- A galvanic cell consists of a Cr^{3+}/Cr half-cell with unknown [Cr^{3+}] and a Ni^{2+}/Ni half-cell with [Ni^{2+}] = 1.20 M. The electromotive force of the cell at 25 °C was measured to be 0.55 V. What is the concentration of Cr^{3+} in the Cr^{3+}/Cr half-cell?

Marks 6

From the standard reduction potentials,

$$Cr^{3+}(aq) + 3e^- \rightarrow Cr(s) \qquad E^o = -0.74\ V$$
$$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s) \qquad E^o = -0.24\ V$$

The most negative is reversed to give an overall reaction and cell potential of

$$3Ni^{2+}(aq) + 2Cr(s) \rightarrow 3Ni(s) + 2Cr^{3+}(aq) \quad E^o = (+0.74 - 0.24)\ V = 0.50\ V$$

From the Nernst equation for this 6 electron reaction,

$$E = E° - \frac{RT}{nF} \ln Q = E° - \frac{RT}{nF} \ln \frac{[Cr^{3+}(aq)]^2}{[Ni^{2+}(aq)]^3}$$

$$= (0.50\ V) - \frac{(8.314\ J\ K^{-1}\ mol^{-1})(298\ K)}{6 \times 96485\ mol^{-1}} \ln \frac{[Cr^{3+}(aq)]^2}{(1.20)^3}$$

Solving this gives,

$$[Cr^{3+}(aq)] = 3.8 \times 10^{-3}\ M$$

Answer: **3.8 × 10^{-3} M**

Calculate the equilibrium constant of the reaction at 25 °C.

The equilibrium constant is related to the standard cell potential through:

$$E^o = \frac{RT}{nF} \ln K$$

Using E^o = +0.50 V,

$$0.50\ V = \frac{(8.314\ J\ K^{-1}\ mol^{-1})(298\ K)}{6 \times 96485\ mol^{-1}} \ln K$$

Solving this gives:

$$K = 5.5 \times 10^{50}$$

Answer: **5.5 × 10^{50}**

ANSWER CONTINUES ON THE NEXT PAGE

Calculate the standard Gibbs free energy of the reaction at 25 °C.

The Gibbs free energy change is related to the standard cell potential through:

$$\Delta G^{o} = -nFE^{o}$$
$$= - 6 \times (96485 \text{ mol}^{-1}) \times (0.50 \text{ V}) = -290 \text{ kJ mol}^{-1}$$

Answer: **-290 kJ mol^{-1}**

Express the overall reaction in the shorthand voltaic cell notation.

$Cr(s) \mid Cr^{3+}(aq) \parallel Ni^{2+}(aq) \mid Ni(s)$