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Demonstration

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Microwave Mapping Demonstration Using the Thermochromic Cobalt Chloride Equilibrium

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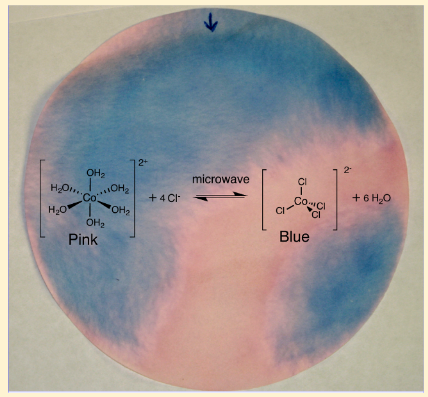
ABSTRACT: An update to the thermochromic cobalt(II) chloride equilibrium demonstration is described. Filter paper that has been saturated with aqueous cobalt(II) chloride is heated for seconds in a microwave oven, producing a color change. The resulting pink and blue map is used to colorfully demonstrate Le Châtelier's principle and to illuminate the hot spots in the microwave oven. The demonstration is a quick, easy, and colorful way to introduce Le Châtelier's principle to students in high school or general chemistry courses.



KEYWORDS: *High School/Introductory Chemistry, First-Year Undergraduate/General, Demonstrations, Inorganic Chemistry, Physical Chemistry, Coordination Compounds, Equilibrium, Transition Elements*

Le Châtelier's principle of chemical equilibria is a common concept in high school and first year general chemistry courses. Le Châtelier's principle states that if an external stress is applied to a system at equilibrium, the composition adjusts in such a way that the stress is partially offset as the equilibrium is reestablished. Color changing equilibria have been used to illustrate this principle. Several articles discuss equilibria involving cobalt(II) complexes and use these equilibria to illustrate Le Châtelier's principle[1−3] (eq 1). This equilibrium responds to chloride concentration, solvent composition, and heat. The relative position of the equilibrium responds to these various stresses and is nicely illuminated by the various colors of the cobalt complexes.

$$\text{heat} + \underset{\text{(pink)}}{[Co(H_2O)_6]^{2+}(aq)} + 4Cl^-_{(aq)} \rightleftharpoons \underset{\text{(blue)}}{[CoCl_4]^{2-}(aq)} + 6H_2O_{(l)} \quad (1)$$

Variations of this demonstration have been discussed in several articles[4−6] in this *Journal*. Bare and Mellon reported painting the aqueous cobalt chloride solution on filter paper[7] and developing the filter paper with a heat gun by driving off the water, thus shifting the equilibrium to the blue $[CoCl_4]^{2-}$ complex (eq 1). We have updated this demonstration by using a microwave oven to dehydrate the filter paper and also to map out the high intensity radiation regions within the microwave oven. We saturate a piece of filter paper with aqueous cobalt(II) chloride and let it partially dry, resulting in light pink filter paper, and then put the filter paper, suspended on a cork ring, in a microwave oven. We expose the filter paper to microwaves for seconds, converting some of the $[Co(H_2O)_6]^{2+}$ in the filter paper to $[CoCl_4]^{2-}$, which shows up as a blue region on the filter paper.

MATERIALS

The following items are needed.

- 1.0 M cobalt(II) chloride solution, 100 mL
- Filter paper (150 mm diameter)
- Plastic container 12 in. × 10 in. × 3 in.
- Spray bottle for water
- Cork ring, 6 in.
- Microwave oven (cannot be used for food)
- Large zip lock bags (for storage)
- Digital camera (optional)

PROCEDURE

A 100 mL volume of aqueous 1.0 M cobalt(II) chloride is prepared. This solution is sufficient for several 15 cm filter paper maps. The filter paper is placed in a shallow plastic container, and the cobalt(II) chloride solution is added dropwise onto the filter paper until it is saturated. The filter paper is removed and air-dried for at least 15 min (Figure 1). The filter paper should be a uniform light pink color ($[Co(H_2O)_6]^{2+}$).

The microwave oven is prepared by removing the carousel and replacing it with a 6 in. cork ring. The filter paper is placed on top of the cork ring in the center of the microwave oven. For comparison it is useful to take a picture before irradiating the filter paper (Figure 1). The microwave oven is run for 20 s

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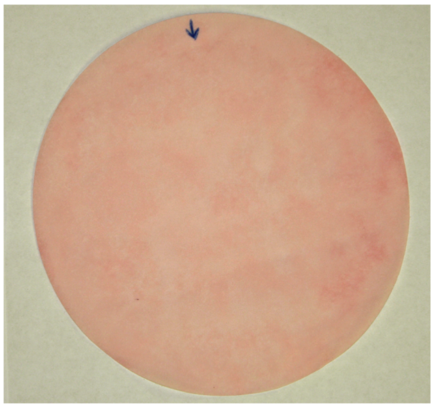

Figure 1. Filter paper pretreated with aqueous $[Co(H_2O)_6]Cl_2$. The small arrow provides a point of reference between various microwave treatments.

at 600 W (the parameters will change depending on the microwave oven used). Through the microwave oven window, the rapid change in the color of the filter paper can be observed. After irradiation the filter paper will show blue and pink areas. The blue areas map out the high intensity microwave regions in the microwave oven. It is best to quickly document the appearance of the filter paper by taking a picture after irradiation because the filter paper will continue changing color as it cools (Figure 2).

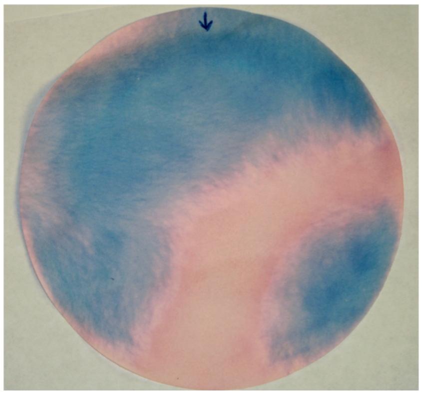

Figure 2. Filter paper after heating in a microwave oven for 20 s at 600 W with carousel removed. The small arrow provides a point of reference for before and after microwave treatment.

The microwave map can be quickly repeated by spraying the filter paper with a fine mist of water, converting the $[CoCl_4]^{2-}$ back to the pink $[Co(H_2O)_6]^{2+}$ (see eq 1). The filter paper can be rehydrated by holding it vertically while spraying the paper with water to prevent water droplets from forming on the paper and then let the paper sit for 5 min and repeat the above process. The filter paper maps can be reused many times by storing them in a zip lock plastic bag between uses.

The effect of a microwave carousel on the filter paper map can also be observed. The cork ring is placed on a carousel and the prepared filter paper is put on top. The microwave oven is heated again for 20 s at 600 W. Another picture of the filter paper is taken (Figure 3) and compared to the earlier experiment with no carousel. The rotating carousel causes a light blue ring to form on the filter paper showing that the microwave radiation has been evenly distributed over the paper

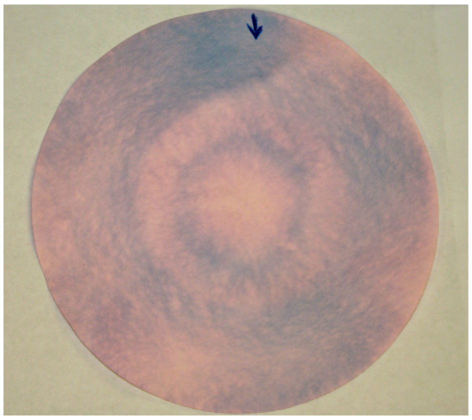

Figure 3. Filter paper after heating in a microwave oven for 20 s at 600 W with the carousel in place. The radial symmetry of the blue and pink regions is a result of the rotating filter paper. The small arrow provides a point of reference for before and after microwave treatment.

with a pink area in the middle of the paper indicating a region of low microwave intensity.

■ HAZARDS

Cobalt(II) chloride hexahydrate[8] is toxic (oral mouse, LD50: 80 mg/kg). It causes eye irritation. Goggles and gloves are recommended for this demonstration. The microwave oven used for this demonstration **should not** be used for food preparation.

■ DISCUSSION AND CONCLUSION

Using the microwave oven in this demonstration connects chemistry to a common appliance in students' lives and makes a connection between microwave cooking and chemistry. The blue regions indicate to the student that spatially there are very different radiation intensities (hot spots) or regions within the microwave oven, hence the need for the carousel to ensure uniform heating. The demonstration emphasizes in a colorful way the rapid effect of microwave absorption and heating. There is also a video online showing the formation of hot spots in the microwave oven using wet thermal paper as the mapping material.[9]

This microwave method represents a fast and fun new way to introduce Le Châtelier's principle. Since the filter paper maps can be reused several times and stored indefinitely in plastic bags, this demonstration provides a quick and easy setup for an in class or small group demonstration. Because the demonstration is so fast, it could also be used as a hands-on activity for small groups. Although not a traditional topic for general chemistry, this demonstration also provides a nice segue for introducing the modern topic of microwave chemical synthesis.[10] It can also be used when introducing the electromagnetic spectrum prior to spectroscopy and electron configurations.

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Notes

The authors declare no competing financial interest.

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