Electrochemistry - 2023 A2 Chemistry 9701

1. Nov/2023/Paper_9701/41/No.3(e, f)

(e) The $E^\ominus$ values for two electrode reactions are given.

$$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O \qquad E^\ominus = +1.77\,V$$

$$Cr^{3+} + e^- \rightleftharpoons Cr^{2+} \qquad E^\ominus = -0.41\,V$$

(i) An electrochemical cell is constructed with the following half-cells (electrodes):

- an acidified solution of H_2O_2, a platinum wire
- Cr^{2+} mixed with Cr^{3+}, a platinum wire.

Identify the positive half-cell and calculate the standard cell potential, $E^\ominus_{cell}$.

positive half-cell .... $E^\ominus_{cell}$ = ... V

[1]

(ii) Calculate the value of $\Delta G^\ominus$ for the cell reaction that occurs, per mole of H_2O_2.

$\Delta G^\ominus$ = ... $kJ\,mol^{-1}$ [2]

(f) The $E^\ominus$ values for two electrode reactions are given.

$$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O \qquad E^\ominus = +1.77\,V$$

$$Co^{3+} + e^- \rightleftharpoons Co^{2+} \qquad E^\ominus = +1.82\,V$$

An electrochemical cell is constructed with the following half-cells.

half-cell 1 an acidified solution of H_2O_2 under standard conditions, a platinum wire

half-cell 2 a solution containing 0.020 mol dm^{-3} Co^{3+} and 2.0 mol dm^{-3} Co^{2+}, a platinum wire

(i) Use the Nernst equation to calculate the value of *E*, the electrode potential of half-cell 2 under these conditions.

E = ... V [2]

(ii) Write an equation for the cell reaction that occurs in this cell under these conditions.

.... [1]

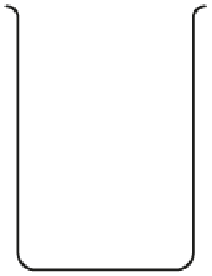
2. Nov/2023/Paper_9701/42/No.3

Some electrode potentials are shown in Table 3.1.

Table 3.1

electrode reaction	$E^\ominus$/V
$V^{2+} + 2e^- \rightleftharpoons V$	–1.20
$V^{3+} + e^- \rightleftharpoons V^{2+}$	–0.26
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$	+1.00
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	–0.44
$Fe^{3+} + 3e^- \rightleftharpoons Fe$	–0.04
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$	+0.89

(a) **(i)** Complete the diagram to show a standard hydrogen electrode.
Label your diagram. Identify all substances. You do **not** need to state standard conditions.



[1]

(ii) An electrochemical cell is set up using an Fe^{3+} / Fe^{2+} electrode and a standard hydrogen electrode.

Identify the positive electrode in the electrochemical cell and the direction of electron flow in the external circuit.

positive electrode ....

Electrons flow from the .... electrode to the .... electrode.
[1]

(b) The vanadium-containing species in the electrode reactions given in Table 3.1 are V, V^{2+}, V^{3+}, VO^{2+} and VO_2^+.

(i) Identify **one** vanadium-containing species that does **not** react with Fe^{2+} ions under standard conditions.

Use data from Table 3.1 to explain your answer.

....

.... [1]

(ii) Identify **all** the vanadium-containing species that will react with Fe^{2+} ions under standard conditions.

.... [1]

(iii) Write an equation for **one** of the possible reactions identified in **(ii)**.

.... [1]

(c) Another electrochemical cell is set up using an Fe^{3+}/Fe^{2+} electrode and an alkaline ClO^-/Cl^- electrode.

The concentration of Fe^{3+} is 1000 times greater than the concentration of Fe^{2+} in the Fe^{3+}/Fe^{2+} electrode. All other conditions are standard.

(i) Use the Nernst equation to calculate the E value of the Fe^{3+}/Fe^{2+} electrode.

Show your working.

E = ... V [2]

(ii) Write an equation for the reaction that occurs in the cell, under these conditions.

.... [1]

(d) Another electrochemical cell is set up using an Fe^{2+}/Fe electrode and an alkaline ClO^-/Cl^- electrode under standard conditions.

Calculate the value of $\Delta G^\ominus$ for the cell.

$\Delta G^\ominus$ = ... $kJ\,mol^{-1}$ [3]

(e) A solution of iron(II) sulfate, $FeSO_4(aq)$ is electrolysed with iron electrodes. Under the conditions used, no gas is evolved at the cathode.

A current of 0.640 A is passed for 17.0 minutes. The mass of the cathode increases by 0.185 g.

Use these results to calculate an experimental value for the Avogadro constant, *L*.

Show your working.

L = ... mol^{-1} [3]

(f) Iron(II) chloride, $FeCl_2$, is oxidised by chlorine to form iron(III) chloride, $FeCl_3$, under standard conditions.

$$2FeCl_2(s) + Cl_2(g) \rightarrow 2FeCl_3(s) \qquad \Delta H^\ominus = -128\,kJ\,mol^{-1}$$

Table 3.2

species	$S^\ominus / J\,K^{-1}\,mol^{-1}$
$Cl_2(g)$	223
$FeCl_2(s)$	120
$FeCl_3(s)$	142

(i) Use Table 3.2 and other data to calculate the Gibbs free energy change, $\Delta G^\ominus$, for this reaction.

Show your working.

$\Delta G^\ominus$ = ... $kJ\,mol^{-1}$ [3]

(ii) Predict whether this reaction becomes more or less feasible at a higher temperature.

Explain your answer.

The reaction becomes .... feasible.

explanation ....

....

[1]

[Total: 18]

3. June/2023/Paper_9701/42/No.1(c _ d)

(c) Potassium sulfite, K_2SO_3, is used as a food additive.

The concentration of sulfite ions, SO_3^{2-}, can be determined by titration using aqueous acidified manganate(VII) ions, MnO_4^-.

- A 250 cm³ solution contains 3.40 g of impure K_2SO_3.
- 25.0 cm³ of this solution requires 22.40 cm³ of 0.0250 mol dm⁻³ acidified MnO_4^- to reach the end-point. All the SO_3^{2-} ions are oxidised. None of the other species in the impure K_2SO_3 are oxidised.

The reaction occurs as shown by the two half-equations.

$$H_2O + SO_3^{2-} \rightarrow SO_4^{2-} + 2H^+ + 2e^-$$

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

(i) Give the ionic equation for the reaction between SO_3^{2-} and acidified MnO_4^-.

.... [1]

(ii) Calculate the percentage purity of the sample of K_2SO_3.
Show your working.

percentage purity of K_2SO_3 = ... [3]

(d) Potassium disulfite, $K_2S_2O_5$, is another food additive. The disulfite ion, $S_2O_5^{2-}$, has the displayed formula shown in Fig. 1.2.

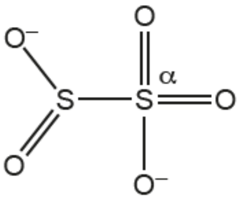


Fig. 1.2

Deduce the geometry (shape) around the S(α) atom in $S_2O_5^{2-}$.

geometry around S(α) .... [1]

4. June/2023/Paper_9701/42/No.9

(a) Define standard cell potential, $E^\ominus_{\text{cell}}$.

....

.... [1]

(b) An electrochemical cell is set up to measure $E^\ominus_{\text{cell}}$ of a cell consisting of an Fe^{3+}/Fe^{2+} half-cell and a Cl_2/Cl^- half-cell.

Draw a labelled diagram of this electrochemical cell.

Include all necessary substances. It is **not** necessary to state conditions used.

[3]

(c) The cell reaction for the electrochemical cell in **(b)** is shown.

$$Cl_2 + 2Fe^{2+} \rightarrow 2Fe^{3+} + 2Cl^- \qquad E^\ominus_{\text{cell}} = +0.59\,\text{V}$$

Calculate $\Delta G^\ominus$, in kJ mol^{-1}, for this cell reaction.

$\Delta G^\ominus$ = ... kJ mol^{-1} [2]

(d) Another experiment is set up using the same electrochemical cell.

In this experiment the Fe^{2+} concentration is 0.15 mol dm^{-3}. All other concentrations remain at their standard values.

The Nernst equation is shown.

$$E = E^{\ominus} + (0.059/z)\log\frac{[\text{oxidised species}]}{[\text{reduced species}]}$$

(i) Use the Nernst equation to calculate the electrode potential, E, for the Fe^{3+}/Fe^{2+} half-cell in this experiment.

$[E^{\ominus}: Fe^{3+}/Fe^{2+} = +0.77\,V]$

E = ... V [1]

(ii) Use your answer to **(d)(i)** to calculate E_{cell} for this electrochemical cell.

E_{cell} = ... V [1]

[Total: 8]

5. March/2023/Paper_9701/42/No.2(a, b)

Hypophosphorous acid is an inorganic acid.

The conjugate base of hypophosphorous acid is $H_2PO_2^-$.

(a) Give the formula of hypophosphorous acid.

.... [1]

(b) $H_2PO_2^-$ is a strong reducing agent. It can be used to reduce metal cations without the need for electrolysis.

equation 1 $HPO_3^{2-} + 2H_2O + 2e^- \rightleftharpoons H_2PO_2^- + 3OH^-$ $E^\ominus = -1.57\,V$

(i) In an experiment, an alkaline $HPO_3^{2-}/H_2PO_2^-$ half-cell is constructed with $[H_2PO_2^-] = 0.050\,mol\,dm^{-3}$.

All other ions are at their standard concentration.

Predict how the value of E of this half-cell differs from its $E^\ominus$ value.

Explain your answer.

....

....

....

.... [2]

(ii) The Cr^{3+}/Cr half-cell has a standard electrode potential of $-0.74\,V$.

An electrochemical cell consists of an alkaline $HPO_3^{2-}/H_2PO_2^-$ half-cell and a Cr^{3+}/Cr half-cell.

Calculate the standard cell potential, $E^\ominus_{cell}$.

$E^\ominus_{cell}$ = ... V [1]

(iii) Complete the diagram in Fig. 2.1 to show how the standard electrode potential of the Cr^{3+}/Cr half-cell can be measured relative to that of the standard hydrogen electrode.

Identify the chemicals, conditions and relevant pieces of apparatus.

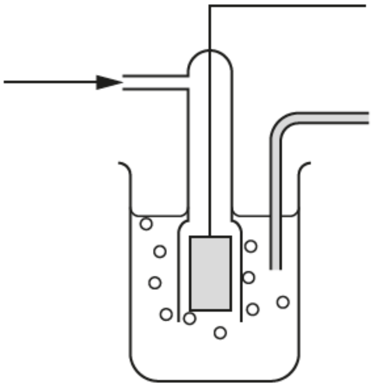


Fig. 2.1

[3]

(iv) Label Fig. 2.1 to show:

- which is the positive electrode
- the direction of electron flow in the external circuit.

[1]

(v) $H_2PO_2^-$ reduces Ni^{2+} to Ni in alkaline conditions.

Use equation 1 to construct the ionic equation for this reaction.

equation 1 $HPO_3^{2-} + 2H_2O + 2e^- \rightleftharpoons H_2PO_2^- + 3OH^-$

.... [1]