# What Can Black Panther Teach Us About Transition Metal Chemistry?

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**Abstract:** This hands-on exercise for high school students utilizes the Marvel Studios' *Black Panther* to expose students to inorganic chemistry through the preparation of three metal complexes that contain cobalt and copper coordinated to glycine (gly, sodium salt) and bipyridine (bpy) ligands. The students worked in teams to prepare their own "vibranium" solutions, which exhibited vibrant colors as shown in the movie.

## Introduction

Inorganic chemistry is a diverse discipline which includes solid-state, bioinorganic and organometallic chemistry [1]. Furthermore, inorganic complexes often exhibit beautiful colors due to partially-filled *d* orbitals. Crystal Field Theory (CFT) is a bonding model that can be used to explain the colors observed from transition metal complexes. However, CFT has limitations because it is based solely on "electrostatic" interactions, specifically with the five *d* orbitals of a given transition metal being split into two energy levels due to the presence of ligands (e.g. gly and bpy). The colors of transition metal complexes are due to the electronic transitions of *d* orbital electrons in the lower energy level promoted to the higher energy level.

As a follow up to our recent contribution [2, 3] "Black Panther, Vibranium and the Periodic Table," we developed a hands-on exercise for high school students to prepare their own "vibranium" solutions during an Extreme Science Saturdays (ESS) program [4] at Lawrence Technological University (LTU).

Extreme Science Saturdays was established in 2006 by former Chair, Dr. Anthony Sky in the LTU Department of Natural Sciences to provide high school students with interactive experiences focused on biology, chemistry and physics. These two hour Saturday workshops, now administered through LTU's Marburger STEM Center [5], are led by Lawrence Tech faculty and focus on diverse topics including business and entrepreneurship, nursing, and forensic chemistry.

## Experimental Conditions

All starting materials were obtained from commercial resources and used as received. The solution of hexaaquacobalt(II) $[Co(H_2O)_6]^{2+}$ was prepared immediately prior to the exercise. Cupric Acetate, $Cu(CH_3COO)_2.H_2O$, Cobalt Nitrate, $Co(NO_3)_2$•6H2O, bipyridine (bpy), Glycine sodium salt hydrate, glycine, and 3% Hydrogen Peroxide ($H_2O_2$), were used without further purification.

**Hexaaquacobalt(II), $[Co(H_2O)_6]^{2+}$ Solution.** Cobalt Nitrate, $Co(NO_3)_2•6H_2O$ (0.63 g, 2.1 mmol) was measured out and carefully placed in a 500-mL volumetric flask. Next, the cobalt nitrate was dissolved in distilled water to give a pale-pink colored solution (0.0043M).

**Tris(2,2-bipyridine)Cobalt(II), $[Co(bpy)_3]^{2+}$.** $[Co(H_2O)_6]^{2+}$ (20-mL) was carefully poured into a 150-mL beaker. Next, bipyridine (0.10 g, 0.64 mmol) into a second 150-mL beaker. The $[Co(H_2O)_6]^{2+}$ solution was poured into the beaker containing bipyridine and stirred for approximately 2–5 min with a stirring rod. A yellow color was observed indicating the formation of $[Co(bpy)_3]^{2+}$.

**Triglycinatocobalt(III), $[Co(gly)_3]$.** Glycine sodium salt hydrate (0.75 g, 0.77 mmol) was weighed into a 150-mL beaker. Next, 10 mL of $[Co(H_2O)_6]^{2+}$ was carefully poured into the beaker. 3% Hydrogen peroxide (5 mL) was added into the beaker using a graduated cylinder. The solution was stirred with a magnetic stir bar on a stir plate for 5 minutes. A violet-purple color was observed for the formation of $[Co(gly)_3]$.

**Bisglycinatocopper(II) monohydrate, $[Cu(gly)_2.H_2O]$.** Glycine (1.4 g, 18.6 mmol) and cupric acetate monohydrate (1.6 g, 8.0 mmol) were each placed in separate 250 mL beakers. The glycine was dissolved in 20 mL of distilled water to give a colorless solution. The cupric acetate monohydrate was dissolved in 25 mL of distilled water to give a blue colored solution. The beakers were placed on a hot plate and stirred with a stirring rod until boiling. The beakers were carefully removed from the hot plate using an oven mitt and tongs and placed on the laboratory countertop. The glycine solution was then poured into the cupric acetate monohydrate solution to give a rich purple-violet color. The solution is allowed to cool for several minutes and then placed in an ice-bath. After crystals begin to form, 10 mL of ethanol was added with continuous stirring to precipitate the pale-blue product. The filtrate exhibited a bright blue color. The product $[Cu(gly)_2.H_2O]$ was collected by vacuum filtration.

## Results and Discussion

The Extreme Science Saturdays workshop with high school students (N = 8) began with a 2 minute movie trailer of Marvel Studios' *Black Panther* [6]. (This exercise can certainly be expanded for a larger audience. Specifically, this exercise could be used for a laboratory experiment in a general chemistry course.) When asked which characters they enjoyed the most in the movie, some students responded "T'Challa and

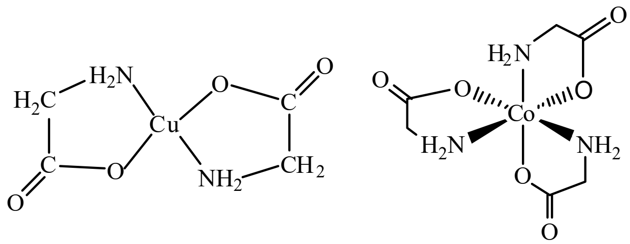

**Figure 1.** Molecular Structures of [$Cu(gly)_2.H_2O$] and [$Co(gly)_3$].

**Figure 2.** Photograph of Solutions in the current experiment: [$Cu(gly)_2.H_2O$] (left) and [$Co(gly)_3$] (right).

his younger sister Shuri." The character Shuri played by actress Letitia Wright led the STEM (Science, Technology, Engineering and Mathematics) advances for the fictional Wakanda nation.

Next, the instructors led a brief discussion with the students focused on where the fictional vibranium (Vb) element would exist in the periodic table, which was followed by hands-on experiments to prepare three transition metal complexes containing copper and cobalt. Transition metals are located in the central part of the periodic table (d-block) [1]. Both copper and cobalt are known to exhibit violet-purple colors depending on the organic ligand coordinated to the metal.

The students were provided with worksheets to complete the experiments. (See supporting materials.) First, the students worked in teams to prepare two cobalt complexes coordinated to bipyridine and glycine based on an article published in this *Journal* [7]. The instructors prepared a hexaaquacobalt(II) [$Co(H_2O)_6$]$^{2+}$ stock solution (0.0043M), which exhibited a pale pink color prior to the exercise. (Each team received 30 mL of the stock solution for the preparation of the cobalt complexes.) The students then worked in teams to observe color changes when the hexaaquacobalt (II) solution is mixed with bipyridine (0.10g) and sodium glycinate (0.75 g). Upon mixing the bypyridine (bpy) and 20 mL of [$Co(H_2O)_6$]$^{2+}$ solution, the students observed a yellow color, which indicates the formation of tris(2,2-bipyridine)cobalt(II), [$Co(bpy)_3$]$^{2+}$. When glycine sodium salt hydrate (0.75 g, 0.77 mmol) and 5 mL of 3% hydrogen peroxide ($H_2O_2$) were mixed with 10 mL of [$Co(H_2O)_6$]$^{2+}$, the students observed a purple-violet color analogous to the "vibranium" solutions illustrated in the movie. The purple-violet color is due to the formation of triglycinatocobalt(III), [$Co(gly)_3$] (Figure 1).

The students then completed a third chemical reaction to synthesize, bisglycinatocopper(II) monohydrate, [$Cu(gly)_2$•$H_2O$] (Figure 1) by mixing copper acetate monohydrate (1.6 g) and glycine (1.4 g) in distilled water (~20–25 mL) [8]. After heating the solutions to boiling, the students carefully poured the glycine solution into the copper acetate solution, generating a gorgeous violet-purple color, which is consistent with the color of the fictitious vibranium solution. After cooling the solution for several minutes in an ice-bath, 10-mL of ethanol was added to precipitate the pale-blue solid. The students, then collected their products using vacuum filtration techniques.

To further engage these future chemists, we allowed them to use their cell phones to take pictures of the colorful solutions (Figure 2) and research the importance of cobalt and copper metals. After the experiments were completed, the instructors led a discussion focused on why the color changes occurred. Specifically, the students learned that these were substitution reactions with the water molecules coordinated to cobalt being replaced by bipyrdine and glycine. In addition, the students learned that the hydrogen peroxide was needed to oxidize Co (II) to Co (III). One student noted the smell of "vinegar" in the laboratory during the synthesis of bisglycinatocopper(II) monohydrate, [$Cu(gly)_2$•$H_2O$], due to the formation of acetic acid as a product.

We did experience some challenges with this exercise, most notably time constraints in the laboratory. The exercise was completed within 2 hours. Upon further reflection of this exercise, we would recommend modifying this exercise to focus on preparing two metal complexes rather than three complexes and allow more in depth discussions of chemistry concepts. In addition, students could then collect spectroscopic data on at least one of the prepared metal complexes.

The students completed surveys based on the workshop, with 86% indicating that they were very satisfied with the experience. When asked what they enjoyed most about the experience, a few student responses included:

> Learning about specific tools in the labs, which I hadn't heard about.
>
> The different color changes and making a precipitate.
>
> The experiments and working with new people and professionals.
>
> The overwhelming kindness of the instructors.

We would also recommend that Marvel Studios' *Black Panther* movie could potentially be useful for an advanced inorganic laboratory discussion focused on the synthesis and characterization of lanthanide complexes [9]. Thus, vibranium science can be incorporated into the inorganic curriculum.

**Supporting Material.** Two Student Laboratory Handouts are available.

## References and Notes

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10. The authors declare no competing financial interest.