Q1.

1 (a)  The EMF of a cell made up of the test electrode and a
standard hydrogen electrode.

EMF measured under standard conditions of T, P and concentration

2

(b)  

(i)  \( E_{\text{left}} = E_{\text{right}} - E_{\text{cell}} = 0.34 - 0.76 = -0.42 \, \text{(V)} \)

(ii)  

(iii) I  pink/red solid/ppt or copper will be formed or blue solution
fades or M dissolves/corrodess

\[ \text{Cu}^{2+} + \text{M} \rightarrow \text{Cu} + \text{M}^{2+} \]

II  hydrogen/gas evolved or M dissolves
(do not allow "M dissolves" for [2] marks in both I and II)

\[ \text{M} + 2\text{H}^+ \rightarrow \text{M}^{2+} + \text{H}_2 \]

6

(c)  

(i)  polarity of d. c. source:  ♂ is on the left, ♀ is on the right

electrolyte is Cu\textsuperscript{2+}(aq)/CuSO\textsubscript{4}/CuCl\textsubscript{2}/Cu(NO\textsubscript{3})\textsubscript{2} etc. or name

(ii)  moles of Cu  = 0.5/63.5  = 7.87 \times 10^{-3}

moles of e\textsuperscript{-}  = 2 \times 7.87 \times 10^{-3}  = 1.57 \times 10^{-2}

no. of coulombs  = 96500 \times 1.57 \times 10^{-2} = 1517 \, (C)

\[ \text{ecf in } n(e^-) \]

time  = 1520/0.5  = 5034 \, \text{seconds}  = 50.7 \, \text{min}

\[ \text{ecf in coulombs} \]

Total 13

Q2.
Q3.

1. (a) (i) Ammeter/galvanometer
   Clock/watch/timer (or rheostat)
   (For items above 2 in number, e.g. voltmeter, penalise [1])

   (ii) Diagram to show ammeter (allow symbol) in circuit, and
        complete circuit with \( \oplus \) terminal of power pack connected to LH
        electrode

   (iii) Volume/amount of hydrogen/gas
        Time
        Current/amperes/ammeter reading
        (ignore extra measurements)

   Part (a): [7]

(b) (i) \( F = L \times e \) [1]

(ii) \( L = 9.63 \times 10^4/1.6 \times 10^{-19} = 6.02 \times 10^{23} \) (must show working) [1]

   Allow 6.0 but not 6 or 6.01

   Part (b): [2]

Total: [9]

Q4.
Q5.

(a) 
(i) A is Cl₂/chlorine

B is NaCl or HCl or Cl⁻ [or words], etc.

C is salt bridge or KC/KNO₃, etc.

D is platinum/Pt

E is Fe²⁺ + Fe³⁺ or mixture of Fe(II) + Fe(III) salts

mention of standard conditions ([Cl⁻] of 1 mol dm⁻³ or Cl₂ at 1 atm
or T = 25°C/298 K)

(ii) \[ E^\circ = E^\circ_{\text{r}} - E^\circ_{\text{i}} = 0.77 - 1.36 = (-)0.59 \text{ (V)} \] (ignore sign)

(since R.H. electrode is negative) electrons flow (from right) to left or to the chlorine
electrode or anticlockwise or from (beaker) E to (beaker) B

(b) 
(i) \[ \Delta H = 3 \times (-167.2) + (-48.5) - (-399.5) \]

\[ = -150.6 \text{ or } 151 \text{ (kJ mol}^{-1}) \]
(correct ans [2])

(ii) \[ 2\text{Fe}^{3+} + \text{Cu} \rightarrow 2\text{Fe}^{2+} + \text{Cu}^{2+} \]

(or molecular: \[ 2\text{FeCl}_3 + \text{Cu} \rightarrow 2\text{FeCl}_2 + \text{CuCl}_2 \])

\[ E^\circ = 0.77 - 0.34 = (+) 0.43 \text{ (V)} \]

(no mark for −0.43V)

[Total: 12 max 11]
2 (a) NaCl: steamy fumes
   \[ \text{NaCl} + H_2SO_4 \rightarrow \text{NaHSO}_4 + HCl \] (or ionic, i.e. without the Na\(^+\))
   or \[ 2\text{NaCl} + H_2SO_4 \rightarrow \text{Na}_2\text{SO}_4 + 2HCl \]

NaBr: orange/brown fumes
   \[ 2\text{NaBr} + 3H_2SO_4 \rightarrow 2\text{NaHSO}_4 + 2H_2O + \text{SO}_2 + \text{Br}_2 \]
   or \[ 2\text{HBr} + H_2SO_4 \rightarrow 2H_2O + \text{SO}_2 + 2\text{Br}_2 \]
   (ignore equations producing HBr)

(b) relevant \( E^\circ \) quoted: C\(_2\)/Cl\(_2\), 1.36; Br\(_2\)/Br\(^-\), 1.07; (H\(_2\)SO\(_4\)/SO\(_2\), 0.17 – not required)

Br\(^-\) is more easily oxidised because its \( E^\circ \) is more negative
or Cl\(_2\) is more oxidising because its \( E^\circ \) is more positive

(c) Allow almost any reducing agent from the Data Booklet (see below) with \( E^\circ \) less than 1.07 V.

But do not allow reducing agents that require conditions that would react with Br\(_2\) in the absence of the reducing agent (e.g. NH\(_3\) or OH\(^-\)), and also do not allow “reducing agents” that could produce, or act as, oxidising agents (e.g. MnO\(_4^2-\) and H\(_2\)O\(_2\))

balanced equ. showing reduction of Br\(_2\) by the chosen reducing agent
(either ionic or molecular)
\[ E^\circ = 1.07 - (E^\circ \text{ of reductant}) = \text{xxx} \text{ (V)} \] (see below)

<table>
<thead>
<tr>
<th>reductant</th>
<th>( E^\circ \text{cell/V} )</th>
<th>reductant</th>
<th>( E^\circ \text{cell/V} )</th>
<th>reductant</th>
<th>( E^\circ \text{cell/V} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>0.27</td>
<td>Fe(=)Fe(^{2+})</td>
<td>1.51</td>
<td>Ni</td>
<td>3.78</td>
</tr>
<tr>
<td>At</td>
<td>2.73</td>
<td>Fe(=)Fe(^{3+})</td>
<td>1.11</td>
<td>Pb</td>
<td>1.20</td>
</tr>
<tr>
<td>Ba</td>
<td>3.97</td>
<td>Fe(^{2+})</td>
<td>0.30</td>
<td>SO(_2)</td>
<td>0.90</td>
</tr>
<tr>
<td>Ca</td>
<td>3.94</td>
<td>H(_2)</td>
<td>1.07</td>
<td>Sn</td>
<td>2.12</td>
</tr>
<tr>
<td>Co</td>
<td>1.35</td>
<td>I(^-)</td>
<td>0.53</td>
<td>S(_2)O(_3)^{2-})</td>
<td>0.98</td>
</tr>
<tr>
<td>Cr(=)Cr(^{2+})</td>
<td>1.98</td>
<td>K</td>
<td>3.99</td>
<td>Sn(^{2+})</td>
<td>0.92</td>
</tr>
<tr>
<td>Cr(=)Cr(^{3+})</td>
<td>1.81</td>
<td>Li</td>
<td>4.11</td>
<td>V</td>
<td>2.27</td>
</tr>
<tr>
<td>Cr(^{3+})</td>
<td>1.48</td>
<td>Mg</td>
<td>3.45</td>
<td>V(^{2+})</td>
<td>1.33</td>
</tr>
<tr>
<td>Cu(=)Cu(^+)</td>
<td>0.55</td>
<td>Mn</td>
<td>2.25</td>
<td>V(^{3+})</td>
<td>0.73</td>
</tr>
<tr>
<td>Cu(=)Cu(^{2+})</td>
<td>0.73</td>
<td>NO(_2)</td>
<td>0.26</td>
<td>VO(^{2+})</td>
<td>0.07</td>
</tr>
<tr>
<td>Cu(^+)</td>
<td>0.92</td>
<td>HNO(_2)</td>
<td>0.13</td>
<td>NH(_4)^+</td>
<td>0.20</td>
</tr>
</tbody>
</table>

\begin{align*}
\text{e.g. for Sn}^{2+}: & \quad \text{Sn}^{2+} + \text{Br}_2 \rightarrow \text{Sn}^{4+} + 2\text{Br}^- \\
& E^\circ = 1.07 - 0.15 = 0.92 \text{ V} \quad \text{(or similarly for other suitable reagents)}
\end{align*}
Q7.

5 (a) (i) \( E^\circ = 0.40 - (-0.83) = 1.23V \)  
(ii) \( 2H_2 + O_2 \rightarrow 2H_2O \)  
(iii) LH electrode will become more negative  
RH electrode will also become more negative / less positive  
(iv) no change 
ecf from (iii)  
(v) increased conductance or lower cell resistance or increased rate of reaction

(b) (i) \( E^\circ = 1.47 - (-0.13) = 1.60V \)  
(ii) \( PbO_2 + Pb + 4H^+ \rightarrow 2Pb^{2+} + 2H_2O \)  
(iii) \( PbO_2 + Pb + 4H^+ + 2SO_4^{2-} \rightarrow 2PbSO_4(s) + 2H_2O \)  
(iv) \( E^\circ_{cell} \) will increase 
as \( [Pb^{2+}] \) decreases, \( E_{electrode(PbO_2)} \) will become more positive, but \( E_{electrode(Pb)} \) will become more negative

[Total: 11]
Q8.

(a) Reaction II – since electrons are used up / required / gained / received (from external circuit)  

\[
\begin{align*}
\text{(b) } & \quad \text{Pb}^{2+} + 2e^- \rightarrow \text{Pb} \quad \quad E^\circ = -0.13\text{V} \\
& \quad \text{PbO}_2 + 4\text{H}^+ + 2e^- \rightarrow \text{Pb}^{2+} + 2\text{H}_2\text{O} \quad \quad E^\circ = +1.47\text{V}
\end{align*}
\]

two correct \( E^\circ \) values

Cell voltage is 1.60(V)

(c) (i) 3(+)  

(ii) They are less heavy / poisonous / toxic / polluting or are safer due to no (conc) \( \text{H}_2\text{SO}_4 \) within them

(d) (i) Platinum or graphite / carbon

(ii) They need large quantities of compressed gases which take up space or the hydrogen would need to be liquefied or the reactant is (highly) flammable / explosive / combustible

(e) Glass: saves energy – the raw materials are easily accessible / cheap or making glass is energy-intensive

Steel: saves energy – extracting iron from the ore or mining the ore is energy intensive or saves a resource – iron ore (NOT just "iron") is becoming scarce either one

Plastics: saves a valuable / scarce resource: (crude) oil / petroleum

[Total: 10]
3 (a) \( L = F/e \) or \( F = Le \)

(b) (i)

allow the conventional symbol to represent (the "P.S." is not required)

- correct cell (2 electrodes + PS circuit)
- ammeter in series
- anode and cathode of the right polarity [IN WORDS]
- \( \text{CuSO}_4(\text{aq}) \) or \( \text{CuCl}_2(\text{aq}) \) or \( \text{Cu}^{2+}(\text{aq}) \) or soln or 1 mol dm\(^{-3}\)

(ii) \( n(\text{Cu}) = (52.542-52.243)/63.5 = 4.71 \times 10^{-3} \) mol \( (4.67 \times 10^{-3}) \)

\( n(e^-) \) required = \( 4.71 \times 10^{-3} \times 2 = 9.42 \times 10^{-3} \) mol \( (9.34 \times 10^{-3}) \)

amount of electricity passed = \( 0.5 \times 30 \times 60 = 900 \) C

no. of electrons passed = \( 900/1.6 \times 10^{-19} = 5.625 \times 10^{21} \)

no of electrons/n(e^-) = \( 5.625 \times 10^{21}/9.42 \times 10^{-3} = 5.97 \times 10^{23} \) mol\(^{-1}\) \( (6.02 \times 10^{23}) \)

(values in italics are if candidate has used \( A_r = 64 \), not 63.5. No last mark if not 3 s.f.: correct ans = [5])

(c)

<table>
<thead>
<tr>
<th>compound</th>
<th>product at anode</th>
<th>product at cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgF</td>
<td>O(_2)</td>
<td>Ag</td>
</tr>
<tr>
<td>FeSO(_4)</td>
<td>O(_2)</td>
<td>H(_2)</td>
</tr>
<tr>
<td>MgBr(_2)</td>
<td>Br(_2)</td>
<td>H(_2)</td>
</tr>
</tbody>
</table>

6 correct \( \Rightarrow [5] \)
5 correct \( \Rightarrow [4] \) etc.

Names can be used instead of symbols. If the atomic symbol (e.g. Br or H or O) is used instead of the molecular formula (e.g. Br\(_2\) etc.) then deduct [1] mark only for the whole table.

Q9.
Q10.

(a) The potential of an **electrode** compared to that of a standard hydrogen electrode (SHE) or the EMF of a **cell** composed of the test electrode and the SHE.

all measurement concentrations of 1 mol dm⁻³ and 298K / 1 atm pressure

(b) 

H₂ and good delivery system [1]
Fe²⁺/Fe³⁺ solution labelled [1]
platinum electrodes (both) [1]
salt bridge and voltmeter [1]
H⁺ or HCl or H₂SO₄ [1]
(acid is not sufficient) [5]
2 (a) (i)

H₂(g) going in (i.e. not being produced) [1]
platinum electrode in contact with solution, with H₂ bubbling over it [1]
H⁺ or HCl or H₂SO₄ [1]
solution at 1 mol dm⁻³ (or 0.5 M if H₂SO₄) and T=298 K, p=1 atm [1]

(ii) \( E^\circ = 1.33 - (-0.41) = 1.74 \) V [1]

\( \text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{Cr}^{3+} \rightarrow 8\text{Cr}^{3+} + 7\text{H}_2\text{O} \) [1]

(iii) Colour would change from orange to green [1] [8]
Q12.

(a) A: voltmeter or V or potentiometer [NOT meter, ammeter, galvanometer]
B: salt bridge or potassium nitrate etc (any sensible soluble salt, e.g. chloride, sulphate, nitrate or phosphate) [NOT just bridge, or filter paper]
C: 1 mol dm$^{-3}$ (or 1M or M) H$^+$ or H$_2$O$^+$ or HCl or HNO$_3$ or 0.5 mol dm$^{-3}$ H$_2$SO$_4$
   (allow unit activity, allow 1.18 mol dm$^{-3}$) [3]

(b) diag

solution containing Fe$^{3+}$/Fe$^{2+}$ at equal or 1 mol dm$^{-3}$ concentrations

(c) (i) $E^\circ$ increases/becomes more positive
(ii) $E^\circ$ decreases/becomes more negative/less positive (both correct) [1]

(d) (i) $2\text{Fe}^{3+} + \text{Cu} \rightarrow 2\text{Fe}^{2+} + \text{Cu}^{2+}$
   or $2\text{FeCl}_3 + \text{Cu} \rightarrow 2\text{FeCl}_2 + \text{CuCl}_2$
   or $\text{Fe}^{3+} + \text{Cu} \rightarrow \text{Fe}^{2+} + \text{Cu}^{+}$ (or with FeCl$_3$)

(ii) $E_{\text{cell}} = (0.77 - 0.34 = +0.43 \text{ (V)}$
   [or $E_{\text{cell}} = (0.77 - 0.52 = +0.25 \text{ if Cu has been oxidised to Cu}^{+} \text{ in (i)}$]

(e) (i) moles(MnO$_4^-$) = $0.02 \times 75/1000 \text{ (or } 1.5 \times 10^{-3} \text{) } [1] \text{ for working}$
   moles(Fe$^{2+}$) = $5 \times 1.5 \times 10^{-3} = 7.5 \times 10^{-3}$
   (mark is for x 5: allow ecf if n(MnO$_4^-$) is wrong) [1]

(ii) moles(Cu) = (moles(Fe))/2 = $3.75 \times 10^{-3}$ [1]
   mass(Cu) = $63.5 \times 3.75 \times 10^{-3} = 0.24g$ [1]
   (ignore sig figs: allow ecf from (i) – i.e. mark is for x 63.5 or x 64)

(if Cu has been oxidised to Cu$^{+}$, the corresponding answers are $7.5 \times 10^{-2}$ [1] and 0.48g [1])
   (if candidates have attempted to oxidise Cu by reducing Fe$^{3+}$ to Fe, they lose the mark in d(ii), but can gain ecf marks for d(ii), (-0.56V or -0.38V) and also for c(ii))

Total: 12
Q13.

2. (a) \( \text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O} \) (or equation = 2)

(b) 

(c) 1.23 (V) (ignore sign)

(d) a better/larger salt bridge or a diaphragm or larger (area of) electrodes
    or increase concentrations/pressure

(e) time = 400 \times 24 \times 60 \times 60 = 34560000 seconds
    charge = current \times time = 0.01 \times 34560000 = 345600 C
    moles of H = 345600/96500 = 3.6 mol
    \( \therefore \) mass of H = 3.6 g

(f) advantages: less pollution/CO\(_2\)/NO\(_x\), etc. or cleaner by-products
    less dependence on fossil fuels/finite resources
    any one

disadvantages: more expensive (to develop or to run)
    takes up more space
    poor power-to-volume ratio
    hydrogen is difficult to store or to transport
    any one
    NOT hydrogen is explosive/flammable

Total 9
Q14.

2 (a) The EMF of a cell made up of the test electrode and a standard hydrogen electrode. (or the EMF of the electrode compared to the S.H.E.)
EMF measured under standard conditions of T, (P) and concentration. (or at 298K and 1 mol dm$^{-3}$)

(b) The stronger the halogen is as an oxidising agent, the more positive is its $E^\circ$ value.
Two examples of F$\_$/F$^\cdot$, Cl$^\cdot$/Cl$^-$, Br$^\cdot$/Br$^-$, I$^\cdot$/I$^-$ quoted
(data:  F$\_$/F$^\cdot$ = +2.87V
Cl$^\cdot$/Cl$^-$ = +1.36V
Br$^\cdot$/Br$^-$ = +1.07V
I$^\cdot$/I$^-$ = +0.54V)

(c) (i)   H$_2$O$_2$ + 2I$^-$ + 2H$^+$ $\rightarrow$ I$_2$ + 2H$_2$O
or   H$_2$O$_2$ + 2Cl$^-$ + 2H$^+$ $\rightarrow$ 2K$^+$ + I$_2$ + 2H$_2$O

$$E^\circ = 1.77 - 0.54 = 1.23 \text{ V}$$

(ii)   Cl$_2$ + SO$_2$ + 2H$_2$O $\rightarrow$ 2Cl$^-$ + SO$_4^{2-}$ + 4H$^+$
or   Cl$_2$ + SO$_2$ + 2H$_2$O $\rightarrow$ 2HCl + H$_2$SO$_4$

$$E^\circ = 1.36 - 0.17 = 1.19 \text{ V}$$

(d) since $E^\circ$(I$^\cdot$/I$^-$) is +0.54V, tin will be oxidised to Sn$^{4+}$
($E^\circ$ for Sn$^{3+}$/Sn$^0$ = -0.14V and $E^\circ$ for Sn$^{2+}$/Sn$^0$ = +0.15V)
Thus:  Sn + 2I$_2$ $\rightarrow$ SnI$_4$

total: 10

Q15.
Q16.

3 (a) \[ K = \frac{22.4}{39.1} = 0.573 \quad \text{thus ratio is:} \quad 1 \]
\[ \text{Cr} = \frac{29.8}{52.0} = 0.573 \]
\[ \text{Cl} = \frac{20.3}{35.5} = 0.572 \]
\[ \text{O} = \frac{27.5}{16.0} = 1.719 \quad \text{3 or KCrClO}_3 \quad \text{(scores 2)} \]

(b) \[ K_2\text{Cr}_2\text{O}_7 + 2\text{HCl} \longrightarrow 2\text{KCrClO}_3 + \text{H}_2\text{O} \]

(c) (i) redox or oxidation

(ii) \[ E^\circ \text{ data and half equations:} \]
\[ \text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \longrightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O} \quad E^\circ = 1.33 \text{ V} \]
\[ \text{Cl}_2 + 2\text{e}^- \longrightarrow 2 \text{Cl}^- \quad E^\circ = 1.36 \text{ V} \]

overall ionic equation:
\[ \text{Cr}_2\text{O}_7^{2-} + 6\text{Cl}^- + 14\text{H}^+ \longrightarrow 2\text{Cr}^{3+} + 3\text{Cl}_2 + 7\text{H}_2\text{O} \]

(iii) (dilution will) lower \( E^\circ \) for \( \text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+} \), or raise \( E^\circ \) for \( \text{Cl}_2/\text{Cl}^- \)

or lower \([\text{Cl}^-]\) or \([\text{H}^+]\) will shift equilibrium in eqn to the left hand side

(iv) \[ \text{Br}_2/\text{Br}^- = +1.07 \text{ V}, \quad \text{so Cr(VI) would oxidise Br}^- \quad \text{(easily)} \]

[Total: 9]

Q17.

5 (a) \[ 2\text{MnO}_4^- + 5\text{H}_2\text{O}_2 + 6\text{H}^+ \longrightarrow 2\text{Mn}^{2+} + 8\text{H}_2\text{O} + 5\text{O}_2 \]

(b) \[ E^\circ_{\text{mnl}} = 1.52 - 0.68 = +0.84 \text{ (V)} \]

(c) (i) (as KMnO₄ is added), colour changed (from purple) to colourless – NOT pink or effervescence/bubbles (of O₂) are produced at end-point, change is to (first) pink

(ii) \[ n(\text{MnO}_4^-) = \frac{0.02 \times 15}{1000} = 3 \times 10^{-4} \]

since \( \text{H}_2\text{O}_2 : \text{MnO}_4^- = 5:2, \)
\[ n(\text{H}_2\text{O}_2) = \frac{(5/2) \times 3 \times 10^{-4}}{5} = 7.5 \times 10^{-4} \text{ in 25 cm}^3 \]

\[ n(\text{H}_2\text{O}_2) = 7.5 \times 10^{-4} \times 1000/25 = 3.0 \times 10^{-2} \text{ mol dm}^3 \]

[Total: 6]
Q18.

8 (a) Graphite / graphene

(b) They do not exist as sheets / layers of carbon atoms

(c) The lengths of nanotubes are much shorter than the curvature of the paper / they are so small that they are not affected by rolling

(d) Any molten ionic salt (or plausible organic ionic compounds)

[Total: 4]
Q19.

1. (a) \( \text{PCl}_5 + 4\text{H}_2\text{O} \rightarrow \text{H}_3\text{PO}_4 + 5\text{HCl} \) (1)

\[ \text{SiCl}_4 + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + 4\text{HCl} \text{ (or giving H}_2\text{SiO}_3, \text{Si(OH)}_4 \text{ etc.)} \] (1)

(b) bond energies:  
- S-S = 264 kJ mol\(^{-1}\)
- Cl-Cl = 244 kJ mol\(^{-1}\)
- S-Cl = 250 kJ mol\(^{-1}\)

\[ \Delta H = 8 \times 264 + 8 \times 244 - 16 \times 250 = +64 \text{ kJ mol}^{-1} \] (2)

(c) (i) +2 (1)

(ii) (half) the sulfur goes up by +2, (1)

(the other half) goes down by −2 (1)

(iii) \( \text{HCl} \text{ (can be read into (iv))} \) (1)

(iv) \( 2\text{SCl}_2 + 2\text{H}_2\text{O} \rightarrow \text{S} + \text{SO}_2 + 4\text{HCl} \) (1)

(v) (+ AgNO\(_3\)) white ppt. (1)

(+ K\(_2\)Cr\(_2\)O\(_7\)) solution turns green (1) (7)

[Total: 11]

Q20.
Q21.

(a) (i) \( \text{Cu(s) } - 2e^- \rightarrow \text{Cu}^{2+}(aq) \) allow electrons on RHS (1)

(ii) \( E^\circ \) for Ag\(^+/\)Ag is +0.80V which is more positive than +0.34V for Cu\(^{2+}/\)Cu, (1)
so it’s less easily oxidised (owtte) (1)

(iii) \( E^\circ \) for Ni\(^{2+} \) is −0.25V, (1)
Ni is readily oxidised and goes into solution as Ni\(^{2+}(aq) \) (1) [Mark (ii) and (iii) to max 3]

(iv) \( \text{Cu}^{2+}(aq) + 2e^- \rightarrow \text{Cu(s)} \) (1)

(v) \( E^\circ \) for Zn\(^{2+}/\)Zn is negative \( l = -0.76V \), so Zn\(^{2+} \) is not easily reduced. (1)

(vi) The blue colour fades because Cu\(^{2+}(aq) \) is being replaced by Zn\(^{2+}(aq) \) or Ni\(^{2+}(aq) \) or [Cu\(^{2+} \)] decreases (1) [7]

(b) amount of copper = 225/63.5 = 3.54(3) mol (1)
amount of electrons needed = 2 x 3.54 = 7.08(9) (7.087) mol (1)
no. of coulombs = 20 x 10 x 60 x 60 = 7.2 x 10^5 C
no. of moles of electrons = 7.2 x 10^5 / 9.65 x 10^4 = 7.46 mol (1)
percentage “wasted” = 100 x (7.461 - 7.087)/7.461 = 5.01 (5.0)% (accept 4.98–5.10) (1) [4]

(c) \( E^\circ \) data: Ni\(^{2+}/\)Ni = −0.25V
Fe\(^{2+}/\)Fe = −0.44V (1)
Because the Fe potential is more negative than the Ni potential, the iron will dissolve (1) [2]

[Total: 13]

Q22.

(a) (i) A few nanometres (accept 0.5–10 nm) (1)

(ii) Graphite/graphene (1)

(iii) van der Waals’ (1)
Carbon atoms in the nanotubes are joined by covalent bonds (1)
as are the hydrogen atoms in a hydrogen molecule
or no dipoles on C or H\(_2\) or the substances are non-polar [4]

(b) More hydrogen can be packed into the same space/volume (1) [1]

(c) If a system at equilibrium is disturbed, the equilibrium moves in the direction which tends to reduce the disturbance (owtte) (1)
When H\(_2\) is removed the pressure drops and more H\(_2\) is released from that adsorbed (1)
The equilibrium H\(_{\text{adsorbed}} \rightleftharpoons \text{H}_{\text{gaseous}} \) (1)
Equilibrium shifts to the right as pressure drops (1) [4]

[Total: 9]
(a) (i) \[2H_2O - 4e \rightarrow 4H^+ + O_2(1)\]

(ii) \[2Cl^- - 2e \rightarrow Cl_2(1)\]

(b) (i) \[E^\circ = (1.23 - (-0.83)) = 2.06V\] (1)

(ii) \[E^\circ = (1.36 - (-0.83)) = 2.19V\] (1)

\(\text{in (i) if (a)(i) as } 4(OH^-) - 4e \rightarrow 2H_2O + O_2 \text{ ecf is } 0.4 - (-0.83) = 1.23 \text{ (1)} \) needs working shown)

(c) (i) \(\text{no change (because } [H_2O] \text{ does not change)}\) (1)

\(\text{smaller/less positive (1)}\)

(ii) \(\text{The (overall) } E^\circ \text{ for } Cl_2 \text{ production will decrease, (whereas that) for } O_2 \text{ production will stay the same. (answer could be in terms of } 1st E^\circ \text{ decreasing and becoming lower than 2nd)(or } E^\circ \text{ for } Cl_2 \text{ becomes less than for } O_2\) \(1\)

(d) (i) \[Cl^- + 3H_2O \rightarrow ClO_3^- + 3H_2(1)\]

(ii) \(n(C) = 250 \times 60 \times 60 = (9 \times 10^5 \text{ C)}\) (1)

\(\text{n(e^-) } = 9 \times 10^5/96500 = 9.33 \text{ mol}\)

\(n(\text{NaClO}_3) = 9.33/6 = (1.55 \text{ mol)} \) – allow ecf (1)

\(\text{Mr(\text{NaClO}_3) = 106.5}\)

\(\text{mass (NaClO}_3\) = 1.55 \times 106.5 = 165.5 \text{ g (1)} \) (165 – 166 gets 3 marks, 993 gets 2 marks as ecf)

\[\text{[Total: 11]}\]

Q23.
1 (a) SiCl₄: white solid or white/steamly fumes

$$SiCl₄ + 2H₂O \rightarrow SiO₂ + 4HCl$$

PCl₅: fizzes or white/steamly fumes

$$PCl₅ + 4H₂O \rightarrow H₃PO₄ + 5HCl$$

(b) (i) \( MnO₄^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 4H₂O + 5Fe^{3+} \)

(ii) \( 5 : 1 \)

(iii) \( n(MnO₄^-) = 0.02 \times 15/1000 = 3 \times 10^{-4} \) (mol)

(iv) \( n(Fe^{3+}) = 5 \times 3 \times 10^{-3} = 1.5 \times 10^{-3} \) (mol) ecf from (ii) or (ii)

(v) \( [Fe^{2+}] = 1.5 \times 10^{-3} \times 1000/2.5 = 0.6 \) (mol dm⁻³) ecf from (iv)

(vi) In the original solution, there was 0.15 mol of Fe³⁺ in 100 cm³.
    In the partially-used solution, there is 0.06 mol of Fe³⁺ in 100 cm³.
    So remaining Fe³⁺ = 0.15 - 0.06 = 0.09 mol.
    This can react with 0.045 mol of Cu, which = 0.045 × 63.5 = 2.86 g of copper.

(c) bonds broken are Si-Si and Cl-Cl = 222 + 244 = 466 kJ mol⁻¹
    bonds formed are 2 × Si-Cl = 2 × 359 = 718 kJ mol⁻¹
    \( \Delta H = -252 \) kJ mol⁻¹

(d) (i) \( Ca₂Si + 6H₂O \rightarrow 2Ca(OH)₂ + SiO₂ + 4H₂ \)

(ii) silicon has been oxidised AND hydrogen has been reduced

[Total: 14]
Q25.

2 (a) (i) \( A = \text{CuSO}_4 \)
\( B = \text{silver} \)

(ii) salt bridge
voltmeter

(b) (i) \( 0.80 - 0.34 = (+) 0.46 \text{ V} \)

(ii) If \( E_{\text{cell}} = 0.17 \), this is 0.29 V less than the standard \( E^\circ \),
so \( E_{\text{Ag electrode}} \) must = 0.80 - 0.29 = 0.51 V

(iii) \( 0.51 = 0.80 + 0.06 \log [\text{Ag}^+] \), so \([\text{Ag}^+] = 10^{(0.80-0.06) / 0.06} = 1.47 \times 10^{-6} \text{ mol dm}^{-3} \) ecf from (ii)

(c) (i) \( K_{sp} = [\text{Ag}^+]^2[\text{SO}_4^{2-}] \)
units = mol^2 dm^-6 ecf on \( K_{sp} \)

(ii) \([\text{SO}_4^{2-}] = [\text{Ag}^+] / 2 \) \( K_{sp} = (1.6 \times 10^{-2})^2 \times 0.8 \times 10^{-2} = 2.05 \times 10^{-6} \text{ (mol}^3 \text{dm}^{-9}) \)

(d) AgCl white
AgBr cream
AgI yellow

Solubility decreases down the group

(e) solubility decreases down the group
as \( M^{2+/ionic radius} \) increases
both lattice energy and hydration (solvation) energy to decrease
enthalpy change of solution becomes more endothermic

[Total: 18]
Q26.

1 (a) \( \text{MgCl}_2 \): forms a (colourless) solution or dissolves.

\[ \text{AlCl}_3: \quad \text{produces a white ppt or steamy fumes} \quad [1] \]

\[
\begin{align*}
2\text{AlCl}_3 \quad \underline{+ \text{or } \text{Al}_2\text{Cl}_6} &\quad + 3\text{H}_2\text{O} \longrightarrow \text{Al}_2\text{O}_3 + 6\text{HCl} \quad [1] \\
(\text{or } \text{AlCl}_3 &\quad + 3\text{H}_2\text{O} \longrightarrow \text{Al(OH)}_3 + 3\text{HCl})
\end{align*}
\]

or forms a (colourless) solution or dissolves \[ [1] \]

\[
\begin{align*}
\text{AlCl}_3 + 6\text{H}_2\text{O} &\longrightarrow [\text{Al}(\text{H}_2\text{O})_6\text{OH})^2^+ + \text{H}^+ + 3\text{Cl}^-] \quad [1]
\end{align*}
\]

\[ \text{SiCl}_4: \quad \text{produces a white ppt or steamy fumes} \quad [1] \]

\[
\begin{align*}
\text{SiCl}_4 + 2\text{H}_2\text{O} &\longrightarrow \text{SiO}_2 + 4\text{HCl} \quad [1] \\
(\text{or balanced equation giving } &\text{H}_2\text{SiO}_3 \text{ or } \text{Si(OH)}_4) \quad [Total: 5]
\end{align*}
\]

(b) (i) \[ n(\text{NaCl}) = 1.10/58.5 = 1.88 \times 10^{-2} \text{ mol} \quad [1] \]

\[ n(\text{KCl}) = 0.90/74.6 = 1.21 \times 10^{-2} \text{ mol} \quad [1] \]

Total \( n(\text{Cl}^-) = 3.08 \text{ or } 3.09 \text{ or } 3.1 \times 10^{-2} \text{ mol} [2 \text{ or more sig. figs. allow ecf} \quad [1] \]

(ii) \[ \text{Ag}^+(\text{aq}) + \text{Cl}^- (\text{aq}) \longrightarrow \text{AgCl(s)} \quad [1] \]

(iii) moles sampled for the titration \( = 3.09 \times 10^{-2} \times 10/1000 = 3.09 \times 10^{-4} \text{ mol ecf} \quad [1] \]

this equals \( n(\text{Ag}^+) \), so vol of \( \text{AgNO}_3 \) \( = 3.09 \times 10^{-2} \times 1000/0.02 = 15.5 \text{ cm}^3 \text{ ecf} \quad [1] \)

[Total: 5]

(c) (i) \[ \text{bonds broken are } \text{C}^-\text{H and I}^-\text{I} \quad = 410 + 151 = 561 \text{ kJ mol}^{-1} (\text{all bonds } = 5731 \text{ kJ mol}^{-1}) \]

bonds formed are \( \text{C}^-\text{I} \) and \( \text{H}^-\text{I} \) \( = 240 + 299 = 539 \text{ kJ mol}^{-1} (\text{all bonds } = 5709 \text{ kJ mol}^{-1}) \)

\[ \Delta H = +22 \text{ kJ mol}^{-1} \quad [2] \]

(ii) \[ 4 \text{HI} \quad + 2 \text{HNO}_3 \longrightarrow 2 \text{I}_2 \quad + \text{N}_2\text{O}_3 \quad + 3 \text{H}_2\text{O} \text{ (or double)} \quad [1] \]

N: (is reduced from) \[ 5 \text{ to } 3 \]

I: (is oxidised from) \[ -1 \text{ to } 0 \quad [1] \]

[Total: 4]

[TOTAL: 14]
1 (a) P: burns with white / yellow flame or copious white smoke / fumes produced
   \[ 4P \text{ (or P}_4\text{)} + 5O_2 \rightarrow P_4O_{10} \]

   S: burns with blue flame / choking / pungent gas produced
   \[ S + O_2 \rightarrow SO_2 \]

(b) (i) \[ 2Ca_3(PO_4)_2 + 6SiO_2 + 10C \rightarrow \] P + 6 CaSiO_3 + 10 CO

(ii)

<table>
<thead>
<tr>
<th>allotrope</th>
<th>type of structure</th>
<th>type of bonding</th>
</tr>
</thead>
<tbody>
<tr>
<td>white</td>
<td>simple / molecular</td>
<td>covalent</td>
</tr>
<tr>
<td>red</td>
<td>giant / polymeric</td>
<td>covalent</td>
</tr>
</tbody>
</table>

(iii)

(in each case P has to be trivalent. Many alternatives allowable for the polymeric red P)

[Total: 11]
Q29.

4 (a) $\text{N}_2 + 2\text{O}_2 \rightarrow 2\text{NO}_2 \text{ (or via NO) or } 2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$

(b) (i) catalytic converter and passing the exhaust gases over a catalyst/Pt/Rh

(ii) $\text{NO}_2 + 2\text{CO} \rightarrow \frac{1}{2} \text{N}_2 + 2\text{CO}_2 \text{ or similar}
\text{ Allow } 2\text{NO}_2 + \text{CH}_4 \rightarrow \text{CO}_2 + \text{N}_2 + 2\text{H}_2\text{O}$

(c) No, it wouldn't be reduced. Because the reaction in (a) does not presuppose a particular fuel (owtte)
\text{ Allow formed from N}_2 \text{ and O}_2 \text{ in air during combustion}$

(d) (i) $\text{SO}_3$ produces acid rain

(ii) $\text{NO} + \frac{1}{2} \text{O}_2 \rightarrow \text{NO}_2$

(iii) $K_p = \frac{(P_{\text{NO}} \cdot P_{\text{SO}_2})}{(P_{\text{NO}_2} \cdot P_{\text{SO}_2})}$
\text{ units: dimensionless/none (don't accept just a blank!)}

(iv) $K_p = 99.8^2/0.2^2 = 2.5 \times 10^8$

(v) It will shift to the right (owtte)
\text{ because the reaction is exothermic. NOT just Le Chatelier argument}$

[Total: 11]

4 (a) volatility: $\text{Cl}_2 > \text{Br}_2 > \text{I}_2$ or boiling points: $\text{Cl}_2 < \text{Br}_2 < \text{I}_2$ or $\text{Cl}_2$ is (g); $\text{Br}_2$ is (l); $\text{I}_2$ is (s) more electrons in $X_2$ down the group or more shells/bigger cloud of electrons
\text{ so there's greater van der Waals dispersion/id-idi/induced/temporary dipole force/attraction}$

(b) (i) $\text{H}_2\text{O} > \text{H}_2\text{S} \text{ (see * below for mark)}$
\text{ due to H-bonding in H}_2\text{O} \text{ (none in H}_2\text{S)}$
\text{ diagram minimum is: H}_2\text{O}^\ddagger \cdots \ddagger \text{H-OH or H}_2\text{O}: \text{H-OH [allow (+) for \ddagger]}

(ii) $\text{CH}_2\text{-O-CH}_3 > \text{CH}_3\text{CH}_2\text{CH}_3 \text{ (see * below for mark)}$
\text{ due to dipole in CH}_2\text{-O-CH}_3 \text{ (O is \ddagger not needed, but O is \ddagger negates) or CH}_3\text{CH}_2\text{CH}_3 \text{ is polar}$
\text{ * correct comparison of boiling points for both}$

(c) $\text{SF}_6$ has 6 bonding pairs/bonds and no lone pairs (bonds can be read into a diagram e.g. S-F, but 'no lone pairs' can only be read into a diagram showing 6 bonded pairs of electrons, clear diagram or 'shape is octahedral')

[Total: 9]