

CHEMISTRY DEPARTMENT

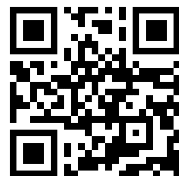


LABORATORY MANUAL

SIC3001 INORGANIC CHEMISTRY III
SID3001 ADVANCED INORGANIC CHEMISTRY

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ISOMERISM AND KINETICS IN COORDINATION CHEMISTRY**INTRODUCTION**

The purpose of this experiment is to prepare and study the kinetics of the interconversion of some of the isomers of a typical coordination compound. Historically, isomerism has played a central role in establishing the basic concepts of coordination chemistry upon which so much of modern inorganic chemistry is based. On the other hand, the reaction kinetics of coordination compounds is an area of continuing intense research activity. Much of the present interest in the mechanisms of the reactions of coordination compounds stems from their relevance to enzyme reactions where the active site frequently involves coordination to a metal ion.

The first part of this experiment involves the preparation of the *cis* and *trans* isomers of dichlorobis(ethylenediamine)cobalt(III) chloride while in the second part the rate of conversion of the racemic *cis* isomer to the *trans* isomer is followed spectrophotometrically.

LEARNING OUTCOME

- Students will be able to differentiate the isomers of coordination compounds with spectroscopic methods.
- Students will be able to determine the rate of conversion of *cis* isomer to *trans* isomer.

METHODOLOGY

(a) Preparation of *Trans*-Dichlorobis(ethylenediamine)cobalt(III) chloride.

To a solution of 16 g of cobalt(II) chloride hexahydrate in 50 mL of water, contained in a 250 / 500 mL Erlenmeyer (or conical) flask, add with stirring 60 mL of a 10% solution of ethylenediamine. A vigorous stream of air is drawn through the solution for 1-2 hours and then 35 mL of concentrated hydrochloric acid is added and the solution evaporated on a steam bath until a crust forms over the surface (ca. 75 cm³).

The solution is allowed to cool and stand overnight before the bright green plates of the hydrochloride, *trans*-[Co(en)₂Cl₂]Cl·HCl are filtered. These are then washed with alcohol and ether and dried. Grind the dried crystals finely using a pestle and mortar, then transfer to a porcelain dish to be dry at 110°C. At this temperature the hydrogen chloride is lost and the crystals have converted into a dull green powder. Yield expected is ca. 8 g. (50 % based on ethylenediamine used).

(b) Preparation of the *cis* isomer.

Dissolve 2-3 g of the *trans* isomer in about 10 mL of water. A solution of the *trans* form yields the less soluble *cis* form on evaporation to dryness over a steam bath. The evaporation may need to be repeated but not more than three times (further repetition of the evaporation causes substantial decomposition) to affect *cis* formation. Finally, unchanged *trans* form may be washed out with a little cold water.

(c) The *cis* to *trans* isomerization.

In methanol solution the purple *cis* form is isomerized to the (thermodynamically) more stable green *trans* form. In order to follow the reaction by spectrophotometry, it is necessary to record the spectra of both the *cis* and the *trans* isomer separately. To save time the following procedure is adopted.

Prepare a solution (0.02 M; 28 mg in 50 cm³) of the *trans* isomer in methanol and record its UV- visible spectrum. Repeat this procedure for the *cis* isomer, recording the UV spectrum immediately after the solution has been prepared; then quickly place the solution, tightly stoppered, into a constant temperature bath at 35°C. Meanwhile from an examination of the spectra (discuss with your Demonstrator) select the most appropriate wavelength to follow the reaction. Measure the optical density *D* at this wavelength at 15 minutes intervals for about 90 min. by withdrawing samples from the thermostated solution. *D*_∞ may be measured by allowing the mixture to stand overnight.

The isomerization reaction is first-order. Then $\ln\{cis\} = -kt + c$. It is easily shown that $\ln(D - D_\infty) = -kt + C'$, so a plot of $\ln(D - D_\infty)$ against time should give a straight line of slope $-k/2.303$. (Note that since the reaction is first-order neither the extinction coefficient for the two isomers nor the initial concentration of the *cis* isomer need be known). From your results, determine *k* and the half-life of the reaction.

REFERENCES

1. L. K. Brice, *J. Chem. Educ.*, 1962, **39** (12), p 634.
2. Daryle H. Busch, *J. Chem. Educ.*, 1964, **41** (2), p 77.

THE PREPARATION AND CHARACTERIZATION OF MESITYLENETRICARBONYLMOLYBDENUM(0)**INTRODUCTION**

Isolated organometallic compounds of the transition elements have been known for a long time (e.g., Zeise's salt – 1827). However, it was not until the 1950's, following the accidental discovery of ferrocene, that the organometallic chemistry of the transition metals became a major area of inorganic research.

Perhaps the most versatile starting materials for the laboratory synthesis of transition metal organometallic compounds are the metal carbonyls. In this experiment, molybdenum hexacarbonyl is reacted directly with an organic aromatic (mesitylene). In general, the reaction can be represented as:

**LEARNING OUTCOME**

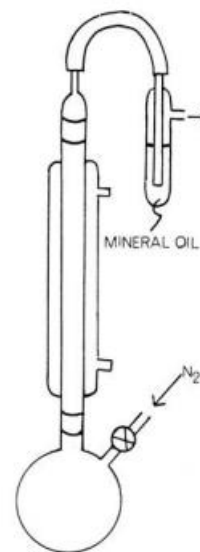
- Students will be able to prepare and characterize air- and moisture-sensitive compounds.

METHODOLOGY

NOTE: THIS PREPARATION MUST BE PERFORMED IN A FUME HOOD. METAL CARBONYLS ARE VERY TOXIC.

Assemble the apparatus as shown in the diagram using a 50 mL two-neck round bottom flask and a simple reflux condenser (water need not be circulated through the condenser: air cooling is sufficient).

Add 1.8 g $\text{Mo}(\text{CO})_6$ to the flask followed by 10 mL of mesitylene, 10 mL decalin and 5-10 mL of toluene or hexane (This facilitates the sublimed $\text{Mo}(\text{CO})_6$ to return back to the reaction mixture during refluxing at 186°C). Flush the apparatus with a moderate stream of nitrogen for about 5 min. After the nitrogen flow is turned off and the stopcock closed, bring the mixture to a moderate boil with the heating mantle. Reflux for 2-3 hours (yield improves with stirring), then turn off the heat and immediately flush with nitrogen to prevent the mineral oil in the bubbler from being sucked back into the reaction vessel.



The apparatus for the preparation of mesitylene tricarbonyl molybdenum (0).

Allow the reaction mixture to cool to room temperature, then filter using a Buchner funnel. For purification, dissolve the filtered crude product in a minimum amount of CH_2Cl_2 (FUME CUPBOARD), pass the solution through a medium frit loaded with ~2-3 cm Celite (aspirator pump). Transfer the filtrate to a rotary evaporator and evacuate to dryness. Remove the resulting fine lemon-colored crystals with a spatula and weigh. Further purification of the recrystallized product may be achieved by vacuum sublimation (100°C, high vacuum).

(a) Characterization

- IR Spectrum.

Record the IR spectrum of the product over the whole range and assign the important bands. Also record the IR spectrum of the compound in solution in CHCl_3 in the region $1800\text{--}2000\text{ cm}^{-1}$. Comment on the differences between the two spectra in this region.

- NMR Spectrum.

Prepare 0.5 mL of a saturated solution of the product in the specially purified CHCl_3 (obtainable from the Laboratory Assistant) and record the NMR spectrum. Comment on the spectrum particularly the information it provides about the structure and bonding of the complex. Explain why free mesitylene shows two peaks at 2.25 and 6.78 ppm (vs. TMS in CDCl_3 of relative intensity 9:3).

QUESTIONS

1. Use spectral data to determine the structure of the complex.
2. To what symmetry group does the complex belong?
3. Discuss the differences in the stretching frequencies of CO in $\text{Mo}(\text{CO})_6$ and the product.

REFERENCES

1. G. E. Coates, M. L. H. Green and K. Wade: *Organometallic Compounds Vol. 11. (The Transition Elements)* 1968.
2. B. Nicholls and M. C. Whiting, *J. Chem. Soc.*, (1959) 551.
3. F. A. Cotton, G. Wilkinson, C. A. Murillo, and M. Bochmann., *Advanced Inorganic Chemistry*, 6th Edition, Wiley-Interscience: New York, 1999.
4. R. J. Angelici, *J. Chem. Ed.*, 45 (1968) 119.

MAGNETIC SUSCEPTIBILITY

INTRODUCTION

Magnetic susceptibility is the degree of magnetization of a material in response to an applied magnetic field. If magnetic susceptibility is positive, then the material can be paramagnetic, ferromagnetic, ferrimagnetic, or antiferromagnetic. Measurements of magnetic properties have been used to characterize a wide range of systems from oxygen, metallic alloys, solid state materials, and coordination complexes containing metals. Most organic and main group element compounds have all the electrons paired and these are diamagnetic molecules with very small magnetic moments. All the transition metals have at least one oxidation state with an incomplete d subshell. Magnetic measurements, particularly for the first-row transition elements, give information about the number of unpaired electrons. The number of unpaired electrons provides information about the oxidation state and electron configuration. The aim of the experiment is (1) to acquaint the student with two of the experimental techniques involved in magnetochemical measurements, *viz*, the Gouy method for solids and the Evans' method for solutions, and (2) to examine the magnetic behavior of a complex in the solid and solution state, and to gain information about stereochemical changes if any. The latest techniques include SQUID, (superconducting quantum interference device) a very sensitive magnetometer used to measure extremely subtle magnetic fields, based on superconducting loops containing Josephson junctions. Commercial SQUID magnetometers are available for temperatures between 300 mK and 400 kelvins, and magnetic fields up to 7 tesla.

LEARNING OUTCOME

- Students will be able to correlate the magnetism of a metal complex with its electronic configuration and ligand strength.

METHODOLOGY

To a stirred solution of 4.0 g of manganese chloride ($\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$) and 10.2 g of sodium acetate ($\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$) in water (150 mL) slowly add acetylacetone (18.8 mL). Follow by adding slowly, with stirring, a solution of potassium permanganate (0.80 g in 40 mL of water) and a few minutes later in small amounts, a solution of sodium acetate trihydrate (10.0 g in 40 mL of water). Heat on a water bath for 20 minutes at about 60°C , cool in ice-cold water and filter off the dark solid. Wash the product with ice-cold water, and dry in a vacuum desiccator over anhydrous calcium sulphate.

Dissolve the dry chelate in warm toluene (20 mL), filter and re-precipitate the complex by cooling and adding petroleum ether ($40\text{-}60^\circ\text{C}$) (about 75 mL). Dry in a vacuum desiccator. Calculate the percentage yield.

- a) Measure the paramagnetic susceptibility of the complex as a solid (see Appendix 3A, p. 9-12).
- b) Run the NMR spectrum of a CHCl_3 solution containing a known concentration of the complex (ca. 0.01 g/mL). Insert a capillary tube containing pure CHCl_3 as external reference (see Appendix 3B).
- c) From the frequency separation of the proton resonance in the CHCl_3 solution relative to the external reference of pure CHCl_3 , calculate the magnetic susceptibility of the complex in solution.

Notes:

NMR spectra of these solvent mixtures are provided. See Appendix 3C for the calculation of the mass susceptibility χ_0 of these solvent mixtures.

Diamagnetic correction of solvent: The frequency separation for the methyl resonance in the solvent mixture relative to the pure toluene capillary is a measure of the solvent susceptibility, hence this frequency shift is equivalent to a diamagnetic correction and must therefore be subtracted from the overall frequency separation measured for the metal complex.

From the corrected frequency separation calculate χ_g , χ_M , and χ_M^{corr} (corrected for the diamagnetism of the ligands, See Appendix 3D), and hence the solution Bohr Magneton Number, μ_{eff} . (see Appendix 3B).

QUESTIONS

- 1) Describe under what conditions spin-only formula will be useful to calculate μ of the complexes (Appendix 3A).
- 2) What conditions should be satisfied by a complex whose magnetic susceptibility we wish to determine in solution? Are there any restrictions to the type of reference solvent we could use? On the basis of your answer, discuss the feasibility of determining μ_{eff} for the following:
 - a. $\text{Fe}(\text{CN})_6^{3-}$ in aqueous solution using the tert-butanol methyl resonance as reference.
 - b. CuCl_4^{2-} in pyridine using the toluene methyl resonance as reference.
 - c. $\text{Ni}(\text{DMG})_2$ in benzene using the methyl resonance of 4-methylpyridine as reference (DMG = dimethylglyoxime).

REFERENCES

1. F. A. Cotton, G. Wilkinson, C. A. Murillo, and M. Bochmann., Advanced Inorganic Chemistry, 6th Edition, Wiley-Interscience: New York, 1999.
2. M. Greenaway and L. E. Trail. J. Chem. Educ., (1983), 60 (8), p 681.

APPENDIX 3A

THE MEASUREMENT OF MAGNETIC SUSCEPTIBILITY

THEORY AND DEFINITIONS

Magnetic susceptibility is defined as the ratio of the intensity of magnetism induced in a substance to the magnetizing force or intensity of field to which it is subjected. It provides important electronic structural information of the transition and rare earth metal complexes.

Traditionally, measurement of magnetic susceptibility has been made using the Gouy and the Faraday methods. The original instruments were originally made from conventional laboratory balances and large permanent magnets. The magnets were brought towards the sample and the positive or negative change of apparent weight was noted. The balances and sample holder were free of ferromagnetic materials. The systems that evolved were very large relying on heavy magnets, fixed in position, and a moving sample.

The late Professor Evans of Imperial College London introduced an innovative step to the measurement. Instead of measuring the apparent weight loss or gain of a suspended sample, the force acting upon a suspended magnet was detected, thereby turning the method on its head. The advantage realized by this step led to the development of the light and inexpensive magnetic susceptibility balance, which is the MSB-MKI. The model used in our laboratory is MSB-AUTO which has many improved features, and which still relies on the advantage first obtained by Professor Evans.

The three most common ways that magnetic susceptibility values are expressed are with reference to the volume of sample, the weight of sample, and the moles of sample. These terms are commonly referred to as volume susceptibility, mass susceptibility, and molar susceptibility. The equations relating these terms are provided below:

VOLUME SUSCEPTIBILITY

The volume susceptibility, χ_v designated is expressed by the following formula:

$$\chi_v = \frac{I}{H}$$

where I is the intensity of magnetism included in the substance and H is the intensity of the applied external magnetic field

The volume susceptibility can be quite variable due to changes in the density of the substance, particularly when the sample is a gas or solid. The mass susceptibility, χ_g , introduces a density factor in the following manner:

MASS SUSCEPTIBILITY

$$\chi_g = \frac{\chi_v}{d}$$

where d is the density of the substance, Note that χ_g has units of reciprocal density, $\frac{\text{cm}^3}{\text{g}}$

MOLAR SUSCEPTIBILITY

The most common way of reporting a magnetic susceptibility value in the literature is by molar susceptibility, designated as χ_M . The relationship of molar susceptibility to mass susceptibility is shown below:

$$\chi_M = \chi_g \times MW$$

where MW is the molecular weight of the substance.

The χ_M is the best value to use when comparing different materials qualitatively or assessing the potential of a quantitative applications since the value of the term is not subjected to variations due to the method of measurement or to sample density.

Since the Auto, like other methods, measures Volume Susceptibility and the literature is quoted in Molar Susceptibility, the conversion between the two values is quite common in magneto chemical studies. *The initial step in the conversion, that is obtaining a χ_g value from χ_v , is done within the Auto provided the length and weight of the sample are known and can be entered into the unit.*

Calculation of magnetic moment

The molar susceptibility obtained has to be corrected for the inherent diamagnetic contribution (χ^{dia}) from the ligands and metal ions using the table of Pascal's constants.

$$\text{i.e. } \chi_M^{\text{corr}} = \chi_{Me}^{\text{exp}} - \chi^{\text{dia}}$$

The relationship between molar susceptibility and effective magnetic moment, μ_{eff} is

$$\mu_{\text{eff}} = 2.84 \sqrt{\chi_M^{\text{corr}} T} \quad \text{Bohr Magnetron}$$

It can also be shown that the effective magnetic moment, μ_{eff} is given by,

$$\mu_{\text{eff}} = \sqrt{n(n+2)} \text{ B.M.}$$

[Note: A system obeying Curie law would have no or negligible orbital contribution towards the magnetic moment].

For the details on the operation of the MSB-AUTO magnetobalance, please refer to the operating manual.

Cleaning and storage of sample tube

[Note: The sample tube used in this magnetobalance is a high precision tube made of silica. It is expensive and should be treated with care!]

The good maintenance of the sample tubes is essential for good results. Sample tubes can be cleaned with conventional detergents and/or organic solvents, depending on the nature of their sample. In difficult cases, strong acids, viz. HCl or HNO₃ may be required. Pipe cleaners have proven to be a useful tool. Similarly, an aerosol can of ethylene dichloride, supplied with a plastic capillary spout (available for degreasing electronic components) has proven invaluable in removing oil from the tubes when analyzing for wear metals.

The tube should be stored in a dust-free environment and its susceptibility should be measured before introducing a sample. As a final precaution, the outside of the tube should be wiped with a dust free wiper just prior to introducing it to the balance, particularly if it has been allowed to lay on the bench.

Packing sample into the tube

The tube is packed as follows. The solid to be measured is ground to a fine powder in a mortar and pestle. HgCo(NCS)₄ forms very fine crystals and can usually be used without grinding. Note that the greatest source of error in Gouy measurements is in homogeneous packing. It is essential that an effective routine for the packing of the powder into the tube is developed and adhered to. Good packing requires time and patience.

A small amount of the compound is picked up from the mortar, placed in the flared mouth of the tube, and tapped to the bottom of the tube. The closed end of the tube is tapped for about a minute on two sheets of filter paper on a wooden bench. (See a demonstrator about this). This process is continued until the tube is filled to the mark - make sure that the sample does not pack down with further tapping. Wipe away any excess compound from the mouth of the tube to remove excess moisture.

Standard to calibrate the balance

Several standards can be used for checking the calibration of the balance. Perhaps one of the most reliable trouble free standard is water ($10^6 \chi_g = -0.720$), since it is readily available in pure form. A singly distilled water sample should suffice.

$\text{HgCo}(\text{SCN})_4$ ($10^5 \chi_g = +1.644$ at 20°C) is considered one of the best solid standards. At other temperature, use the relation

$$\frac{d\chi_g}{dt} = -0.05 \times 10^{-6} \text{ cgs/K}$$

to obtain the exact χ_g value.

The ethylenediamine salts of nickel, $\text{Ni}(\text{en})_3 \text{S}_2\text{O}_3$ ($10^5 \chi_g = +1.104$) is also a useful secondary standard.

Many solid samples of paramagnetic substances, if properly dried and ground and packed, usually give within 2% of their literature value.

If it is necessary to recalibrate, please refer to Section 5.2 of the original operator's manual.

APPENDIX 3B

EVANS' METHOD FOR MAGNETIC SUSCEPTIBILITIES

(Extracted from *J. Chem. Ed.*, 46, 1969, 167)

This method is based on the principle that the position of a given proton resonance in the spectrum of a molecule is dependent on the bulk susceptibility of the medium in which the molecule is found. The shift of a proton resonance line of an inert substance due to the presence of paramagnetic ions is given by the theoretical expressions⁵.

$$\frac{\delta\nu}{\nu_0} = \frac{2\pi}{3} (\chi_v - \chi'_v) \quad (1)$$

where $\delta\nu$ is the shift, ν_0 is the applied field, χ_v is the volume susceptibility of the solution containing paramagnetic ions, and χ'_v is the volume susceptibility of the reference solution. For example, if an aqueous solution of paramagnetic substance with 3% of t-butyl alcohol as an inert reference substance is placed in the inner tube of a concentric cell, and an identical solution without the paramagnetic substance is placed in the annular section of the cell, two resonance lines will usually be obtained for the methyl protons of the t-butyl alcohol due to the difference in the volume susceptibilities of the solutions. This is in accord with eqn. (1). The gram susceptibility, χ_g of the dissolved substance is given by the expression⁵.

$$\chi_g = \frac{3 \delta\nu}{2\pi\nu_0 m} + \chi_0 + \chi_0 \left(\frac{d_0 - d_s}{m} \right) \quad (2)$$

where $\delta\nu$ is the frequency separation between the two lines in cycles/sec, ν_0 is the frequency at which the proton resonances are being studied in cycles/sec, m is the mass of substance contained in 1 cm³ of solution, χ_0 is the mass (gram) susceptibility of the solvent (-0.72×10^{-6} cc g⁻¹ for dilute t-butyl alcohol solutions), d_0 is the density of the solvent, and d_s that of the solution. For highly paramagnetic substances, the last term can often be neglected⁵. The molar susceptibility, the effective magnetic moment and the "spin only" number of unpaired electrons may be calculated by the same procedure used for the Gouy measurements (See Appendix 3A).

APPENDIX 3C

MASS SUSCEPTIBILITY OF SOLVENT MIXTURES

For a mixture of non-interacting components,

$$\text{Mass susceptibility, } \chi_o = \sum m_f(i) \cdot \chi_o.$$

$$\text{where } m_f = \frac{m_i}{\sum_i m_i} \text{ which is the mass fraction of the } i\text{-th component}$$

Use of this equation and the table below would enable us to calculate the mass susceptibility of the solvent mixtures used in this experiment.

TABLE

SOLVENT	MASS SUSCEPTIBILITY $\chi_o \times 10^{-6}$ (c.g.s. or Gaussian units)	DENSITY (gcm^{-3})
Benzene	-0.702	0.876
Toluene	-0.7176	0.863
Pyridine	-0.622	0.981
Chloroform	-0.497	1.49

APPENDIX 3D

DIAMAGNETIC CORRECTIONS

When making diamagnetic corrections, an addition to the measured value is made for each atom present in the molecule.

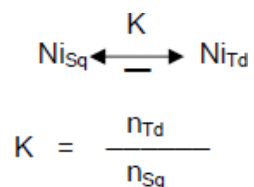
The relevant diamagnetic susceptibilities are given in the table below:

TABLE

DIAMAGNETIC CORRECTIONS (c.g.s. units) (All values x 10 ⁻⁶ /g atom)	
Element / ion	Diamagnetic correction values
H	-2.93
C	-6.00
C (aromatic)	6.24
O (alcohol)	-4.61
O (carbonyl)	+1.73
N (C=N)	-5.57
Mn ³⁺	-10.0
Ni ²⁺	-12.8

APPENDIX 3E

Consider at equilibrium we have n mol of each of the square planar and tetrahedral forms present, each with a MOLAR magnetic susceptibility of χ_M , then for the equilibrium:



We can write,

$$\chi_M^{\text{obs}} = \frac{n_{\text{sq}}}{\Sigma n} \cdot \chi_M^{\text{sq}} + \frac{n_{\text{Td}}}{\Sigma n} \cdot \chi_M^{\text{Td}}$$

But since

$$\chi_M^{\text{obs}} = 0, \quad \text{then,}$$
$$\chi_M^{\text{obs}} = \frac{n_{\text{Td}}}{(n_{\text{Td}} + n_{\text{sq}})} \cdot \chi_M^{\text{Td}}$$

Now

$$\mu_{\text{eff}} = 7.977 \times 10^2 [\chi_M (\text{SI}) \cdot T]^{1/2}$$

i.e., $\mu_{\text{eff}}^2 = \text{constant} \times \chi_M$ at a given temperature, thus we can write

$$\mu_{\text{eff}}^2 = \frac{n_{\text{Td}}}{(n_{\text{sq}} + n_{\text{Td}})} \mu_{\text{eff}}^2(\text{Td})$$

Assuming that the maximum Bohr Magneton Number, μ_{eff} , for a tetrahedral $[\text{Ni}(\text{salen})_2]$ complex in solution is about 3.3 (See Reference 1), it is then possible to obtain an expression for K which can be solved using the observed value for μ_{eff} , (obs) which you calculate from your data.

ELECTRONIC SPECTRA OF NICKEL(II) COMPLEXES, A d^8 SYSTEM

INTRODUCTION

Tanabe-Sugano (TS) diagrams are correlation diagrams that depict energies of electronic states of the complexes (or Terms) as a function of the strength of the ligand field. Ligand field is the electric field that is created by the ligands around a metal ion when the complex is formed. The strength of the ligand field is measured by the parameter Dq , which is related to the octahedral crystal field splitting by $10Dq = \Delta_o$. The energy of an electronic state in a TS diagram is denoted by E .

Figure 1 shows d^8 diagram. In the diagrams the term energies, E , are expressed as E/B and plotted against Δ_o/B , where B is the Racah parameter.

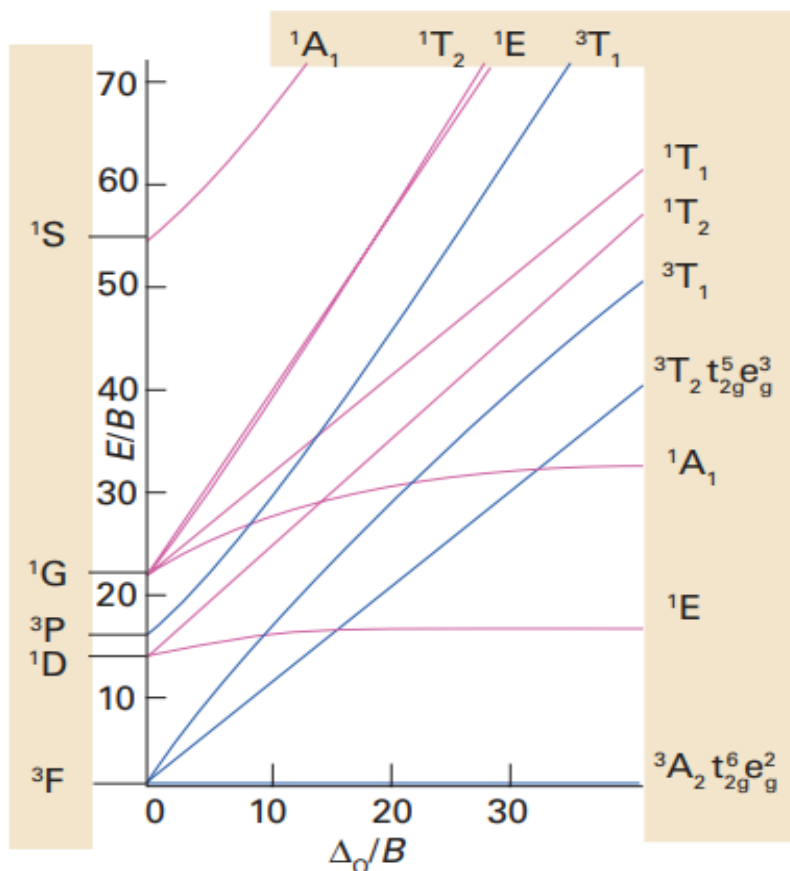


Figure 1: TS diagram for d^8 system (Shiver & Atkins, 2010).

The lowest energy term is set to 0, and all other states are defined relative to the ground state. The terms for d^8 configuration include 3F , 1D , 3P , 1G and 1S . Since the 3F is the ground state we will assume that the two transitions observed in the absorption spectrum arise from the 3F and 3P states. (Note that spin allowed transitions ($\Delta S = 0$) will be the most intense). Electron-electron repulsion splits the term into components with different energies as shown in Figure 2.

Atomic term	Number of states	Terms in O_h symmetry
S	1	A_{1g}
P	3	T_{1g}
D	5	$T_{2g} + E_g$
F	7	$T_{1g} + T_{2g} + A_{2g}$
G	9	$A_{1g} + E_g + T_{1g} + T_{2g}$

Figure 2: Splitting of free-ion terms in octahedral field (Shriver & Atkins, 2010).

The purpose of the experiment is to extract the value of the ligand-field splitting parameters from the electronic absorption spectrum of a complex with more than one d electron, when electron-electron repulsions are important.

The strategy involves fitting the observed transitions (UV visible spectra) to the correlation lines in a Tanabe-Sugano diagram and identifying the values of Δ_o and B.

LEARNING OUTCOME

- Students will be able to explain the effect of ligand strength on the electronic spectra of metal complex by using the Tanabe-Sugano diagram.

METHODOLOGY

Preparation of Nickel(II) Complexes:

**obtain complex 1 from the lab assistant and prepare complexes 2, 3, 4 and 5.*

- $[\text{Ni}(\text{bipy})_3]\text{SO}_4 \cdot 6\text{H}_2\text{O}$

Warm an aqueous solution containing 15 g of 2,2-bipyridyl and 6 g of $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$. Cool and filter. Dissolve 5 g of the chloride and add 5 cm^3 of a 1 M solution of Na_2SO_4 . $\text{Ni}(\text{bipy})_3\text{SO}_4$ crystallizes out.

Reference: J. Chem. Soc., 1971 (A), 1637, 1640.

2. $[\text{Ni}(\text{en})_3]\text{Cl}_2 \cdot 2\text{H}_2\text{O}$

Add 3.0 mL of 70% aqueous ethylenediamine to a solution of 2.38 g (0.01 mol) $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ in 100 mL of water. Filter the purple solution to remove the small amount of anhydrous iron oxide which precipitates and is then evaporated to a volume of 40 to 50 mL on a steam bath.

Add two drops of ethylenediamine, and cool the solution in an ice bath. Collect the orchid-colored crystals by suction, wash twice with 95% ethanol, and air-dried. The yield is *ca.* 2.86 g (80%). Several more grams may be recovered from the mother liquor by adding ethanol and cooling.

3. $[\text{Ni}(\text{NH}_3)_6]\text{Cl}_2$

Dissolve 2 g $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ in 3 mL water. Add 6 mL NH_3 and heat for 10 min. but do not boil. (Use fume-hood.) Then cool the solution in an ice bath and slowly add 6 mL ethanol while stirring. Filter with suction. Wash the precipitate with ethanol and acetone; and air-dried. Record your yield.

4. $[\text{Ni}(\text{DMSO})_6]\text{Cl}_2$

Dissolve 2 g of $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ in minimum ethanol (approx. 3-4 mL) and mix with the same volume of ether, followed by 4.0 mL of dimethylsulfoxide (DMSO). Cool the mixture in the refrigerator until crystals are formed. Filter and dry in a vacuum desiccator.

Reference: J. Inorg. Nucl. Chem., (1961), 16, 219.

5. $\text{K}_4[\text{Ni}(\text{NCS})_6] \cdot 4\text{H}_2\text{O}$

Dissolve 0.01 mole of $\text{Ni}(\text{SO}_4) \cdot 7\text{H}_2\text{O}$ and KSCN in water (Work out appropriate amounts). Evaporate to dryness. Extract with absolute alcohol. Filter off the K_2SO_4 and concentrate on the alcoholic solution to obtain the complex.

Reference: Inorg. Chem. 4 (1965), 715, 823.

Prepare solutions as described in Table 1.

Table 1: Solutions of complexes to be prepared.

<u>Complex</u>	<u>Solvent and Blank</u>	<u>Concentration</u>
1. $[\text{Ni}(\text{bipy})_3]\text{SO}_4 \cdot 6\text{H}_2\text{O}$	Water	0.05 M
2. $[\text{Ni}(\text{en})_3]\text{Cl}_2 \cdot 2\text{H}_2\text{O}$	20% en	0.05 M
3. $[\text{Ni}(\text{NH}_3)_6]\text{Cl}_2$	Aqueous NH_3	0.05 M
4. $[\text{Ni}(\text{DMSO})_6]\text{Cl}_2$	DMSO	0.05 M
5. $\text{K}_4[\text{Ni}(\text{NCS})_6] \cdot 4\text{H}_2\text{O}$	10 M KSCN in water	0.05 M

bipy = 2,2-bipyridyl ; en = ethylenediamine ; DMSO = dimethylsulfoxide

Record the spectrum of each solution in the region 200 – 1100 nm and calculate Δ_o and B , for each ligand.

QUESTIONS

1. Determine all the spin-allowed electronic transition for d^8 system.
2. Arrange the ligands in the spectrochemical series, that is in order of increasing Δ_o .
3. Assign the 2 bands in the observed spectrum of complex 5 and estimate the frequency of the missing band.
4. Estimate the frequency of the absorption maximum for the ${}^3A_{2g} \rightarrow {}^3T_{1g}(P)$ transition in complex 1. Why is it not possible to get this directly from the spectrum? (Do not include limitations of instrumentation as a valid reason).
5. The energy versus Δ correlations for ${}^3T_{1g}(P)$ and ${}^3T_{1g}(F)$ deviate from linearity, why?

REFERENCES

1. C. E. Housecroft and A. G. Sharpe, *Inorganic Chemistry*, 5th edn., Pearson Prentice Hall, 2018.
2. M. Weller, T. Overton and J. Rourke, *Inorganic Chemistry*, 7th edn, Oxford University Press, 2018.
3. F. A. Cotton, G. Wilkinson, C. A. Murillo, and M. Bochmann. *Advanced Inorganic Chemistry*, 6th Edition, Wiley-Interscience: New York, 1999.
4. Cotton, *J. Chem. Educ.* 1964, 41, 466.
5. Sutton, *J. Chem. Educ.* 1960, 37, 498.
6. Manch & Fernelius. *J. Chem. Educ.* 1961, 38, 192.
7. Forster & Goodgame. *Inorg. Chem.* 1965, 4, 823.
8. R. S. Drago. *Physical Methods in Inorganic Chemistry*, Rheinhold, New York, 1965.

MINI PROJECT

Each student is required to synthesize and characterize a Schiff base ligand and its metal complex. The compounds will be characterized by using IR, ^1H NMR, UV-Vis, and/or Gouy balance. Before the synthesis begins, student must:

1. Identify the availability of amines, ketones, aldehydes and metal salts in the teaching lab.
2. Search for a scientific article that reported the synthesis of a Schiff base and its metal complex. The synthesis must use the chemicals that are available in the lab.
3. If the article reports only the preparation of Schiff base, you may refer to other article for the synthesis of the metal complex.
4. Discuss with your lecturer before you start the experiment.

Students may search for their articles from SciFinder-n, Scopus, ScienceDirect, Google, Open Access, ResearchGate, and many more.

Upon completion of the experiment, student is required to prepare and submit a complete typed or handwrite report that consist of the following:

Title

The title must be the complete title of the project.

Objectives

List the objectives of the experiment.

Introduction

Introduce about Schiff base, complexes of Schiff base and others that is relevant to the project.

Experimental/ Methodology

All methods must be written in past tense.

Results

Tabulate all results here; important IR vibrational bands, NMR signals, melting points, and others.

Discussion

Discuss your findings. Interpret and explain the results.

Conclusion

State whether the objectives have been achieved.

References

List all references from scientific publications. Avoid Wikipedia, blogs and irrelevant websites.

Appendices

Attach all spectra here.

**If the report is typed, please attach a Turnitin report for plagiarism check.*