zn atom in the ground state.
(e)(ii) From which sublevel are electrons removed when a Zn atom in the ground state is oxidized?

Solution 1

(a)(i)

Mark scheme

- E_cell = E_cathode - E_anode = 0.34 V - (-1.31 V) = 1.65 V, using the given standard reduction potentials for the O2/OH- cathode half-reaction and the ZnO/Zn anode half-reaction. 1 point for the correct cell potential (1.65 V).

Solution 1

(a)(ii)

Mark scheme

- The arrow should point to the left: OH- ions migrate from the cathode (right, where O2 is reduced and OH- is produced) toward the anode (left, where Zn is oxidized and OH- is consumed) through the electrolyte as the cell operates. 1 point for correctly indicating this right-to-left direction of migration.

Solution 1

(b)(i)

Mark scheme

- The mass of the cell increases as it operates. 1 point for correctly indicating an increase in cell mass.

Solution 1

(b)(ii)

Mark scheme

- Oxygen gas from the surrounding air enters the cell and reacts with Zn(s), producing ZnO(s); because mass (from O2) is added from outside the cell and ZnO(s) has more mass than the original Zn(s), the total mass of the cell increases as it operates. 1 point for this justification referencing the overall cell reaction 2Zn(s) + O2(g) -> 2ZnO(s).

Solution 1

(c)(i)

Mark scheme

- The cell potential will be lower at the top of the mountain, where air pressure (and thus the partial pressure of O2) is lower. 1 point for correctly indicating a lower cell potential.

Solution 1

(c)(ii)

Mark scheme

- O2(g), a reactant in the overall cell reaction, is at a lower partial pressure at the higher elevation; a lower O2 pressure makes the reaction quotient Q larger (closer to the equilibrium constant K). By the Nernst equation E_cell = E_cell_standard - (RT/nF) ln Q, moving Q closer to K decreases the magnitude of the cell potential. 1 point for a justification that relates lower O2 pressure/concentration to a larger Q, or a qualitative Nernst-equation argument reaching the same conclusion.

Solution 1

(d) Mark scheme

- For Na: 1.0 g Na x (1.0 mol Na / 22.99 g Na) x (1.0 mol e- / 1.0 mol Na) = 0.043 mol e-. For Ca: 1.0 g Ca x (1.0 mol Ca / 40.08 g Ca) x (2.0 mol e- / 1.0 mol Ca) = 0.050 mol e-. Because each mole of Ca releases 2 mol of electrons (vs. 1 mol for Na) and this outweighs Ca's larger molar mass, the 1.0 g Ca anode transfers more electrons (0.050 mol vs. 0.043 mol) and the cell with the Ca anode would transfer more electrons. 1 point for correctly calculating moles of electrons for both Na and Ca; 1 point for correctly taking 1 vs. 2 mol of electrons per mole of metal into account and reaching the correct conclusion that Ca transfers more electrons.

Solution 1

(e)(i)

Mark scheme

- Ground-state electron configuration of Zn: 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^10, equivalently written [Ar] 4s^2 3d^10. 1 point for the correct configuration.

Solution 1

(e)(ii)

Mark scheme

- Electrons are removed from the 4s sublevel when a ground-state Zn atom is oxidized (for transition/post-transition metals, the outermost ns electrons are lost before the (n-1)d electrons). 1 point for the correct answer (4s sublevel).