Magic with copper

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Abstract

A demonstration exploring the colours of various complexes and precipitates of copper is proposed. It is organised as part of the show of 'a magician', who uses a series of test tubes and colourless liquids in an attempt to impress the audience with the vivid colours appearing 'out of nowhere'. In the end he/she assumes the role of a chemistry instructor and explains what has happened in terms of chemical changes.

Key words: General chemistry; magic; demonstration experiments; copper; complexes; precipitates.

Introduction

During 2011, a series of 'evenings with magic' was organised at the Institute of Chemistry (one of the departments within the Faculty of Natural Sciences and Mathematics, of the Ss Cyril & Methodius University in Skopje, Macedonia). These events were aimed at high school students, hoping that they would serve not only for fun, but also to 'whet their appetite' for chemistry, and hopefully help them make their decision to devote themselves to the study of chemistry or some other science.

Besides the quite numerous and well-known "magic" experiments (Ford, 1993; Roesky & Möckel, 1996; Gray, 2009; Shakhashiri, 1983; Summerlin, Borgford & Ealy, 1987; Summerlin & Ealy, 1988), an experiment was prepared that we offer here to our readers.

The magic: the way it is performed

The "magician" (undercover instructor) walks before the audience, behind the demonstration desk. On the desk there is a series of large test tubes (of total volume between 50 and 100 mL). Initially, all test tubes are empty except one that contains some brown powder at the bottom. Also, there are six identical beakers (the volume of each of them being 100 mL) that are filled with colourless liquids.

The magician starts the show with the test tube with the brown substance, adding one of the colourless liquids. The content of the test tube immediately turns green (Fig. 1; for a coloured version of the figures in this paper see the outside back cover of this issue).

The magician transfers about one third of the green contents to an empty test tube, and adds the second colourless liquid. The colour of the liquid is now pale blue (Fig. 2).

An analogous procedure is applied four more times (one third of the content being transferred to an empty test tube each time, and the next liquid from the beaker being added). The content of the test tubes is dark blue, colourless, white and brownish-black, respectively (Figs 3–6).

The magician bows and disappears.

The chemistry behind the magic

Shortly after the magician leaves, the instructor enters, explaining that behind any "magic" there is a sound scientific explanation. In this case, a series of chemical reactions give products having different colours. The brown substance in the first test tube is anhydrous copper(II) chloride. The six colourless liquids are: aqueous solution of sodium chloride, distilled water, diluted aqueous ammonia, aqueous solution of potassium cyanide, diluted sulfuric acid and aqueous solution of sodium sulfide (some experimenting is necessary for finding the optimum concentrations of the reagents).

This is what happens in the above sequence of reactions, the results of which are shown in Figs. 1–6:

1. $CuCl_2$(s, brown) +2Cl^-(aq) = $[CuCl_4]^{2-}$(aq, green)
2. $[CuCl_4]^{2-}$(aq, green) + 6H_2O(l) = $[Cu(H_2O)_6]^{2+}$(aq, pale blue) + 4Cl^-(aq)
3. $[Cu(H_2O)_6]^{2+}$(aq, pale blue) + 4NH_3(aq) = $[Cu(NH_3)_4]^{2+}$(aq, dark blue) + 6H_2O(l)
4. $[Cu(NH_3)_4]^{2+}$(aq, dark blue) + 5CN^-(aq) = $[Cu(CN)_4]^{3-}$(aq, colourless) + 4NH_3(aq) + ½$(CN)_2$(g)
5. $[Cu(CN)_4]^{3-}$(aq, colourless) + 3H^+(aq) = CuCN(s, white) + 3HCN(aq)
6. 2CuCN(s, white) + S^{2-}(aq) = Cu_2S(s, brownish-black) + 2CN^-(aq)

All colours are, therefore, related to the existence of complexes or precipitates of copper. The stability of the complexes and the solubility of the precipitates are very important to the sequence.

The first complex is tetrachlorocuprate(II). It is responsible for the green colour of the solution. This complex is the least stable in the sequence. When

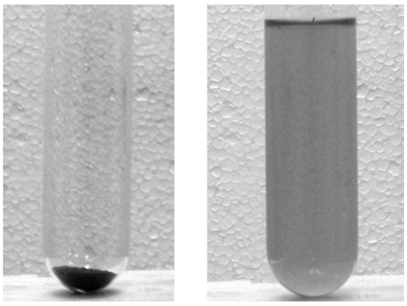

Fig. 1.

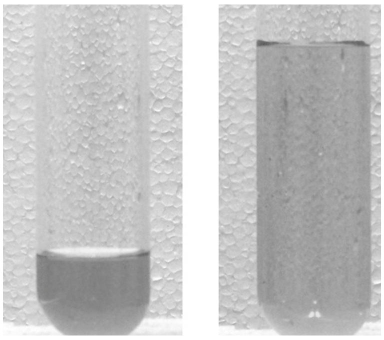

Fig. 2.

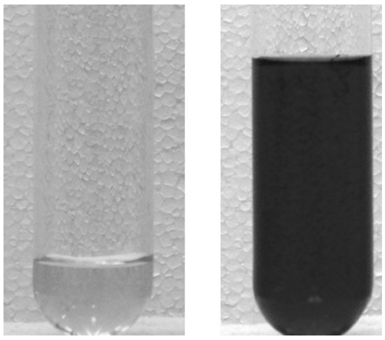

Fig. 3.

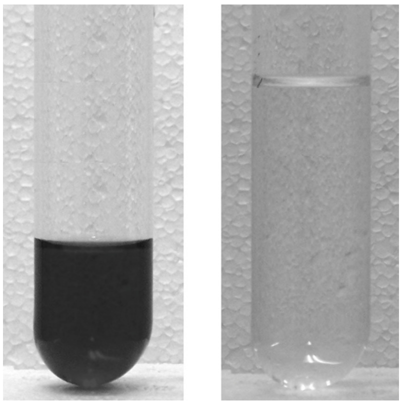

Fig. 4.

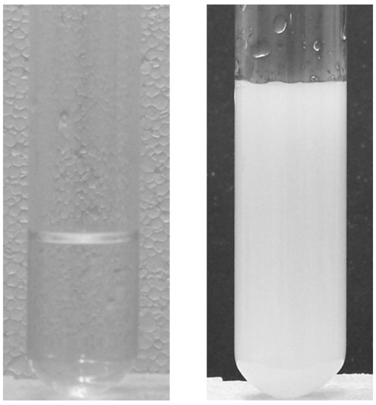

Fig. 5.

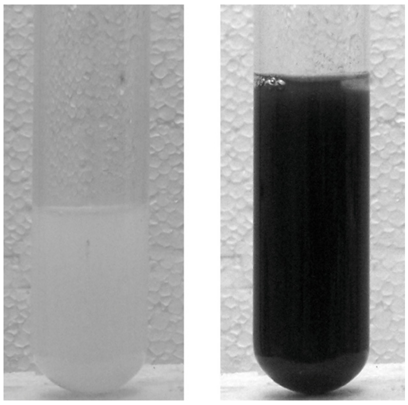

Fig. 6.

diluted with distilled water it dissociates and the slightly more stable (pale blue) hexaaquacopper(II) is formed. Much more stable is the dark blue tetraammincopper(II), but even more stable than that is the colourless tetracyanocuprate(I). The latter cannot survive in an acidic medium and simply forms a CuCN precipitate. However, in the presence of sulfide anions, CuCN is dissolved and the much less soluble precipitate Cu_2S is formed.

Thus, the chemical reactions in the above sequence always lead to a more stable complex, or to a less soluble precipitate. The pH value of the medium is very important, as demonstrated by the disappearance of the $[Cu(CN)_4]^{3-}$ and the formation of CuCN. The true nature of the latter cyanide complex was resolved some 40 years ago (Parkash & Zýka, 1972).

With a more advanced audience (especially if the proposed experiment is adopted/modified as a part of a lesson), it is possible to discuss the events on a more quantitative basis by giving the numerical values of the stability constants of the complexes and the K_{sp} values for the precipitates. Another alternative would be to let the students consult the relevant literature and find the above mentioned values by themselves.

Conclusions

Chemistry "magic" is not only appropriate for scientific fairs or chemistry spectacles. It can be useful in the classroom, leading to more vivid lectures. The above experiment could be used during lectures devoted to reactions that go to completion; or when discussing precipitates and their solubility; or when explaining the stability of complexes; or when discussing the chemistry of copper and the properties of its compounds.

Safety concerns and disposal

Copper salts are toxic in high concentrations, although in low concentrations copper is an essential element. In the (unlikely) event of copper poisoning, a physician should administer dimercaprol (a heavy metal chelating agent).

Potassium cyanide is a very toxic substance! Hydrogen cyanide and soluble cyanides block the transport of oxygen to the cells. The average lethal dose for humans is 1.5 mg/kg. In case of poisoning ask for medical assistance immediately. Breathing of pure oxygen is recommended in the meantime.

Concentrated sulfuric acid and aqueous ammonia are corrosive substances. Wear face shield and gloves when working with them (for example, when preparing diluted solutions). Concentrated aqueous ammonia is also a primary irritant, affecting the eyes and the respiratory system.

Dispose of all waste according to local safety regulations.

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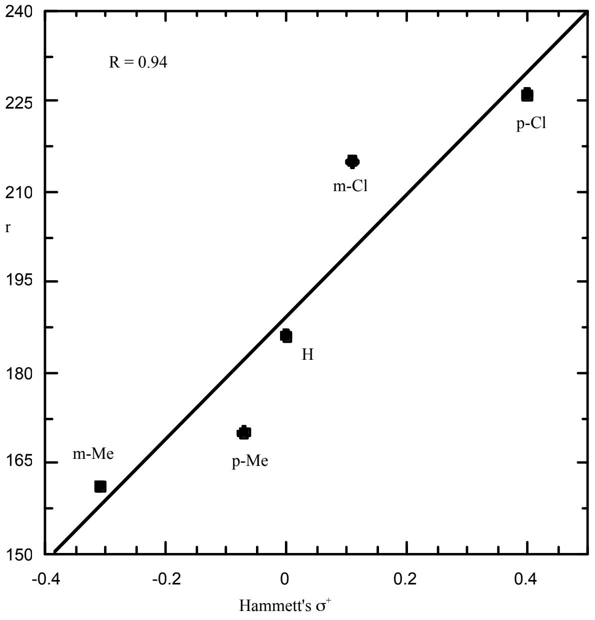
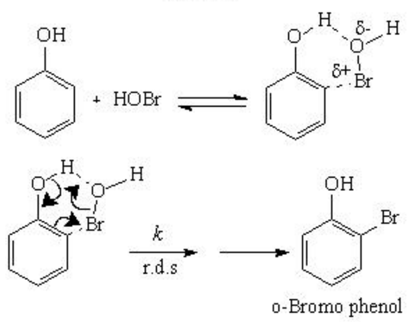


Fig. 8: Plot of inter-nuclear distance (r) vs Hammett's σ+ in the reaction of NBA with phenols.

Scheme 6



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