5-12-1937

A Consideration of the Cobalt Complexes

Jack Maloney
A CONSIDERATION

of the

COBALT COMPLEXES

This paper is submitted to the Faculty of Ursinus College in partial fulfilment of the requirements for honors in the Department of Chemistry.

May 12, 1937

Submitted by

Approved by

Jack J. Maloney

R. D. Sturges
Inorganic Chemistry ............ Remsen

Treatise on Chemistry .......... Roscoe & Schorlemmer

Laboratory Methods of Inorganic Chemistry ... Biltz, Hall & Blanchard

Inorganic Complex Compounds .... Schwarz & Bass

Plus extensive laboratory work involving the actual preparation of all the compounds considered in this paper.
One of the most interesting and certainly one of the most colorful categories of inorganic compounds is the group of complex cobalt compounds. Before considering the actual preparation of some of these compounds, it will be well to consider briefly the various structural problems which arise, not only in the case of the cobalt complexes but in any other type of complex as well.

Reflecting back momentarily on our early study of inorganic chemistry, we recall our elementary concepts as to just how various elements united. We were taught that the combining weight of an element was equal to the weight of that element which would combine with the arbitrary unit of hydrogen. Likewise we learned that the atomic weight of an element was equal either to the combining weight or to some integral multiple of it. Water, for instance, we found corresponded to the formula H₂O, indicating that oxygen is capable of holding two hydrogen atoms. The formula HCl shows that chlorine has the power of holding only one hydrogen atom. From this sprang our idea of valence, the valence of a particular element being equal to the number of atoms of hydrogen (or any univalent element) with which an atom of the element will combine.

Under this Kekulé system of valence, it was held that the valence of a certain element is constant and invariable. The question then arose: if the valence of an element never changes, then how do you account for a formula like CO, where it would appear that carbon has a valence of two instead of the customary four? The upholders of the invariable valence theory were not daunted by such a query, for they had an explanation all ready. They, perhaps rationalistically, assumed that there were still unsaturated valences or bonds in such compounds. Accordingly, CO would structurally look like this:
The two bonds to the right, of course, represent the unsaturated state. Soon more troublesome compounds were introduced which the supporters of invariable valence could not explain so easily. Therefore, it has been concluded that the valence of an element may vary, but in any individual case, "it is fixed and can never be exceeded".

These concepts of valence are satisfactory in considering the more simple compounds, but they are worthless when working with complex compounds containing groups of molecules in which all the valences are satisfied. Accordingly, we find it necessary to view such compounds in the light of the Coordination Theory.

Our problem at hand is to see how a compound which according to its valences is satisfied, yet it has the power to take on additional molecules. Let us use the words of A. Werner, the originator of the Coordination Theory. He says, "Even when, to judge by the valence number, the combining power of certain atoms is exhausted, they still possess, in most cases, the power of participating further in the construction of complex molecules with the formation of very definite atomic linkages. The possibility of this action is to be traced back to the fact that, besides the affinity bonds designated as principal valences, still other bonds at the atoms, called auxiliary valences, may be called into action".

Let us analyze what Dr. Werner has said, by considering a definite example. There is a cobalt compound with the formula CoCl₃·6NH₃. We find that on treating this compound with silver nitrate, the three chlorine atoms are precipitated. On the other hand, the ammonia molecules are not effected by treatment with acid. This would lead us to believe that, in some way or other, the chlorine atoms are only loosely connected, while the
ammonia radicals are in complex union with some element which destroys their characteristic functional properties. On the basis of Werner's theory we write the formula –

\[ \left[ \begin{array}{c}
\text{H}_3\text{N} \\
\text{H}_3\text{N} \\
\text{H}_3\text{N} \\
\end{array} \right] \text{Co} \quad \begin{array}{c}
\text{NH}_3 \\
\text{NH}_3 \\
\text{NH}_3 \\
\end{array} \left\{ \right. \text{Cl}_3
\]

The dotted lines represent the six auxiliary valences connected to the cobalt atom. This combination enclosed in the brackets is known as the "central atom" of the complex. The cobalt and ammonia inside this "central atom" have lost their chemical characteristics as shown by various tests. On the other hand we find the chlorine atoms still retain all their properties and are easily precipitated by silver nitrate.

Cobalt has six auxiliary valences - therefore, six is the coordination number of cobalt. These auxiliary valences are always inside the brackets or the inner sphere.

It might be advisable at this point to consider the concept of anions and cations as evidenced in the complex compounds. We know, of course, that a complex can either be negative (anion), positive (cation), or neutral. Now let us consider how it is possible to determine if a complex is a cation, an anion, or if it is neutral.

**Ex. 1.**

\[ \left[ \begin{array}{c}
\text{H}_3\text{N} \\
\text{H}_3\text{N} \\
\text{H}_3\text{N} \\
\end{array} \right] \text{Co} \quad \begin{array}{c}
\text{NH}_3 \\
\text{NH}_3 \\
\text{Cl} \\
\end{array} \left\{ \right. \text{Cl}_2
\]

(a) The valence of the central atom, Co, is 3

(b) The number of univalent acid radicals is 1 (Cl)

In order to find the valence of the complex nucleus, we need but to subtract 1 from 3, giving us plus 2 as the valence of the complex.
This complex is therefore a bivalent cation. Let us consider one more example:

Ex. 2.

\[
\begin{array}{c}
\text{H}_3\text{N} \\
\text{H}_3\text{N} \\
o_2\text{N} \\
\end{array}
\begin{array}{c}
\text{Co} \\
\text{Co} \\
\text{NO}_2 \\
\end{array}
\begin{array}{c}
\text{NO}_2 \\
\text{NO}_2 \\
\end{array}
\]

(a) The valence of the central atom is 3 (Co)
(b) The number of univalent acid radicals is 4, \((\text{NO}_2)_4\)

Subtracting \(-3 - 4 = -1\)

The complex is, therefore, a univalent anion.

In considering any type of compound, it is most important that the system of nomenclature be well understood. There are several basic rules which must be followed when naming these complexes. The various constituents are named in the following order -

1st - The acid radical
2nd - Groups like \((\text{H}_2\text{O}), (\text{O}), (\text{O}_2), \text{or (OH)}\)
3rd - The ammine groups
4th - The central atom
5th - The name of the acid radical not in the nucleus.

Let us try naming some of the compounds which will be discussed later -

\[
[\text{Co(NH}_3)_4\text{CO}_3]\text{NO}_3
\]

1. The acid radical is the carbonate and since it is bivalent the suffix "o" is added------------------------carbonato
2. There are four ammine groups------------------------tetrammine
3. The central atom is cobalt------------------------cobaltic
4. The group outside the nucleus is \(\text{NO}_3\)------------------------nitrate

The name of the above compound is carbonatotetramminecobaltic nitrate.
One more example will serve to make the rules clear -

\[ \text{Co(NH}_3\text{)}_5 \text{H}_2\text{O} \text{ Cl}_3 \]

1. There is no acid radical in the nucleus.
2. There is an \( \text{H}_2\text{O} \) group-------------------\text{aquo}
3. There are five ammine radicals---------------\text{pentammine}
4. The central atom is cobalt---------------\text{cobaltic}
5. The atom outside the nucleus is Cl----------\text{chloride}

The name of the compound is aquopentamminecobaltic chloride.

There are two major divisions of complex compounds: the addition compounds and the so-called penetration compounds. The addition compounds are formed when one or more molecules add to a compound by means of the auxiliary valences. In this case, the added molecules are all bound directly in the nucleus. In penetration compounds, molecules are taken on which replace radicals already inside the saturated complex nucleus, and force them outside the central sphere.

In my experiments with the cobalt complexes, I came across a compound which is very interesting in that it is neither an anion nor a cation, but is neutral and, therefore, a non-electrolyte. This compound will serve to illustrate the addition type of compound. The compound is \[ \text{Co(NH}_3\text{)}_3\text{(NO}_3\text{)}_3 \], which, according to our scheme of nomenclature, is called trinitrotetramminecobalt. Likewise utilizing some of the information presented earlier in this paper, we can show that this compound is neutral. The method, of course, is to subtract the number of univalent acid radicals from the valence of the central atom. In this case that would amount to subtracting 3 from 3, giving us zero and indicating neutrality. I prepared this compound by first dissolving ammonium chloride and sodium nitrite in water, ammonium nitrite being formed. The ammonium nitrite was then treated with cobaltous chloride, producing cobaltous nitrite. This is in turn treated with ammonia and oxidized (cobaltous to cobaltic and nitrite to nitrate). On standing several days
yellowish-brown crystals of trinitrotriamminecobalt appear. Structurally our compound looks like this -

\[
\begin{align*}
\left[ \begin{array}{c}
\text{O}_2\text{N} \\
\text{O}_2\text{N} \\
\text{O}_2\text{N}
\end{array} \right]
& \quad \begin{array}{c}
\cdots
\end{array}
& \quad \begin{array}{c}
\text{Co} \\
\text{NH}_3 \\
\text{NH}_3
\end{array} \\
\begin{array}{c}
\text{O}_2\text{N} \\
\text{O}_2\text{N} \\
\text{O}_2\text{N}
\end{array}
& \quad \begin{array}{c}
\cdots
\end{array}
& \quad \begin{array}{c}
\text{NH}_3 \\
\text{NH}_3
\end{array}
\end{align*}
\]

Solutions of this compound will not conduct an electric current nor will they give precipitates with mercuric chloride, oxalates, or chromates.

As an illustration of what is meant by a penetration compound, let us consider dinitrotetramminecobaltic chloride, \([\text{Co(NH}_3]^\text{4(NO}_2] \text{Cl}.\) This compound, like the one above, is formed by reacting ammonium chloride and sodium nitrite, yielding ammonium nitrite, which is in turn treated with cobaltous chloride. For the purpose of illustrating the penetration idea, let us assume that the intermediate product formed at this point, corresponds to this -

\[
\begin{align*}
\left[ \begin{array}{c}
\text{Cl} \\
\text{O}_2\text{N} \\
\text{O}_2\text{N}
\end{array} \right]
& \quad \begin{array}{c}
\cdots
\end{array}
& \quad \begin{array}{c}
\text{Co} \\
\text{NH}_3 \\
\text{NH}_3
\end{array} \\
\begin{array}{c}
\text{O}_2\text{N} \\
\text{O}_2\text{N} \\
\text{O}_2\text{N}
\end{array}
& \quad \begin{array}{c}
\cdots
\end{array}
& \quad \begin{array}{c}
\text{NH}_3 \\
\text{NH}_3
\end{array}
\end{align*}
\]

The compound is next treated with ammonia and oxidized -

\[
\begin{align*}
\left[ \begin{array}{c}
\text{Cl} \\
\text{O}_2\text{N} \\
\text{O}_2\text{N}
\end{array} \right]
& \quad \begin{array}{c}
\cdots
\end{array}
& \quad \begin{array}{c}
\text{Co} \\
\text{NH}_3 \\
\text{NH}_3
\end{array} \\
\begin{array}{c}
\text{O}_2\text{N} \\
\text{O}_2\text{N} \\
\text{O}_2\text{N}
\end{array}
& \quad \begin{array}{c}
\cdots
\end{array}
& \quad \begin{array}{c}
\text{NH}_3 \\
\text{NH}_3
\end{array}
\end{align*}
+ \quad \begin{array}{c}
\text{NH}_3
\end{array}
\quad \rightarrow
\begin{align*}
\left[ \begin{array}{c}
\text{H}_2\text{N} \\
\text{O}_2\text{N} \\
\text{O}_2\text{N}
\end{array} \right]
& \quad \begin{array}{c}
\cdots
\end{array}
& \quad \begin{array}{c}
\text{Co} \\
\text{NH}_3 \\
\text{NH}_3
\end{array} \\
\begin{array}{c}
\text{O}_2\text{N} \\
\text{O}_2\text{N} \\
\text{O}_2\text{N}
\end{array}
& \quad \begin{array}{c}
\cdots
\end{array}
& \quad \begin{array}{c}
\text{NH}_3 \\
\text{NH}_3
\end{array}
\end{align*}
\]
\[
\text{Cl}
\]
What has happened is evident from the formula. The added molecule of ammonia has entered the sphere, forcing the chlorine atom into a position outside the central union. The process of penetration has taken place.

The more definite and specific name given to the compound above is I.6 dinitrotetramminecobaltic chloride. The I.6 refers to the positions of the nitrate atoms in the structural outlay of the compound. It seems that many compounds answer to the same empirical formula, yet possess different physical and chemical properties. Such compounds are spoken of as being isomeric. Their differences in physical and chemical properties indicate that the compounds are not identical in structure. Dr. Werner has advanced a theory which maintains that the constituents of the inner sphere are arranged differently in space. Therefore we may visualize the spacial structure around a cobalt atom as this:

![Diagram of dinitrotetrammine cobaltic chloride]

We have reason to believe that this particular dinitrotetrammine salt has the two nitrate groups in the positions designated by 1 and 2 in the structural scheme.

![Diagram showing positions of nitrate groups]

The I.6 compounds are also known as croceocobalt salts.
Another substance which I prepared will illustrate how a compound with an empirical formula identical to the one above has a decidedly different spacial arrangement and consequently different properties. This compound is specifically called 1.2 dinitrotetramminecobaltic nitrate. Referring once again to the numbered spacial arrangement, we notice how it differs from the 1.6 salt.

\[
\begin{array}{c}
\text{NO}_2 \\
H_3N \\
H_3N \\
H_3N \\
\text{NH}_3
\end{array}
\]

The 1.2 compounds are also known as flavocobalt salts.

I prepared this 1.2 dinitrotetramminecobaltic nitrate from a compound which I had previously made, carbonatotetramminecobaltic nitrate, \([\text{Co(NH}_3\text{)}_4\text{CO}_3]\text{NO}_3\). By treating this with water and nitric acid, the carbonate group is replaced by two water molecules, forming a blood-red solution of diaquotetramminecobaltic nitrate, \([\text{Co(NH}_3\text{)}_4\text{(H}_2\text{O)}_2]\text{NO}_3\). Sodium nitrite is added, together with nitric acid, resulting in the evolution of nitric oxide and the replacement of the two water molecules by two nitrate radicals, yielding \([\text{Co(NH}_3\text{)}_4\text{(NO}_3\text{)}_2]\text{NO}_3\).

Along side of the spacial diagrams of the 1.2 and 1.6 salts, given above, I have put the names of the type of compound each represents. In one case the name is flavocobalt salt, whereas the other is a croceocobalt salt. Croceocobalt salts are those having four \text{NH}_3 radicals, and two \text{NO}_3 groups in the 1.6 positions. The flavocobalt salts are similar except that the acid groups are in the 1.2 positions.
If two chlorine or bromine atoms were to replace the nitrate groups in the above, the resulting compounds would be known as praseo-salts (the two chlorine or bromine atoms being in the 1, 6 positions), or as violeo-salts (the two chlorine or bromine atoms being in the 1, 2 positions).

The praseo-salt can best be prepared in the laboratory by a method using carbonatotetramminecobaltic nitrate as the starting compound. \(\left[\text{Co(NH}_3\right)_4\text{Co}_2\text{Br}_2\right]\text{NO}_3\). This is first treated with con. H Br and then heated. Carbon dioxide is given off and a mixture of dibromotetramminecobaltic bromide, \(\text{Co(NH}_3\right)_4\text{Br}_2\text{Br}\), and bromoaquato-tetramminecobaltic bromide, \(\left[\text{Co(NH}_3\right)_4\text{Br H}_2\text{O}\right]\text{Br}\), results. The former is, of course, the compound we are looking for, so the latter can easily be removed by dissolving it in water. In the light of what we have said before concerning praseo-salts, the nuclear structure of dibromotetramminecobaltic bromide is -

One of the less involved types of compounds in the series of cobalt complexes is the class called luteocobalt salts. These salts have a nucleus entirely saturated with ammonia radicals, while outside the central sphere are three acid radicals - \(\left[\text{Co(NH}_3\right)_6\right]X_3\). I prepared the nitrate of this class, which has the formula \(\left[\text{Co(NH}_3\right)_6\right](\text{NO}_3)_3\), and
which is called hexamminecobaltic nitrate. Using cobaltous carbonate as my initial compound, I obtained cobaltous nitrate by reacting it with nitric acid. Ammonia is added, and the compound is oxidized to the cobaltic state by the introduction of iodine. The ammonia radicals connect to the six auxiliary valences of the cobalt atom and the lutec-salt is formed - \([\text{Co(NH}_3\text{)}_6\text{(NO}_3\text{)}_3\text{]}.\) Or structurally -

\[
\begin{pmatrix}
\text{H}_2\text{N} \\
\text{H}_3\text{N} \\
\text{H}_3\text{N} \\
\end{pmatrix}
\begin{pmatrix}
\text{NH}_3 \\
\text{NH}_3 \\
\text{NH}_3 \\
\end{pmatrix}
\begin{pmatrix}
\text{N}_3\text{O}_3 \\
\text{N}_3\text{O}_3 \\
\end{pmatrix}
\]

I previously mentioned carbonatotetramminecobaltic nitrate which was used in the preparation of 1,2 dinitrotetramminecobaltic nitrate. Before preparing the latter substance, it was necessary for me to compound the former. I treated cobaltous nitrate with ammonium carbonate, which supplied the carbonate radical; then with con. ammonia which provided the four ammine radicals. This entire mixture was next oxidized by passing air through it for several hours, changing the cobalt valence from two to three. On concentrating this oxidized mixture and allowing it to cool, purple crystals of carbonatotetramminecobaltic nitrate settle out.

\[
[\text{Co(NH}_3\text{)}_4\text{CO}_3\text{]}\text{NO}_3\cdot\frac{1}{3}\text{H}_2\text{O}
\]

\[
\begin{pmatrix}
\text{H}_2\text{N} \\
\text{H}_3\text{N} \\
\text{H}_3\text{N} \\
\end{pmatrix}
\begin{pmatrix}
\text{NH}_3 \\
\text{NH}_3 \\
\text{NH}_3 \\
\end{pmatrix}
\begin{pmatrix}
\text{CO}_3 \\
\text{NO}_3 \\
\end{pmatrix}
\]
It is quite an easy task to transform the carbonatotetramminecobaltic nitrate, \([\text{Co(NH}_3\text{)}_4\text{CO}_3\text{]NO}_3\]\(\text{Co(NH}_3\text{)}_4\text{CO}_3\text{]NO}_3\), into chloropentamminecobaltic chloride, \([\text{Co(NH}_3\text{)}_5\text{Cl}]\text{Cl}_2\]. By looking at the equations it can readily be seen that to accomplish this it will be necessary to substitute an ammonia radical and a chlorine atom for the carbonate group, giving us \([\text{Co(NH}_3\text{)}_5\text{Cl}]\) for the central sphere. This complex radical is a bivalent cation and is therefore capable of "taking on" two negative atoms, such as \(\text{Cl}_2\). Now that we know what must be done we can proceed with the actual preparation. By reacting the carbonatotetramminecobaltic nitrate with hydrochloric acid, chloroaquotetramminecobaltic chloride, \([\text{Co(NH}_3\text{)}_4(\text{H}_2\text{O})\text{Cl}]\text{Cl}_2\), is formed. By adding ammonia and heating, an ammonia radical is substituted for the chlorine atom in the sphere and we have a compound called aquopentamminecobaltic chloride, \([\text{Co(NH}_3\text{)}_5\text{H}_2\text{O}]\text{Cl}_2\). Finally by acidification with hydrochloric acid, the \((\text{H}_2\text{O})\) is replaced by \((\text{Cl})\), and the end compound is chloropentamminecobaltic chloride, \([\text{Co(NH}_3\text{)}_5\text{Cl}]\text{Cl}_2\), a violet-red salt.

Many of the cobalt complexes can be prepared in various ways. In my preparations I have usually selected the most well known or most practical method. Chloropentamminecobaltic chloride, however, has two equally important methods of preparation, and, therefore, I compounded the substance by both procedures. The one method is given directly above. The other involves the use of cobalt carbonate. Hexamminecobaltous chloride, \([\text{Co(NH}_3\text{)}_6]\text{Cl}\), is produced by reacting the cobaltous carbonate with hydrochloric acid, ammonia, and ammonium carbonate. By oxidizing this solution with air, a mixture of compounds results, the one pertinent to our procedure being the oxycobaltammine chloride, \([\text{Co}_2\text{O}_2(\text{NH}_3)_10]\text{Cl}_4\). The addition of ammonium carbonate brings about the formation of chloropentamminecobaltic chloride, \([\text{Co(NH}_3\text{)}_5\text{Cl}]\text{Cl}_2\), and aquopentammine-
cobaltic chloride, \([\text{Co(NH}_3\text{)}_5\text{H}_2\text{O}]\text{Cl}_2\). The latter product can be changed into chloropentamminecobaltic chloride by replacing the \((\text{H}_2\text{O})\) by a chlorine atom. The chlorine atom is supplied by hydrochloric acid, and the final product is \([\text{Co(NH}_3\text{)}_5\text{Cl}]\text{Cl}_2\).

In the preparation of chloropentamminecobaltic chloride we came across aquopentamminecobaltic chloride as an intermediate product. Now let us consider how we might perform the reverse of this - in other words, prepare aquopentamminecobaltic chloride from chloropentamminecobaltic chloride. This is best done by dissolving the chloropentamminecobaltic chloride in ammonia and heating, yielding aquopentamminecobaltic chloride, \([\text{Co(NH}_3\text{)}_5\text{H}_2\text{O}]\text{Cl}_3\). It does not separate, however, until the solution is treated with cold hydrochloric acid. It is important that the solution during the addition of hydrochloric acid be very cold, for if it is not, chloropentamminecobaltic chloride will be re-formed. The aquopentamminecobaltic chloride is one of the series of compounds known as roseo-salts, all of which contain either one, two or three molecules inside the sphere.

Thus we have considered something of the Coordination Theory; have glanced briefly at the determination of whether a compound is negative, positive, or neutral; have discovered just how the complex compounds are named; have viewed examples of penetration and addition types of compounds; have accounted for isomeric phenomena on the basis of spacial structure; and, finally, have prepared eight of the typical cobalt complexes which serve to clarify not only the various points summarized in this paragraph but many other idiosyncrasies of the complexes as well.

The following chart will serve as a comprehensive summary of the laboratory work.
<table>
<thead>
<tr>
<th>Compound</th>
<th>Formula</th>
<th>Type</th>
<th>Color</th>
<th>Preparation</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinitrotetramminecobalt</td>
<td>$[\text{Co}(\text{NH}_3)_3(NO_2)_2]$</td>
<td>neutral</td>
<td>Yellow-brown</td>
<td>Cobalt Chloride</td>
<td>Ammonia</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sodium Nitrite</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ammonium Chloride</td>
<td></td>
</tr>
<tr>
<td>1.6 Dinitrotetramminecobalt</td>
<td>$[\text{Co}(\text{NH}_3)_4(\text{NO}_2)_2]\text{Cl}$</td>
<td>croco-</td>
<td>Yellow-orange</td>
<td>Cobalt chloride</td>
<td>Sodium Nitrite</td>
</tr>
<tr>
<td>chloride</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ammonium Chloride</td>
</tr>
<tr>
<td>1.2 Dinitrotetramminecobalt</td>
<td>$[\text{Co}(\text{NH}_3)_4(\text{NO}_2)_2]\text{Cl}$</td>
<td>flavo-</td>
<td>Brown-yellow</td>
<td>Carbonatotetramminecobalt nitrate</td>
<td>Nitric Acid - Sodium Nitrite</td>
</tr>
<tr>
<td>chloride</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hexamminecobalt nitrate</td>
<td>$[\text{Co}(\text{NH}_3)_6]\text{NO}_3$</td>
<td>luteo-</td>
<td>Yellow-brown</td>
<td>Cobalt carbonate</td>
<td>Nitric Acid - Sodium Nitrite</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ammonia</td>
<td>Iodine</td>
</tr>
<tr>
<td>Carbonatotetramminecobalt nitrate</td>
<td>$[\text{Co}(\text{NH}_3)_4\text{CO}_3]\text{NO}_3$</td>
<td></td>
<td>Purple</td>
<td>Cobalt carbonate nitrate</td>
<td>Ammonia</td>
</tr>
<tr>
<td>Chloropentamminecobalt chloride</td>
<td>$[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{Cl}_2$</td>
<td></td>
<td>Violet-red</td>
<td>Hydrochloric acid</td>
<td>Ammonia</td>
</tr>
<tr>
<td>Chloropentamminecobalt chloride</td>
<td>$[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{Cl}_2$</td>
<td></td>
<td>Violet-red</td>
<td>Carbonatotetramminecobalt nitrate</td>
<td>Ammonium Carbamate</td>
</tr>
<tr>
<td>Aquopentamminecobalt chloride</td>
<td>$[\text{Co}(\text{NH}_3)_5\text{H}_2\text{O}]\text{Cl}_3$</td>
<td>taso-</td>
<td>Bright-red</td>
<td>Chloropentamminecobalt chloride</td>
<td>Hydrochloric Acid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ammonia</td>
</tr>
</tbody>
</table>