A-Level Chemistry

Formation of Coloured Ions

Question Paper

Time available: 60 minutes
Marks available: 56 marks

1. (a) Explain why complexes formed from transition metal ions are coloured.

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(3)

The iron content of iron tablets can be determined by colorimetry.

Method:

- Dissolve a tablet in sulfuric acid.
- Oxidise all the iron from the tablet to $Fe^{3+}(aq)$.
- Convert the $Fe^{3+}(aq)$ into a complex that absorbs light of wavelength 490 nm
- Make the solution up to 250 cm^3
- Measure the absorbance of light at 490 nm with a colorimeter.
- Use a calibration graph to find the concentration of the iron(III) complex.

(b) Calculate the energy, in J, gained by each excited electron in the absorption at 490 nm

Speed of light, $c = 3.00 \times 10^8$ m s^{-1}

Planck constant, $h = 6.63 \times 10^{-34}$ J s

Energy gained by each electron _____ J

(3)

(c) Describe how a calibration graph is produced and used to find the concentration of the iron(III) complex.

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(3)

(d) The concentration of iron(III) in the solution is 4.66×10^{-3} mol dm^{-3}

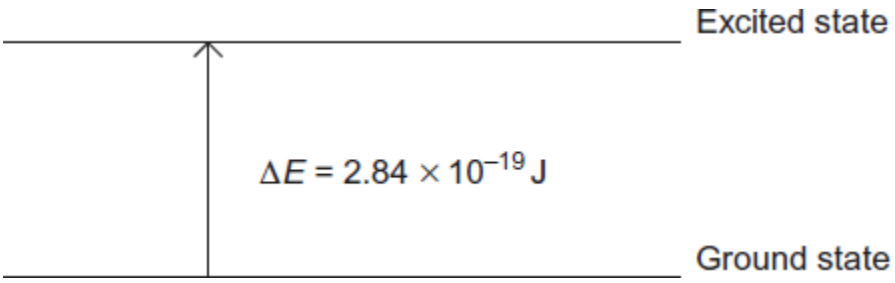
Calculate the mass, in mg, of iron in the tablet used to make the 250 cm^3 of solution.

Mass of iron in the tablet _____ mg

(2)

(Total 11 marks)

2. 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 _____

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(2)

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

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(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 _____

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(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)

3. 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+}.

(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 $[Cr(H_2O)_6]^{3+}$.

(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.

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(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.

(7)

(Total 19 marks)

4. This question is about copper chemistry.

(a) Aqueous copper(II) ions $[Cu(H_2O)_6]^{2+}(aq)$ are blue.

(i) With reference to electrons, explain why aqueous copper(II) ions are blue.

(3)

(ii) By reference to aqueous copper(II) ions, state the meaning of each of the **three** terms in the equation $\Delta E = hv$.

(3)

(iii) Write an equation for the reaction, in aqueous solution, between $[Cu(H_2O)_6]^{2+}$ and an excess of chloride ions.
State the shape of the complex produced and explain why the shape differs from that of the $[Cu(H_2O)_6]^{2+}$ ion.

(3)

(b) Draw the structure of the ethanedioate ion ($C_2O_4^{2-}$).
Explain how this ion is able to act as a ligand.

(2)

(c) When a dilute aqueous solution containing ethanedioate ions is added to a solution containing aqueous copper(II) ions, a substitution reaction occurs. In this reaction four water molecules are replaced and a new complex is formed.

(i) Write an ionic equation for the reaction. Give the co-ordination number of the complex formed and name its shape.

(4)

(ii) In the complex formed, the two water molecules are opposite each other.
Draw a diagram to show how the ethanedioate ions are bonded to a copper ion and give a value for one of the O–Cu–O bond angles. You are **not** required to show the water molecules.

(2)

(Total 17 marks)