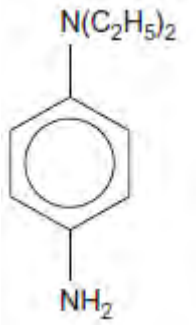
Q1. Chlorine can be found in water. One method for the determination of chlorine in water is to use colorimetry.

A colourless sample of water from a vase of flowers was analysed after the addition of compound Z as the addition of Z resulted in a purple solution.

Compound W



(a) Calculate the M_r of Compound **W**.

.....

.....

.....

(1)

(b) Determine the percentage, by mass, of nitrogen in this compound.

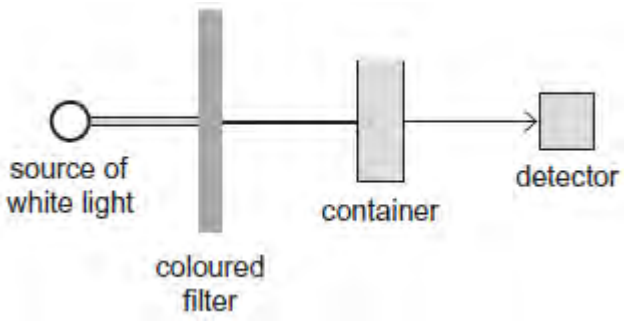
.....

.....

.....

(1)

(c) A simplified diagram of a colorimeter is shown below.



(i) Suggest why it is important that the container for each sample has the same dimensions.

.....

.....

(1)

(ii) Suggest why the coloured filter is used.

.....

.....

(1)

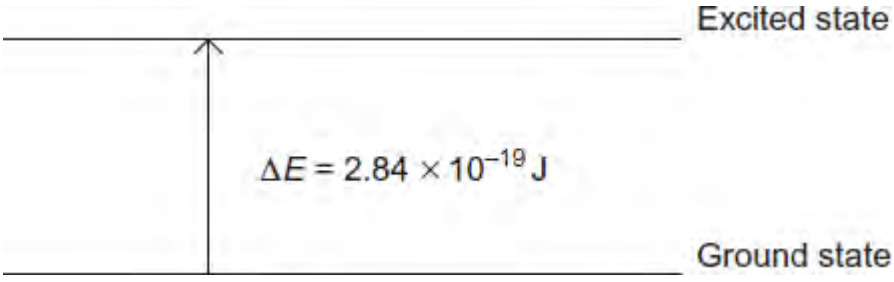
(iii) Suggest **one** reason why a colorimetric method might be chosen in preference to titration.

.....

(1)

(Total 5 marks)

Q2. This diagram represents the energy change that occurs when a d electron in a transition metal ion is excited by visible light.



(a) Give the equation that relates the energy change ΔE to the Planck constant h and the frequency of the visible light v.

Use this equation and the information in the diagram to calculate a value for the frequency of the visible light, and state the units.
The Planck constant $h = 6.63 \times 10^{-34}$ J s.

Equation .....

Calculation .....

.....

.....

.....

.....

(2)

(b) Explain why this electron transition causes a solution containing the transition metal ion to be coloured.

.....

.....

.....

.....

.....

(2)

(c) The energy change shown in the diagram represents the energy of red light and leads to a solution that appears blue.
Blue light has a higher frequency than red light.

Suggest whether the energy change ΔE will be bigger, smaller or the same for a transition metal ion that forms a red solution. Explain your answer.

Energy change .....

Explanation .....

.....

.....

.....

(2)

(d) State **three** different features of transition metal complexes that cause a change in the value of ΔE, the energy change between the ground state and the excited state of the d electrons.

Feature 1 .....

Feature 2 .....

Feature 3 .....

(3)
(Total 9 marks)

Q3. You may find the following electrode potential data helpful when answering this question.

Electrode half-equation	$E^{\ominus}$ / V
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l)$	+1.23
$Cr^{3+}(aq) + e^- \longrightarrow Cr^{2+}(aq)$	–0.44
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	–0.76
$Cr^{2+}(aq) + 2e^- \longrightarrow Cr(s)$	–0.91

(a) Describe the colour changes that you would observe when an excess of zinc is added to an acidified solution of potassium dichromate(VI) in the absence of air.

For each colour change, identify the coloured ions responsible and write an equation for each reaction that occurs with zinc.
In the equations, you should represent the ions in their simplest form, for example Cr^{3+}.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

(5)

(b) Describe what you would observe when dilute aqueous sodium hydroxide is added, dropwise until in excess, to a dilute aqueous solution containing chromium(III) ions.

Write **two** equations to illustrate your observations.
In these equations you should give the full formula of each of the complexes, for example $[Cr(H_2O)_6]^{3+}$.

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(4)

(c) When an aqueous solution containing $[Cr(H_2O)_6]^{3+}$ ions is warmed in the presence of Cl^- ions, $[Cr(H_2O)_5Cl]^{2+}$ ions are formed and the colour of the solution changes.

Name this type of reaction.

Suggest, in terms of electrons, why the colours of the complex ions are different.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

(3)

(d) The chromium(II) ion $[Cr(H_2O)_6]^{2+}$ has different properties from the $[Cr(H_2O)_6]^{3+}$ ion.

Use data from the table above to explain why, in an open container, $[Cr(H_2O)_6]^{2+}(aq)$ ions change into $[Cr(H_2O)_6]^{3+}(aq)$ ions.

Suggest the identity of the products formed in each case when sodium carbonate solution is added to separate solutions containing $[Cr(H_2O)_6]^{2+}(aq)$ ions and $[Cr(H_2O)_6]^{3+}(aq)$ ions.

Explain why the $[Cr(H_2O)_6]^{3+}(aq)$ ions behave differently from the $[Cr(H_2O)_6]^{2+}(aq)$ ions.

In your answer to this part of the question, equations are **not** required.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

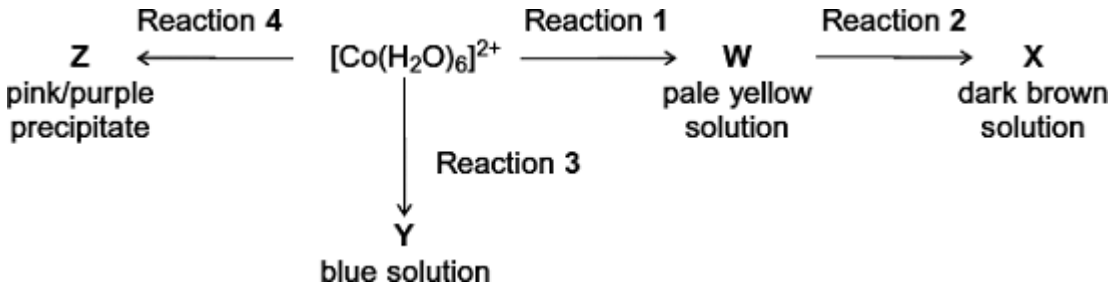
.....

.....

(7)
(Total 19 marks)

Q4. This question is about cobalt chemistry.

(a) Consider the following reaction scheme that starts from $[Co(H_2O)_6]^{2+}$ ions.
W, **X** and **Y** are ions and **Z** is a compound.



For each of the reactions **1** to **4**, identify a suitable reagent.

Identify **W**, **X**, **Y** and **Z** and write an equation for each of reactions **1** to **4**.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(12)

(b) A flue-gas desulfurisation process involves the oxidation, by oxygen, of aqueous sulfate(IV) ions (SO_3^{2-}) into aqueous sulfate(VI) ions (SO_4^{2-}). This reaction is catalysed by Co^{2+} ions in an acidic aqueous solution.

Write an equation for the overall reaction of sulfate(IV) ions with oxygen to form sulfate(VI) ions.

Suggest why this overall reaction is faster in the presence of Co^{2+} ions.

Suggest a mechanism for the catalysed reaction by writing **two** equations involving Co^{2+} and Co^{3+} ions. You will need to use H^+ ions and H_2O to balance these two equations.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)
(Total 16 marks)