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Colour Reactions of Co (II)

Many salts and complexes of transition metals have bright and attractive colours. This is because electronic transitions (charge-transfer or $d-d$) occur in these molecules in the visible range (400–700 nm) of the spectrum. Thus, potassium permanganate, chromium chloride, copper sulfate, potassium ferrocyanide are all colourful materials.

The colour resulting from a metal ion, however, depends on the nature, number and spatial arrangements of ligands (neutral or anionic) surrounding it besides the number of electrons in its valence shell. This is because the electric field generated by the ligands is different in each case, which in turn affects the energy levels of the orbitals in which the electrons of the metal are housed. These are the electrons involved in the transitions caused by the absorption of light. Absorption of light in the visible range then results in the appearance of its complementary colour.

Divalent cobalt is a readily available metal ion with which a variety of colours may be observed by simply changing the ligands around it. Co (II) is a d^7 system, and it can form both octahedral and tetrahedral complexes. The following experiments, which can be carried in any undergraduate chemistry laboratory, show vivid colour changes using ligand exchange reactions of Co (II).

Procedure: Dissolve 3.0 g of $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ in water to make 25 mL of an approximately 0.5 molar solution, and divide this solution into five 20 mL test tubes. The solution is pink in colour. The first test tube is kept as the reference.

To tube no. 2, add conc. HCl dropwise (**CAUTION:** conc. HCl is corrosive and must be handled with appropriate precautions). The solution turns deep blue. Now add 1 molar AgNO_3 solution dropwise. A white precipitate starts to form, while the supernatant returns to its original pink colour!

To tube no. 3 add solid NaNO_2 crystals, and shake the solution

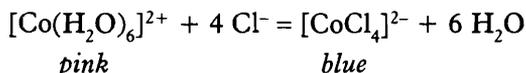
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to dissolve the added salt. A wine-red solution results.

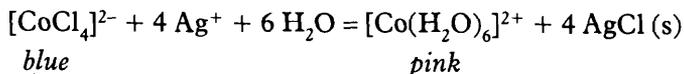
To tube no. 4 add solid NH_4SCN crystals, and shake to dissolve. You get an indigo colored solution.

To tube no. 5 add acetone dropwise. You will soon start seeing two layers, a blue layer in the top, and a pink layer on the bottom. When sufficient acetone is added, the two layers can be mixed to produce a blue colour.

Chemistry: In tube no. 2, the addition of Cl^- converts pink octahedral $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ into blue tetrahedral $[\text{CoCl}_4]^{2-}$ according to the following equation:



On the other hand, when AgNO_3 is added, the equilibrium shifts back to the octahedral aqua-complex since Ag^+ removes the Cl^- from the complex.



In tubes no. 3 and 4, octahedral nitrite $[\text{Co}(\text{NO}_2)_6]^{4-}$ and thiocyanate $[\text{Co}(\text{SCN})_6]^{4-}$ complexes are formed, which have wine-red and indigo colours, respectively. Note, however, that the exact colours of these will depend upon the concentrations. Try to dilute the indigo solution with water and see what happens!

In tube no. 5, acetone essentially acts as a dehydrating agent, as it mixes freely with water. This causes the conversion of the pink octahedral complex to a blue tetrahedral complex, similar to what you have seen in tube no. 2.

Incidentally, the last transformation is commonly utilized for indicating humidity. At high humidity the pink octahedral complex is formed, whereas at low humidity the blue tetrahedral complex results!

Similar colour changes can also be observed with a variety of other transition metal ions such as Fe^{3+} , Ni^{2+} , and various oxidation states of vanadium.