The Unusual Colour of Copper Deposited on a Graphite Electrode in an Aqueous Solution of $CuSO_4$

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Abstract

The colour of the copper layer deposited on a graphite electrode during electrolysis of an aqueous solution of copper(II) sulfate looks whitish-grey when inspected in situ. Taking the electrode out of the solution reveals the familiar orange-red colour of deposited copper. The explanation is found in terms of the almost ideal complementary colours of the copper metal (orange red) and the copper(II) sulfate solution (bluish-cyan).

Electrolysis can be defined as a process of chemical change occurring on the electrodes in a solution (or in a melt) as a result of a direct current between the electrodes. The changes are simply the reactions of reduction (on the cathode, the negatively charged electrode) and oxidation (on the anode, the positively charged electrode).

Examples of electrolysis may be found in Fowles (1959), Roesky and Möckel (1996), Shakhashiri (1992), and Summerlin, Borgford, and Ealy (1987). Many more can be found on the World Wide Web. One of the most familiar, and also least expensive, demonstrations of this phenomenon is the electrolysis of an aqueous solution of copper(II) sulfate. Simply place two graphite electrodes in a solution of, say, 1 mol/L $CuSO_4$(aq), connect the electrodes to the poles of a source of direct current ($\approx$ 5-15 V), and inspect the electrodes after several minutes. The electrode connected to the negative pole (the cathode) is covered with a layer of elemental copper that can be recognized by its characteristic orange-red colour. No visible changes to the anode are detected.

One of us (VMP) has performed this demonstration dozens of times over several decades. However, if it was not for students recently noticing something odd, the phenomenon being reported and analysed here would have probably remained unnoticed.

The Demonstration

Unlike on other occasions when we perform this demonstration for more-experienced university students, this time we guided the discussion with a class of 7 high school students. The electrolysis was performed in a U-tube (Figure 1). We first elicited students' expectations, to find that they predicted correctly that copper metal would deposit on the cathode. The switch was then turned on.

After 3-4 minutes, one of the students asked about the nature of the grey deposit on the cathode tip. Indeed, the graphite electrode tip did look grey, as shown in Figure 2. After about a further 5 minutes, the process was stopped and the electrodes were removed from the solution to reveal the characteristic, well-known colour of copper on the cathode (Figure 3). We now had an observation that needed to be explained: Why does the deposit look grey when the electrode is in the solution? It turned out that the explanation for the seemingly unusual phenomenon was simple and straightforward.

The Explanation

By chance, it happens that both colours (i.e., that of the elemental copper layer on the cathode and that of the solution) are very close to a pair of complementary colours (Wikipedia, 2010). These colours can be simulated on a computer screen by a pair of truly complementary colours, as shown in Figure 4. The RGB attributes[1] of the blue-cyan colour are 0 (R), 155 (G), and 255 (B). Those of the orange-red one were chosen to be equal to their complements; that is, 255 (R), 100 (G), and 0 (B).

Figure 1. The setup for the electrolysis of $CuSO_4$(aq).

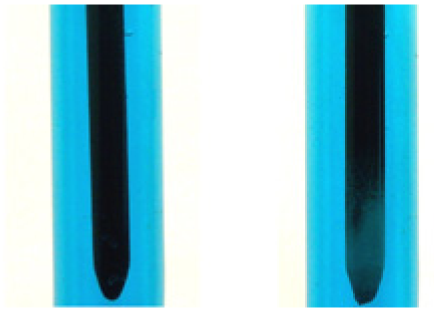

Figure 2. The graphite cathode in the $CuSO_4$(aq) solution before (left) and after (right) passing the current. A whitish-grey cover is noticeable on the lower part of the electrode (right).

Figure 3. The graphite anode (left) and cathode (right) after being taken out of the solution.

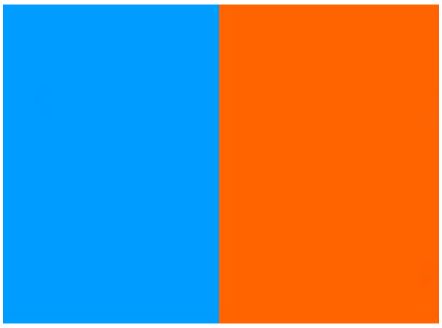

Figure 4. A simulated pair of complementary, blue-orange colours.

If the colours in Figure 4 were from two light sources, their combined effect would be white light, which is readily confirmed by the fact that the sum of their attributes equals 255, 255, 255 (i.e., white colour). However, both the solution and the metallic copper layer on the graphite tip are absorbing media. If they were ideal absorbers, they would mutually absorb the light of their complementary colour (i.e., the one emitted by the other medium). In short, in the case of ideal absorbers, one would not notice any change on the graphite electrode while in solution because it is already black.

However, ideal absorbers do not exist. As a result, one sees the copper layer as a grey colour. This is due to the combined effect of the complementary colours of the partly absorbing $CuSO_4$ aqueous solution and the partly absorbing copper layer. Of course, once removed from the solution, the copper layer reveals its true colour (Figure 3).

As with all "big truths," this one is also based on a fairly simple explanation. The amazing part is that it went unnoticed for several decades, only because the instructor knew too well what the result is supposed to be and, despite all his accumulated experience, appeared to be "blind" (i.e., did not pay attention) to the grey layer on the graphite.

Additional Demonstrations and Checks

One could experiment with viewing Figure 4 through blue and orange light filters. For example, when using a blue filter, there is virtually no difference between the blue and white background, while the orange looks practically black, and we thank reviewer Kevin Carlton for pointing to this additional activity. Also, it could be worthwhile, after the electrolysis activity has been completed but before offering any explanation, to place a copper rod in the solution, to point to its whitish-grey colour, and to ask the students to explain what happened to the copper. In case they think it has reacted with the solution, take it out of the solution, show that it still has its usual colour, and put it back in the liquid. We thank reviewer Wilfred Sugumar for this suggestion.

Note

[1]In *Photoshop*, as well as in many other computer programs, the RGB attributes are determined by 24 bits; 8 bits for each of the elementary colours (i.e., Red, Green, and Blue). Therefore, each colour may vary in intensity from 0 (minimum) to 255 (maximum). There are altogether more than 16 million combinations, ranging from black (0,0,0) to white (255,255,255). The attributes of any pixel can be read, returning a triplet value of the form (R,G,B), where R, G, and B $\in$ [0, 255].

References

Fowles, G. (1959). *Lecture experiments in chemistry* (5th ed.). London: Bell & Sons.

Roesky, H. W., & Möckel, K. (1996). *Chemical curiosities*. New York: VCH Publishers.

Shakhashiri, Z. B. (1992). *Chemical demonstrations: A handbook for teachers of chemistry* (Vol. 4). Madison: The University of Wisconsin Press.

Summerlin, L. R., Borgford, C. L., & Ealy, J. B. (1987). *Chemical demonstrations: A sourcebook for teachers* (Vol. 2). Washington, DC: American Chemical Society.

Wikipedia. (2010). *Complementary color*. Retrieved March 9, 2010, from http://en.wikipedia.org/wiki/Complementary_color .