1. (a)

	3d					4s
Mn [Ar]	↑	↑	↑	↑	↑	↑↓
Mn^{2+} [Ar]	↑	↑	↑	↑	↑	

2

(b) (i) $[Mn(H_2O)_6]^{2+}$ 1

(ii) $[Mn(H_2O)_6]^{2+} + 2NH_3 \rightarrow Mn(OH)_2 + 2NH_4^+ + 4H_2O$

or

$[Mn(H_2O)_6]^{2+} + 2NH_3 \rightarrow [Mn(H_2O)_4(OH)_2] + 2NH_4^+$

or

$[Mn(H_2O)_6]^{2+} + 2OH^- \rightarrow Mn(OH)_2 + 6H_2O$

or

$[Mn(H_2O)_6]^{2+} + 2OH^- \rightarrow [Mn(OH)_2(H_2O)_4] + 2\ H_2O$

Any of above score 2 marks as follows:**(1)** mark for species **(1)** mark for balance

Deprotonation or Acid /base **(1)** 3

(iii) (Mn(II) is) oxidised / undergoes oxidation **(1)**
to Mn(IV) / Mn(III) / to higher oxidation state/ will increase **(1)**
Variable oxidation states **(1)**
coloured compounds **(1)** 4

(c) (i) from +4 to +6/ up by 2 / +2 1

(ii) Amount of $KMnO_4$ = 0.0228 × 0.0216 mol 1

= 4.925×10^{-4}mol

(iii) Amount of SO_3^{2-} in $25cm^3$ = 5/2 × 4.925 × 10^{-4}mol 1

= 1.231×10^{-3} mol

(iv) Amount of SO_3^{2-} in $250cm^3$ = 10 × 1.231 × 10^{-3} mol **(1)**
= 1.231×10^{-2} mol
Mass of pure Na_2SO_3 = 126 x 1.231 × 10^{-2} g **(1)**
= 1.551g 2

(v) Purity of sample = (1.551g/ 1.75g) x 100%

= 88.6% 1

[16]

2. (a) (i) The potential difference between a standard hydrogen electrode and the (half-) cell **(1)**
all concentrations measured at 1 mol dm^{-3} and any gases are at 1 atm pressure **(1)** 2

(ii) Fluorine or F_2 **(1)** 1

(b) (i) all/listed **(1)** 1

(ii) iodine **and** bromine **(1)** 1

(iii) *This answer is consequential on part (ii)*
Mix solution of Cr(II) **-** blue with the oxidising agent given in (ii) **(1)**
goes green and **stays** green / but does not go orange **(1)** 2

[7]

3. (a)

		3d					4s
Sc	[Ar]	↑					↑↓
Cr	[Ar]	↑	↑	↑	↑	↑	↑
Cr^{3+}	[Ar]	↑	↑	↑			

Cr^{3+} consequential on structure for Cr 3

(b) Electronic configuration differs from previous element by an electron in a d (sub) shell / electrons are filling the d-shell **(1)**
transition elements have one ion with partially-filled d-shell **(1)** 2

Not *'highest energy shell is the 'd'-shell*
outer electron in 'd' shell

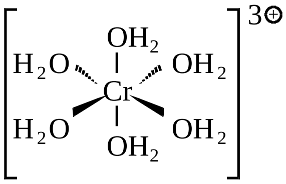
(c) (i)

[Ar]	↑	↑	↑	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓

(last six pairs: Ligand electrons)

2

Correct electron structure for complex ion **(1)**
ligand electrons identified **(1)** 6 pairs identified stand alone mark
Consequential on structure of Cr^{3+}

(ii) 

There must be some attempt to show a 3-D structure
'Octahedral' could rescue a poor diagram

(iii) d-orbitals split (in energy by ligands) / or diagram to illustrate
electron transitions / jumps from **lower** to **higher** energy level **(1)**
absorbs light in visible region **(1)** — 3

(d) (i) Green **precipitate (1)**
(deep) green **solution** in excess sodium hydroxide **(1)** — 2

(ii) Deprotonation / acid base **(1)** — 1

[14]

4. (a) (i) $[Ar]3d^6$ **(1)** — 1
allow $1s^2$ etc

(b) (i)
- Zn / Iron **(1)** not the zinc ion or iron ion
- more negative potential than -0.28V **(1)**
  NB this mark must show evidence of use of the data

gives +E for reduction reaction **(1)**
consequential on second mark — 3

(ii)
- rate too slow / activation energy too high / kinetically stable / allow oxide layer if metal electrode specified **(1)**
- non-standard conditions **(1)** — 2

(c) (i) $Co(H_2O)_6^{2+}$ **(1)** — 1

(ii) Example:
$Co(H_2O)_6^{2+} + 4Cl^- \rightarrow CoCl_4^{2-} + 6\ H_2O$
Any valid equation that shows a ligand exchange but begins with
$Co(H_2O)_6^{2+}$ **(1)**
ligand exchange correctly balanced **(1)** — 2

[9]

5. (a) An element that has at least one of its **ions** has an incomplete d shell **(1)** — 1

(b) (i) Coloured ions / compounds/ complexes/ solutions **(1)**
variable oxidation states **(1)** — 2

(ii) $Cr(H_2O)_6^{2+}$ / hexa aqua chromium (II) ion **(1)**
Not Cr^{2+} or Cr(II). — 1

(c) (i) — 2

Cr	Cl	H_2O
19.5 / 52	40 / 35.5	40.5 / 18 **(1)**
0.375	1.127	2.25
0.375/0.375	1.127/0.375	2.25/0.375 **(1)**
1	3	6

NB 2 method marks

(ii) Violet $Cr(H_2O)_6^{3+}.3Cl^-$ **(1)**
Green is $[Cr(H_2O)_5Cl]^{2+}2Cl^-.H_2O$ **(1)** — 2
NB for 2 marks must make clear which is which and must be a salt which adds up to $Cr(H_2O)_6Cl_3$

[8]

6. (a) (i) — 1

↑	↑	↑	↑	↑	↑

(ii) — 1

↑	↑	↑			

Allow single headed arrows or other suitable notation
[Mark (ii) consequentially on (i)]

(b) (i) Covalent **(1)**
Coordinate or dative **(1)** — 2

(ii) Deprotonation or acid-base — 1

(iii) $[Cr(H_2O)_3(OH)_3]$ or $Cr(OH)_3$ — 1

(iv) Ligand exchange or ligand substitution — 1

(v) $[Cr(NH_3)_6]^{3+}$ or $[Cr(OH)_x(H_2O)_y(NH_3)_z]^{charge}$ — 1

$x + y + z = 6$, z at least one, correct charge will be between 0 and +3, x = max 3

(c) • **d –** orbitals/subshell/energy level split (in energy by ligands)/diagram to illustrate **(1)**

• Electron transitions/jumps from **lower** to **higher** energy level **(1)**

• **Absorbs** light in visible region/reference to white light **(1)** 3

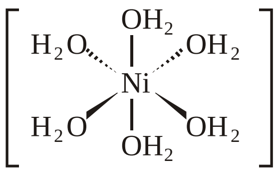
If imply or state that emission is occurring, only the first marking point is available

[11]

7. (a) (i) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^2$ 1

(ii) $1s^2 2s^2 2p^6 3s^2 3p^6\ 3d^8$ 1

(b)



(1)

Shape mark
Must be 3–D ie wedges or dashes
labelled covalent between O–H *OR* arrow to $H_2O$and labelled covalent bond **(1)**
labelled dative covalent between O atom and ion **(1)** 3

(c) (i) $[Ni(H_2O)_4(OH)_2]$
ALLOW $Ni(OH)_2$ 1

(ii) Deprotonation **(1)**
two successive deprotonations / neutral species producing insoluble compound **(1)** 2

(iii) Ligand exchange **(1)**
giving (soluble) $[Ni(H_2O)_{0\ or\ 2}(NH_3)_{6\ or\ 4}]^{2+}$ *OR in words* **(1)** 2

[10]

8. (a) (i) Use E^{θ} values for reduction of Fe^{3+} to Fe^{2+} by Zn (E^{θ}_{cell} = + 1.53V) **(1)**
and Fe^{2+} to Fe by Zn (E^{θ}_{cell} = +0.32V)**(1)**
They have positive E^{θ} so are feasible **(1)** *NOT* "will happen"
OR
ALLOW Zn^{2+}/Zn is more negative than both Fe^{3+}/Fe^{2+} and Fe^{2+}/Fe **(1)**
so zinc is a stronger reducing agent **(1)**
so zinc reducing both is feasible **(1)** 3

(ii) Reduction of Fe^{2+} has high activation energy / kinetically stable 1

(b) (i) $MnO_4^{-} + 5Fe^{2+} + 8H^{+} \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$
Species **(1)**
Balance **(1)**
Any state symbols ignored. 2

(ii) purple colour of MnO_4^{-} lost **(1)**
end point when yellow / colourless solution **(1)**
becomes (permanently) pink **(1)** 3

(c) Amount MnO_4^{-} in 1st titration = $0.0182\ dm^3 \times 0.0200\ mol\ dm^{-3}$
$= 3.64 \times 10^{-4}$ mol **(1)**

Amount Fe^{2+} in original solution = 5 × above value = 1.82×10^{-3} mol **(1)**

Amount Fe^{2+} in 2nd titration = amount of Fe^{2+} and Fe^{3+} original solution **(1)**

$= 0.0253\ dm^3 \times 0.0200\ mol\ dm^3 \times 5 = 2.53 \times 10^{-3}$ mol

Amount of Fe^{3+} in original solution = 0.00253 – 0.00182 = 7.10×10^{-4} mol **(1)**

Amount zinc needed to reduce Fe^{3+} = ½ × 0.000710 = 0.000355 mol
Mass of zinc = 0.000355 mol × 65.4 g mol^{-1} = 0.0232 g **(1)** 2,3 or 4 SF
Consequential on their moles iron

The marks are for the following processes:

Either volume of MnO_4^{-} to moles of MnO_4^{-} **(1)**

Convert to moles of Fe^{2+} by multiplying either moles of MnO_4^{-} by 5 **(1)**

Realising that 2nd titration measures total number of moles of iron **(1)***)*

Subtracting to get original moles Fe^{3+} **(1)**

Going to moles Zn then mass Zn **(1)**

OR
Volume MnO_4^- for Fe^{3+}, which has been reduced by zinc **(1)** 3rd point

= 25.3 cm^3 – 18.2 cm^3 = 0.0253 dm^3 – 0.0182 dm^3 = 0.0071 dm^3 **(1)** 4th point

Amount of MnO_4^- = 0.0071 dm^3 × 0.0200 mol dm^{-3} = 1.42 × 10^{-4} mol **(1)** 1st point

Amount Fe^{3+} reduced by zinc = 5 × above value = 7.10 × 10^{-4} mol **(1)** 2nd point

Amount zinc needed = ½ × 7.10 × 10^{-4} = 3.55 × 10^{-4} mol
mass of zinc needed = 3.55 × 10^{-4} mol × 65.4 g mol^{-1} = 0.00232 g **(1)** 5th point — 5

(d) (i) $[Fe(H_2O)_6]^{2+} + H_2O \rightarrow [Fe(H_2O)_5OH]^+ + H_3O^+$
H_3O^+ in equation **(1)**
other ion in equation **(1)**
(Fe^{2+}) polarises the O–H bond in ligand **(1)** — 3

(ii) $[Fe(H_2O)_6]^{3+}$ more acidic than $[Fe(H_2O)_6]^{2+}$ **(1)**
Fe^{3+} higher charge density than Fe^{2+} **(1)**
Fe^{3+} ion if more polarising **(1)** — 3

[20]

9. (a) (i) $1s^22s^22p^63s^23p^63d^{10}4s^2$ — accept any order — 1

(ii) $1s^22s^22p^63s^23p^63d^{10}$ — Conseq on (a) (i) — 1

(b) **d-block**: last (added) electron is in a d–(sub) shell / orbital **(1)**
Not transition: does not form **ions** with partially filled d-(sub) shell / orbitals **(1)** — 2

(c) 3D-drawing e.g. wedges / hatches or perspective diagram **(1)**
Labels covalent bond within water molecule **(1)**. This must be drawn out /use of a key is acceptable.
Shows dative covalent bond from water to central Zn^{2+} **(1)**
Labels a 90° angle **(1)**
Ignore absence of charge on ion — 4

(d) (i) White precipitate /solid /suspension **(1)** NOT powder
Colourless solution (in excess ammonia) NOT "clear" **(1)** 2

(ii) $[Zn(H_2O)_6]^{2+} + 2NH_3 \rightarrow [Zn(OH)_2(H_2O)_4] + 2NH_4^+$
Or
$[Zn(H_2O)_6]^{2+} + 2OH^- \rightarrow [Zn(OH)_2(H_2O)_4] + 2H_2O$
Or
$[Zn(H_2O)_6]^{2+} + 2OH^- \rightarrow Zn(OH)_2 + 6H_2O$
Or
$[Zn(H_2O)_6]^{2+} + 2NH_3 \rightarrow Zn(OH)_2 + 2NH_4^+ + 4H_2O$ **(1)**
$[Zn(OH)_2(H_2O)_4] + 4NH_3 \rightarrow [Zn(NH_3)_4(H_2O)_2]^{2+} + 2OH^- + 2H_2O$
Or
$Zn(OH)_2 + 4NH_3 \rightarrow [Zn(NH_3)_4]^{2+} + 2OH^-$
(1) for cation formed
(1) for balancing equation with the correct species **(2)** 3

(e) (i) d-(sub) shell / orbital**s** are full / $3d^{10}$ arrangement of electrons **(1)**
No jumps of d-electrons /no d-d transitions **(1)**
Any mention of e^- falling back down or "no splitting of d-orbitals" and second mark is not awarded 2

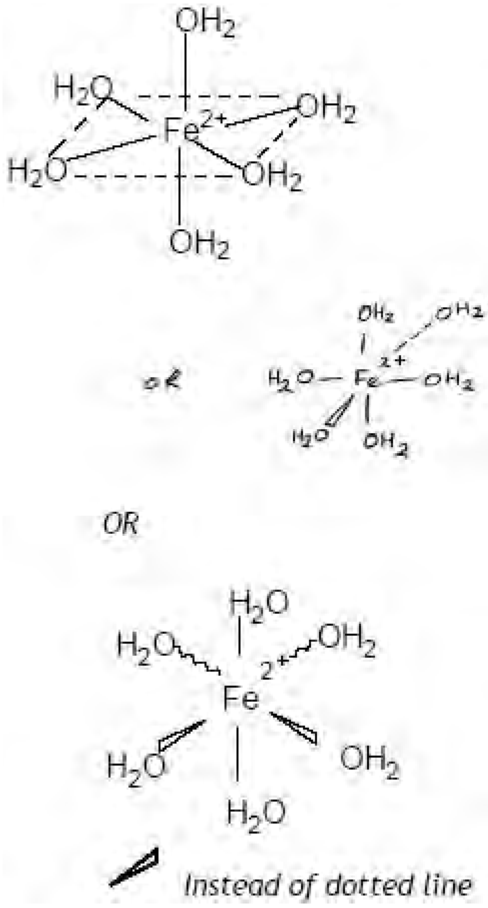
(ii) Cr is a transition metal / Cr can have d-d transitions /CrO_4^{2-} is yellow / Cr(+6) or Cr(VI) is yellow 1

[16]

10. (a) (i) <u>Fe [Ar]</u>
$3d^6 4s^2$
or $3d_6 4s_2$
or 3d64s2
or $4s^2 3d^6$ **(1)**

<u>Fe^{2+} [Ar]</u>
$3d^6$
or $3d_6$
or $3d^6 4s^0$ **(1)**
Letter d must be lower case
Any additional letters of numbers **(0)** 2

(ii) *The mark is for the shape*



ALLOW bond to H of H_2O (except on left side if OH_2 is given)
IGNORE charge unless incorrect 1

(iii) $[Fe(H_2O)_6]^{2+} + 2OH^- \rightarrow [Fe(OH)_2(H_2O)_4] + 2H_2O$

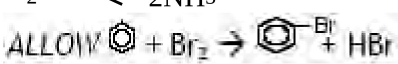
OR

$[Fe(H_2O)_6]^{2+} + 2OH^- \rightarrow Fe(OH)_2 + 6H_2O$

OR equations with 2NaOH as reactant and $2Na^+$ as product
IGNORE state symbols 1

(iv) Green precipitate / solid $\rightarrow$ foxy-red / red-brown / brown / orange
Both colours and precipitate / solid needed
NOT darkens 1

(v) $N_2 + 3H_2 \rightarrow / \rightleftharpoons 2NH_3$



OR equation with Cl_2 1

(b) (i) Emf of cell / potential difference of cell containing Fe^{2+} and Fe **(1)**
and standard hydrogen electrode / half cell *NOT* 'SHE'
OR hydrogen electrode and 1 mol dm^{-3} H^+ and 1 atm H_2 **(1)**
1 mol dm^{-3} Fe^{2+}
IGNORE temperature — 3

QWC*(ii) Emf of hydrogen electrode is zero – *stated or implied* (e.g. if calculate E_{cell} = +0.44(V)) **(1)**
$Fe + 2H^+ \rightarrow Fe^{2+} + H_2$ **(1) –** *equation stand alone*
Potential for the reaction is positive so reaction is feasible **(1)**
OR
H^+ and (½)H_2 has a more +ve electrode potential than Fe^{2+} and Fe **(1)**
H^+ will oxidise Fe / H^+ is an oxidising agent / Fe is a reducing agent for H^+ / other correct redox statement **(1)**
$Fe + 2H^+ \rightarrow Fe^{2+} + H_2$ **(1) –** *stand alone* — 3

(iii) High E_a so slow reaction / reactants are kinetically stable
IGNORE any mention of non-standard conditions — 1

(c) $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ or words E^0 = **(+) 0.23**V **(1)**
So I^- would reduce Fe^{3+} / Fe^{3+} would oxidise I^- / E^0 positive so reaction L → R **(1)**
OR reverse argument **(2)**
OR
Fe^{3+} and Fe^{2+} has a more positive electrode potential than I_2 and I^- **(1)**
I^- will reduce Fe^{3+} / Fe^{3+} will oxidise I^- **(1)** — 2

[15]

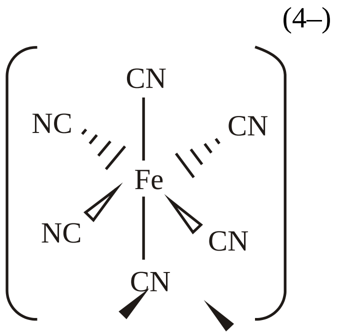
11. (a) (i) Forms **ions** which have partially filled *d*-orbitals
OR
Forms ions which have a partially filled *d*-subshell — 1

(ii) Scandiurn / Sc **and** Zinc / Zn — 1

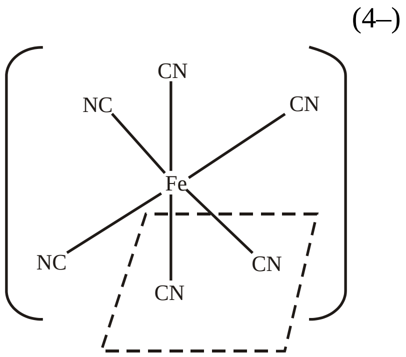
(b) (i) Fe^{2+} [Ar] $3d^6$
Mn^{2+} [Ar] $3d^5$ **(1)** *for both correct* — 1

(ii) Fe^{3+} is $3d^5$ / half filled *d*-subshell which is more stable than $3d^6$ **(1)**
Mn^{2+} is (already) $3d^5$ (which is more stable than $3d^4$) **(1)** — 2

(c) Shape **(1)**
Bonding to correct atoms **(1)**



OR



2

(d) Two As atoms oxidised from +3 to +5 per mole of As_2O_3
(loss of $4e^-$) **(1)**

$\therefore$ if 5 moles oxidised, total $20e^-$ Lost / change in oxidation no. = 20 **(1)**

$\therefore$ 4 moles MnO_4^- reduced, total $20e^-$ gained / change in oxidation no. 20
$\therefore$ each Mn(VII) gains $5e^-$ / change in oxidation no. 5 **(1)**

$\therefore$ Mn(ll) / Mn^{2+} **(1)** *NOT standalone mark* 4

(e) (i) $VO_3^- + 2H^+ / 2H_3O^+ \rightarrow VO_2^+ + H_2O / 3H_2O$ 1

(ii) No because oxidation no. of V is +5 in VO_2^+ / Oxidation no. of V unchanged (at +5) 1

(iii) First green colour : VO_2^+ **and** VO^{2+} **(1)**

Second green colour : V^{3+} / $[V(H_2O)_6]^{3+}$ **(1)**

Violet colour : V^{2+} / $[V(H_2O)_6]^{2+}$, **(1)** 3

[16]

12. (a) $3OCl^- \rightarrow 2Cl^- + ClO_3^-$ **(1)**

chlorine (in OCl^-) is (simultaneously) oxidised from +1 to +5 **(1)**
and reduced from +1 to –1 **(1)**
If only oxidation numbers given **max 1 (out of 2)**
If oxidation numbers omitted **max 1 (out of 2)** 3

(b) (i) blue / black to colourless 1

(ii) no. moles $S_2O_3^{2-}$ used = 12.5 × 0. 1 / 1000 = 1. 25 × 10^{-3} **(1)**

no. moles I_2 = 1.25 × 10^{-3} / 2 = 6.25 × 10^{-4} **(1)**
no. moles ClO^- = no. moles 1_2 **(1)**
no. moles ClO^- in original 10 cm^3 = 10 × 6.25 × 10^{-4}

= 6.25 × 10^{-3} **(1)**

no. moles ClO^- in 1 dm^3 = 100 × 6.25 × 10^{-3} **(1)** = 0.625 — 5

(iii) mass Cl_2 = 0.625 × 71
= 44.4 (g)
mark consequentially on (ii)
must be 3s.f. in final answer — 1

(c) Cl_2 is the stronger oxidising agent because Cl_2 oxidises S from (+)2 to (+)6 **(1)**
but l_2 oxidises S from (+)2 to (+)2.50 **(1)** — 2

QWC (d) O_2 oxidises KI / iodide to l_2. or balanced equation **(1)**
ll_2 reacts with starch / paper to give blue / black **(1)** — 2

[14]

13. (a)

3d 4s

[Ar]  **(1)**

3d 4s

[Ar]  **(1)**

Allow ↑ instead of ↿ and ↓ instead of ⇂ — 2

(b) Forms **ion(s)** which have a partially OR an incompletely filled *d*-(sub)shell OR *d*-orbital(s) — 1

(c) (i) Dative (covalent) OR co-ordinate **(1)**

Covalent **(1)** — 2

(ii) $[Ni(H_2O)_6]^{2+} + 2NH_3 \rightarrow [Ni(OH)_2(H_2O_4)] + 2NH_4^+$

OR

$[Ni(H_2O)_6]^{2+} + 2NH_3 \rightarrow Ni(OH)_2 + 4H_2O + 2NH_4^+$

OR

$[Ni(H_2O)_6]^{2+} + 2OH^- \rightarrow [Ni(OH)_2(H_2O_4)] + 2H_2O$

OR

$[Ni(H_2O)_6]^{2+} + 2OH^- \rightarrow Ni(OH)_2 + 6H_2O$

IGNORE state symbols

IGNORE missing square brackets in any formula 1

(iii) H^+ removed (by NH_3 OR OH^-) **(1)**

From (H_2O) **ligands (1)**

NOT just from "complex" 2

(iv) Ligand exchange

OR ligand replacement

OR ligand substitution 1

(v) $[Ni(OH)_2(H_2O)_4] + 6NH_3 \rightarrow [Ni(NH_3)_6]^{2+} + 2OH^- + 4H_2O$

OR

$Ni(OH)_2 + 6NH_3 \rightarrow [Ni(NH_3)_6]^{2+} + 2OH^-$

Allow formation of $[Ni(NH_3)_4]^{2+}$ OR $[Ni(NH_3)_4(H_2O)_2]^{2+}$

cation formed **(1)**

balancing equation **(1)** 2

(d) QWC *d*-orbital**s** split (in energy) by ligands **(1)**

ALLOW d-sublevel

absorbs light (in visible region) **(1)**

NOT "uv light"

electron is promoted OR electron moves to a **higher** energy level **(1)**

Any mention of emission of light can only score 1st mark 3

[14]