Biography of Alfred Werner and a brief review on the controversy of Werner theory with Jørgensen theory regarding constitution and configuration of coordination compounds

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ABSTRACT

In this general and popular review article we memorialized briefly about the biography of Alfred Werner who got the Noble prize on 1913 for his great contribution in the coordination chemistry. In this article we are recapitulated the controversy between Jørgensen and Werner (on the basis of literature survey) over the constitution and configuration of metal-amine complexes for celebrating the 100 anniversary of the Nobel prize in chemistry awarded to Alfred Werner.

Keywords: Alfred Werner; Werner theory; Controversy with Jørgensen chain theory; Metal-amine complexes.

1. INTRODUCTION: BIOGRAPHY OF WERNER

Alfred Werner was born on December 12, 1866 in Mulhouse, Alsace (Which was then part of France, but annexed by Germany in 1871. Werner was the fourth and last child of Jean-Adam Werner, a foundry worker and former locksmith, and his second wife, Salome Jeannette Werner, who was a member of a wealthy family. He went to Switzerland to study chemistry at the Swiss Federal Institute (Polytechnikum) in Zurich where he obtained his doctorate degree in 1891 under the supervision of the distinguished organic chemist Arthur Hantzsch (Kauffman et al., 1966). The first fruit was his doctoral thesis, "On the spatial arrangement of atoms in nitrogen compounds" (Chakravorty et al., 1999). He cleverly extended the tetrahedral carbon concept to nitrogen which makes understandable large number of vexed problems in nitrogen chemistry (Kauffman et al., 1966). Then he went to Paris for his postdoctoral study and during this time he spent a semester with the celebrated chemist Berthelot. One night in late 1892 he awoke at 2 a.m. with the solution regarding constitution of molecular compounds and by 5 p.m. of the following day he had finished the paper entitled 'Beitrag zur Konstitution anorganischer Verbindungen' (Kauffman et al., 1966). He was trained as an organic chemist and not performed a single experiment in the field of coordination chemistry at the time when he published his revolutionary paper. This work later termed as “an ingenious impudence”. On 31st August, 1893 he was appointed as extraordinary Professor für organische Chemie (Associate Professor) at the Universität Zürich where he spent the rest of his career (Kauffman et al., 1966). In 1894 he became a Swiss citizen and married Emma Wilhelmina Giesker, with whom he had two children, Alfred and Charlotte. An enthralling lecturer and prolific researcher promoted to full professor in 1895 (Kauffman et al., 1966). He won the Nobel Prize for Chemistry in 1913 for throwing fresh light on “the linkage of atoms in the molecules” which was the basis for modern coordination chemistry. Shortly thereafter he began to suffer from a general, progressive, degenerative arteriosclerosis and died on November 15, 1919, at the early age of 53 (Kauffman et al., 1966).

2. NOBEL LAUREATE IN CHEMISTRY

In 1913, Werner was awarded Nobel Prize in recognition of his work on the linkage of atoms in molecules (James et al. 1993; Kauffman et al., 1981) by which he has thrown fresh light on old problems and opened up new field of research, especially in inorganic chemistry. His reaction was: ‘I had not completely eliminated the thought that it would come some day, but I hadn’t expected it this year’. In fact, Werner received 19 nominations for the prize, the first together with Jørgensen and others in 1907. However, only after his group proved the chirality of certain coordination compounds did his theory finally becomes accepted, and Werner was awarded the Nobel Prize in 1913 (Werner et al., 1966).

2.1. Werner’s lab

His old lab (till 1909) was very small. It was nicknamed the “CATACOMBS” meaning “unfinished storage room for woods”. It was with poor lighting, cold cement floor and poor ventilation, very unhealthy always with the smell of pyridine. It is said many times “the best works come out of the worst laboratories”. In 1906, when he got money for building a new lab, he said in his traditional speech “It will have water, air, steam and vacuum connection. On 27th February, 1909, his students hired four musicians who played a sad farewell to the old building and then marched in front of the automobile which brought the things to the new institute (Kauffman et al., 1981).
2.2. Werner as a teacher

All reports from those who actually heard Werner’s lecture during his prime are unanimous in their glowing description. They differ only their choice of superlative: Enthralling! Inspiring! Magical! Fascinating! A perfect joy! In the winter semester 1913/14 during which Werner got the Nobel Prize, 336 students took his course into an auditorium with seating capacity of 209 (Werner et al., 1966; Kauffman et al., 1981). Throughout, his first lecture of the day began at 8.15 am and he was always on time, even after the late hours spent at his favorite drinking spots. The only recorded instance of his being late to a lecture was on the occasion of the first resolution of a coordination compound. In this case the lecture was cancelled at the last moment. Shortly after he had received the Nobel Prize he became ill with symptoms: headaches for hours and days at a time, dizziness, and memory defects. It was diagnosed as “general arteriosclerosis” - A chronic condition characterized by thickening and hardening of the arteries and the build-up of plaque on the arterial walls. It slows or impairs blood circulation especially to the cerebrum. Cigarette smoking, obesity, elevated cholesterol levels, and sedentary life style may cause this disease. His physician ordered to abstain from cigarette and alcohol and spend some time in health resort. His health was not improving but he optimistically insisted that the worst was over and his recovery was certain. He believed “The entire illness was exhaustion caused by overwork, and since the illness developed slowly, it will also retreat slowly”. During the winter semester 1917/18 made a valiant attempt to resume his lecture. But that time he started to forget names. In the morning he would remember only the events of previous morning and in the afternoons, only those of the previous afternoons. Difficulty in speech and articulation began to appear. He would rehearse each lecture word by word even then he was unable to complete the actual lecture. On 24 July, 1918 the director received a petition with 42 signatures which declared that the petitioners had the highest respect for Werner as a scientist and scholar but that in the interest of their academic careers they lodged the complaints and requested for an improvement in a situation which has become intolerable. On 24th August 1918, Werner wrote “I am forced to request a complete leave for the winter semester. I hope to return fully recovered next spring. My nerves are not yet in order. On 6th May 1919, his wife wrote ‘The illness has unfortunately made such advancement that a resumption of activity at the university is unthinkable’ and his retirement became official on 15th October 1919. He died just one month later on 15th November, 1919.

His funeral oration: Anyone who met him a few months ago was painfully touched by the breakdown of his powers; anyone who had seen him in full activity receive the impression of a victorious, inflexible, intellectual fighter for whom no task was too hard, no problem too difficult, before whom all obstacles had to give way. Let us remember this picture of him during this last hour….. A man with many excellent qualities who used his talents in the service of science and teaching. Let us remember this man here and not the frail invalid whom terrible suffering dragged slowly to death (Kauffman et al., 1981).

2.3. Solphus Mads Jørgensen (1837-1914)

Jørgensen have major contributions to the chemistry of cobalt, chromium, platinum and rhodium compounds. He was a professor of chemistry in University of Copenhagen. As a researcher: methodical, purposeful, thorough and solitary. He was a member of the Royal Swedish Academy of Sciences in 1899 and believed the best theory for Molecular compounds is the chain theory: Blomstrand-Jørgensen theory. Werner’s revolutionary theory was actually based on experimental data carefully gathered by Jørgensen.

2.4. Nomination for Noble Prize

Jørgensen, who was very influential and famous at that time, opposed Werner’s coordination chemistry. Henri Moissan actually nominated Jørgensen for the Nobel Prize in 1907, only weeks before his own death. He wrote to the Nobel committee (in French): “Within this particular area of the chemistry of metal ammonia bases, which connects the inorganic chemistry with the most complicated organic chemistry, Mr. Jørgensen occupies a great position. With a few exceptions, he has coordinated and presented all the series of these compounds with the trivalent metals … Mr. Jørgensen’s work is important and deserves to be bestowed attention.” And: “Mr. Werner’s investigations and interpretations of this subject have in no way reduced the value of the results achieved by Mr. Jørgensen” (Kauffman et al., 1981; Cohen et al., 1967).

2.5. Jørgensen theory

Ammonia molecule can link together as –NH3 – chains, analogous to –CH2 – chains in hydrocarbon. These chains involved ‘pentavalent’ nitrogen, which now we know that it is not possible as nitrogen is capable of forming at most four bonds. Halogen atoms that could not be precipitated immediately with silver nitrate were called ‘nearer’ and considered to be bonded directly to the metal atom. Halogen atoms that were precipitated immediately with silver nitrate were called ‘farther’ and were considered to be bonded through ammonia chains as represented in 1 (Cohen et al., 1967). Despite the chain theory admitted limitations, it permitted the Correlation of a considerable amount of empirical data.

2.6. Werner Theory

Werner postulated two types of valency–

1) Primary or ionisable valency: satisfied only by anions
2) Secondary or nonionisable valency: satisfied by anions and neutral molecules having donor atoms like N, O, S etc. (Kauffman et al., 1981; Bowman-James et al., 2005). This is illustrated in Fig.1.

2.6.1. Co-ordination number of complexes

The secondary valences are directed in space around the central metal atom, and the combined aggregate forms a ‘complex’. ‘Complex’ exists as a discrete unit in solution. Typical configuration for coordination number 6 is octahedral and coordination number 4 is square planar or tetrahedral (Fig.2).

2.6.2. Examination of Cobalt ammines considering two facts

Constitution: the manner of bonding of the constituent atoms & groups.
Configuration: the spatial arrangement of these atoms & groups. The classifications of isomers are shown below.

2.6.3. Constitution of Cobalt ammines: A comparison between Jørgensen and Werner theories

The controversy between Jørgensen and Werner theories regarding the interpretation of their experimental results on the structures of coordination compounds, especially constitutions of metal ammines
complexes, (Cohen et al., 1967) are represented here in tabular form (Table 1 to Table 6) for each type of complexes. Werner pointed out that properties of these compounds agreed with his theoretical predictions. Jørgensen protested that very few tramine complexes of trivalent metals then known were too poorly characterized to allow any conclusions to be drawn. Then some more tramine complexes of Co(III), Ir(III) and Rh(III) were synthesized (Kauffman et al., 1997) and none found to contain the ionic chloride. Among these compounds [Co(NH$_3$)$_3$(NO$_3$)$_3$] was extremely crucial in the werner-Jørgensen controversy. The structures and conductivity data (Fig.3) of the series of compounds [Co(NH$_3$)$_3$(NO$_3$)$_3$]-K$_3$

### 2.6.3. Conductivity measurements

The controversy between Jørgensen and Werner over the constitution of metal-amine complexes provide us with an excellent illustration of synergism. During the course of this competition, each chemist did his best to prove his view and in the process a tremendous amount of fine experimental work was performed by both (Cohen et al. 1967). The basic postulates were verified in every particular. Werner ideas eventually triumphed but Jørgensen’s experimental observations are thereby in no way invalidated. On the contrary his experiments, performed with extreme care have proved completely reliable and form the foundation of Werner theory. From the beginning Werner continuously acknowledged his great debt to Jørgensen’s experimental contributions.

### Table 1 Type MA$_6$–Hexaammines (luteo salts)

<table>
<thead>
<tr>
<th>Jørgensen</th>
<th>Werner</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Co(NH$_3$)$_6$]Cl$_3$</td>
<td></td>
</tr>
</tbody>
</table>

The conductivity should show four ions from both structures. So all the properties can be explained from both the theories (Kauffman et al., 1981)

### Table 2 Type Ma$_5$b–Pentaammines: Purpureo Salts (Kauffman et al., 1981; Cohen et al., 1967)

<table>
<thead>
<tr>
<th>Jørgensen</th>
<th>Werner</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Co(NH$_3$)$_5$Cl]Cl$_2$</td>
<td></td>
</tr>
</tbody>
</table>

i) Two-third of chlorine atoms are not linked to the metal through ammonia
ii) These chlorine atoms give immediate precipitation with silver nitrate, the rest one is precipitated only on long boiling
iii) A negative group, coordinated to central metal atom, can’t simultaneously satisfy one of the primary valency of metal - his criticism to Werner.

### Table 3 Type Ma$_5$b–Pentaammines: Aquapentaammines (roseopentaammines)

<table>
<thead>
<tr>
<th>Jørgensen</th>
<th>Werner</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Co(NH$_3$)$_5$(H$_2$O)Cl]</td>
<td></td>
</tr>
</tbody>
</table>

i) Here, oxygen is considered as tetravalent and nitrogen as quinquevalent
ii) One third of chlorine atom is bonded to the metal through oxygen of water molecule

Three ionic chlorides as observed experimentally can be explained by both theories (Kauffman et al., 1981).
### Table 4 Type Ma₅₋₆-pentaammines: Nitropentaammines & nitritopentaammines

<table>
<thead>
<tr>
<th>Jørgensen</th>
<th>Werner</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Co(NH₃)₅NO₂]Cl₂</td>
<td>[Co(NH₃)₅NO₂][NO₂]³</td>
</tr>
</tbody>
</table>

This type of isomerism is called structural isomerism, salt isomerism or linkage isomerism which is possible with ambidentate ligand. Jørgensen and Werner were in agreement regarding the linkage isomerism but differed on the structure (Kauffman et al. 1981).

### Table 5 Ma₅₋₆-tetraammines (Kauffman et al., 1981)

<table>
<thead>
<tr>
<th>Jørgensen</th>
<th>Werner</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Co(NH₃)₄Cl₂]Cl</td>
<td>[Co(NH₃)₄Cl₂][NO₂]</td>
</tr>
</tbody>
</table>

Conductivity studies indicate presence of two ionic species in solution

Possibility of stereoisomerism encountered for Werner type Complex

### Table 6 MA₅₋₆-triammines

<table>
<thead>
<tr>
<th>Jørgensen</th>
<th>Werner</th>
</tr>
</thead>
<tbody>
<tr>
<td>([\text{Co(NH}_3\text{)}_3\text{Cl}])</td>
<td>([\text{Co(NH}_3\text{)}_3\text{Cl}])</td>
</tr>
</tbody>
</table>

1) Formation of two ions in solution
2) precipitation with silver nitrate

This type of compound played an important role in the suppression of Blomstrand-Jorgensen chain theory by the Werner coordination theory (Kauffman et al., 1981).

### Table 7 Conductivity Data (Kauffman et al., 1981)

<table>
<thead>
<tr>
<th>Class of compound</th>
<th>Jørgensen Formula</th>
<th>No. of ions</th>
<th>Werner Formula</th>
<th>No. of ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA₆</td>
<td>([\text{Co(NH}_3\text{)}_6\text{NO}_2\text{]})</td>
<td>4</td>
<td>([\text{Co(NH}_3\text{)}_6\text{NO}_2\text{]})</td>
<td>4</td>
</tr>
<tr>
<td>MA₅B</td>
<td>([\text{Co(NH}_3\text{)}_5\text{NO}_2\text{]})</td>
<td>3</td>
<td>([\text{Co(NH}_3\text{)}_5\text{NO}_2\text{]})</td>
<td>3</td>
</tr>
<tr>
<td>MA₄B₂</td>
<td>([\text{Co(NH}_3\text{)}_4\text{NO}_2\text{]})</td>
<td>2</td>
<td>([\text{Co(NH}_3\text{)}_4\text{NO}_2\text{]})</td>
<td>2</td>
</tr>
<tr>
<td>MA₃B₃</td>
<td>([\text{Co(NH}_3\text{)}_3\text{NO}_2\text{]})</td>
<td>2</td>
<td>([\text{Co(NH}_3\text{)}_3\text{NO}_2\text{]})</td>
<td>0</td>
</tr>
<tr>
<td>MA₂B₄</td>
<td>Unaccountable</td>
<td>–</td>
<td>K₃[Co(NO₂)₆]</td>
<td>2</td>
</tr>
<tr>
<td>MAB</td>
<td>Unaccountable</td>
<td>–</td>
<td>Unknown for Co</td>
<td>3</td>
</tr>
<tr>
<td>MB₅</td>
<td>Unaccountable</td>
<td>–</td>
<td>K₂[Co(NO₂)₆]</td>
<td>4</td>
</tr>
</tbody>
</table>

### 3. CONTROVERSY ARISES LATER WITH CONFIGURATION

Idea of an octahedral configuration and its geometric consequences was originated by J. H. Van’t Hoff in 1875 which eventually made Werner to predict theoretically various configurations (Fig.4) for co-ordination no. 6 like, and compare with the number actually obtained. By this method, he was able not only to discredit completely the rival chain theory but also demonstrate that Co(III) possess an octahedral configuration (Kauffman et al., 1997).

### 4. GEOMETRICAL ISOMERISM

Possible number geometrical isomers for each type of complex in various configurations are shown in Fig.5 to Fig.8. In geometrical aspect the distinction of octahedral configuration over others were inconclusive for MA₅ and MA₅B type of
complexes. Whereas only the octahedral configuration among the others results only two geometrical isomers for MA$_4$B$_2$ and MA$_3$B$_3$ type of complexes. For M(AA)$_3$ type of complexes it was found by Werner that the octahedral configuration among the others results only two optical isomers. Werner discredits completely the rival Jørgensen chain theory with demonstration of the octahedral configuration of Co (III) and proved that isomerism in inorganic complexes was merely a geometric consequence of octahedral structure. The theoretically predicted and experimentally found isomers for different types of complexes in different geometrical arrangement are listed in the following Table 8.

4.1. Controversy over MA$_4$B$_2$

The structure of the isomers for this type of complexes proposed by Jørgensen and Werner are shown in Fig.9 and Fig.10 respectively. The first and probably the best known case of geometric isomerism in inorganic complexes. Discovered in 1890 by Jorgensen. In coordination theory Werner stated “This interesting isomerism is the first confirmation of the conclusion resulting from the octahedral configuration” (Figure 10). Unlike Jorgensen he considered the isomerism is merely a geometric consequence of octahedral structure (Fig.9) (Kaufman et al., 1981).

4.2. Assignment of Configurations

Werner assigned the violeo salt the cis configuration by preparing them by treating the carbonato complex with conc. HCl. [Co(NH$_3$)$_4$(NO$_2$)$_2$]X:

The structure of the isomers for this type of complexes proposed by Jørgensen and Werner are shown in Fig.11 and Fig.12 respectively. The orange yellow trans compound was first prepared by W. Gibbs in 1875 from oxidation of Co(II) chloride salt and the brownish yellow cis compound by Jorgensen in 1994 from carbonatotetraaminecobalt(III) and considered them as nitro and nitrito isomers. Werner argued that flavo salt could not be nitrito compound since [Co(en)$_2$(ONO)$_2$]X had been prepared and found to exhibit entirely different properties being red and acid

Figure 3
Conductivity plot (Molecular conductance vs. Ionic charge, (Kaufman et al., 1981)

Figure 4
Possible configurations for coordination no 6

Figure 5
Geometrical isomers for complexes of type MA$_6$ and MA$_5$B. (Kaufman et al., 1981)

Figure 6
Geometrical isomers for complexes of type MA$_4$B$_2$. (Kaufman et al., 1981)

Figure 7
Geometrical isomers for complexes of type MA$_3$B$_3$. (Kaufman et al., 1981)

Figure 8
Geometrical isomers for complexes of type M(AA)$_3$. (Kaufman et al., 1981)
sensitive. He thus considered both as nitro compounds differ only in the orientation in space. Jørgensen felt that Werner was being inconsistent in agreeing with him that \([\text{Co(NH}_3\text{H})_3\text{NO}_2]X_2\) and \([\text{Co(NH}_3\text{H})_3\text{ONO}]X_2\) are structural isomers yet insisting that flavo and croceo salts are stereo isomers. He argued that if these are stereo isomers then other isomer pairs of type \(\text{MA}_2\text{B}_2\) should also exist (Kauffman et al., 1981).

### 4.3. Cis and trans-[Co(NH)_3Cl_2]X: The Major Point of Contention

Werner’s theory predicted both cis and trans isomers (Fig.13) for this series also but only trans isomers were known at that time. In fact, until 1907 every synthetic routes to prepare the violeo salt (cis isomer) ultimately resulted to the formation of the trans violeo salt criticizing Werner’s theory that it predicted on the existence of many compounds that were then unknown. Jørgensen listed more than a dozen of such compounds (Fig.14). Among the tetraamines not containing en, only isomers of NO\(_2\) and SO\(_2\) were known and they could well be the structural isomers (Kauffman et al., 1981).

### 4.4. Synthesis of cis-[Co(NH)_3Cl_2]Cl

In general ammonia complexes are less stable than the corresponding en-complexes. The synthesis of the cis isomer was difficult because they rapidly undergo aquation to form chloroaqua salt. Therefore, Werner tried by keeping the temperature low and HCl conc\(^{-}\) high. The cis-isomer was prepared as shown in Scheme 1 to Scheme 3.

### 4.5. Discovery of Ammonia-violeo salts

Werner faced difficulties in synthesizing the violeo compounds due to rapid aquation at room temperature. At very low temperature and high hydrochloric acid concentration he successfully synthesized these en complexes and jubilantly informed Jørgensen about his discovery even before submitting the manuscript to the journal: “I am taking the liberty of sending you in the same mail a sample of the long sought ammonia-violeo series \([\text{Co(NH}_3\text{H})_3\text{Cl}]X\) and hope that you too will take pleasure in it.”

When Jørgensen learned of the preparation of these compounds whose existence was a necessary consequence of the coordination theory but not of Jørgensen chain theory, he promptly virtually ended the Jørgensen-Werner controversy.

### Table 8 Number of isomers in different types of complexes

<table>
<thead>
<tr>
<th>Compound type</th>
<th>Theoretically predicted isomers</th>
<th>Experimentally found isomers</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{MA}_2)</td>
<td>One form only</td>
<td>One form only</td>
<td>One form only</td>
</tr>
<tr>
<td>(\text{MA}_2\text{B}_2)</td>
<td>One form only</td>
<td>One form only</td>
<td>Two geometric</td>
</tr>
<tr>
<td>(\text{M(AA)}\text{B}_2)</td>
<td>Three geometric ((1, 2; 1, 3; 1, 4))</td>
<td>Three geometric ((1, 2; 1, 3; 1, 4))</td>
<td>Two geometric ((1, 2; 1, 3; 1, 4), 6)</td>
</tr>
<tr>
<td>(\text{MA}_2\text{B}_2)</td>
<td>Three geometric ((1, 2; 1, 3; 1, 4))</td>
<td>Three geometric ((1, 2; 1, 3; 1, 4))</td>
<td>Two geometric ((1, 2; 1, 3; 1, 4), 6)</td>
</tr>
<tr>
<td>(\text{M(AA)}\text{B}_2^<em>) or (\text{M(AA)}\text{BC}^</em>)</td>
<td>Two geometric</td>
<td>Two geometric</td>
<td>Two geometric ((1, 2; 1, 3; 1, 4), 6)</td>
</tr>
<tr>
<td>(\text{M(AA)}\text{B}_2)</td>
<td>One form only</td>
<td>Two geometric</td>
<td>One asymmetric pair</td>
</tr>
</tbody>
</table>

\(^*\text{AA represents a symmetrical bidentate (chelate) ligand. Such ligands coordinate at two adjacent positions. They can span cis positions but not trans positions (Kauffman et al., 1981).}\)

### 4.6. Optical Activity

Herein one point should be noted that the compounds resolved by Werner up to 1914 represent a remarkable variety of compound types, they all contained Carbon. Because of the then prevalent view that optical activity is connected with carbon, his critique argued that the optical activity of these complexes are somehow related to the carbon containing ligands.

In 1914 Werner resolved a completely carbon free \(\text{M(AA)}\text{type complex e.g. hexol with formula } [\text{Co(Co(NH}_3\text{H})_3\text{OH}_2\text{]Br}_6\) showing optical activity (Kauffman et al., 1975) of octahedron irrespective of the presence of carbon atom and was able to silence even the most skeptical of his opponents and vindicate unequivocally his octahedral concept. The compound, ironically enough, had been first discovered sixteen year previously by Jørgensen.
5. SUMMARY
The important findings of this article may be summarized as follows: 1) until 1893 the Jørgensen Chain theory was the most acceptable approach to describe inorganic complexes though failed to explain some experimental facts. 2) In the span of 1893-1911 Werner’s theory build its gigantic triumph based on simple experiments and able to discredit all the rivals by discovering octahedral geometry. 3) Nevertheless the foundation of Werner’s coordination theory based upon the experimental facts collected by the erstwhile scientists along with Jørgensen. 4) Werner proposed a revolutionary approach in which the constitution and configuration of metal-ammines (now colloquially called “Werner complexes”), double salts, and metal salt hydrates were logical consequences of a new concept (Ernst et al., 2011), the coordination number. He classified metal-ammines into two classes—those with coordination number six, for which he postulated an octahedral configuration, and for complexes with coordination number four, he proposed a square planar or tetrahedral geometry. He also postulated two types of valence—primary valence, which bonded the anion to the metal atom, and secondary valence, which bonded the ammonia to the metal atom. 5) Werner ideas soon encompassed almost the entire field of inorganic chemistry (Constable et al., 2013) and even found application in organic, analytical and physical chemistry, as well as biochemistry, geochemistry and mineralogy. He was one of the first to show that stereochemistry is not limited to organic chemistry but is a general phenomenon.

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