A Colorful Grignard Reaction

Preparation of the Triarylmethane Dyes from 4-Bromo-N,N-Dimethylaniline

Douglass F. Taber,1 Robert P. Meagley, and Danielle Supplee
University of Delaware, Newark, DE 19716

Undergraduate organic chemistry students are fascinated by the synthesis and use of dyes. Previous laboratory experiments have focused on either dye separation (1), or on diazo dyes prepared by coupling of aromatic diazonium salts (2). As part of our continuing effort to upgrade the sophomore organic laboratory experience (3), we report a conceptually new experiment that combines Grignard preparation with dye synthesis.

The preparation of the Grignard reagent from bromobenzene is a standard experiment in the sophomore organic laboratory course (4). It occurred to us that if the Grignard reagent could be prepared from 4-bromo-N,N-dimethylaniline (1) (eq 1), addition to diethyl carbonate followed by acid hydrolysis could lead to the triarylmethane dye (5) Crystal Violet (2), whereas addition to methyl benzotetrazole followed by acid hydrolysis could lead to the dye Malachite Green (3).

![Chemical Structures](image)

Crystal Violet (Gentian Violet) and Malachite Green are two of the best known of the triarylmethane dyes. In addition to being a topical antiseptic, Crystal Violet is especially well known as the purple dye used in school ditto masters.

In the event, this dye synthesis turned out to be operationally very easy. The Grignard reagent forms smoothly in refluxing tetrahydrofuran, without any dangerous exotherms. Addition of ethyl carbonate and brief reflux, followed by the addition of 10% aqueous hydrochloric acid gives a brown mixture. A piece of cotton cloth dipped in this mixture comes out a muddy purple. A brief rinse under running water, however, reveals a bright magenta dye.

Analogously, addition of methyl benzotetrazole (in the place of diethyl carbonate) followed by hydrolysis gives a similar brown mixture. A piece of cotton cloth dipped in this mixture, then rinsed, is dyed the rich blue-green shade of Malachite Green.

We have used this experiment successfully in the first semester of our sophomore organic laboratory course. This experiment combines a first experience with the preparation and reaction of an organometallic reagent with a visible demonstration of the reality of resonance delocalization and stabilization. If time allows, the yield of the reaction can also be determined spectrophotometrically. We have found that the students receive this experiment with real enthusiasm.

Experimental Section

Crystal Violet

- **Caution:** These dyes stain readily. Be careful to avoid contact with skin or clothing. The student may want to wear gloves while handling the dye preparation. Both Crystal Violet and Malachite Green are somewhat toxic (see Baker MSDS C5720-01, M0280-01). Further, the byproducts from the preparation are of unknown toxicity. The dye preparations reported here are not to be used either on clothing or on other articles that will be handled repeatedly.

The dye preparation is carried out in a 250-mL round bottomed flask equipped with a reflux condenser. The flask and condenser are rinsed with a few milliliters of dry THF, then the flask is charged with magnesium (0.80 g), THF (45 mL), 4-bromo-N,N-dimethylaniline (5 g), and a small crystal of iodine. The mixture is warmed gently to reflux, and maintained there for 30 min, during which time the original dark color changes to the typical “dirty dishwater” shade of the Grignard reagent.

The flask is cooled to room temperature (external ice-water bath), then diethyl carbonate (0.49 g) in 5 mL of THF is added in one portion. The mixture is warmed to reflux for an additional 5 min, then cooled again to room temperature (external ice-water bath). Aqueous hydrochloric acid (15 mL of a 10% solution) is added slowly (the reaction with the remaining magnesium is vigorous). The result is a muddy purple mixture.

A sample of cotton cloth is immersed in this mixture for at least one minute, then removed, and rinsed under running water and blotted dry. It should now be intensely colored.

Malachite Green

The same procedure as above is followed, except that methyl benzotetrazole (0.85 g) is substituted for diethyl carbonate.

Additional Exercises

Creative Dyeing

If time allows, other cloth samples can be twisted and dyed, to give spectacular “tie-dyed” effects. The dye mixture can also be applied directly to the cloth with a brush, then carefully rinsed off. Malachite Green and Crystal Violet can make pleasing combinations when applied to adjacent areas on the same piece of cloth (see cover of this issue for color photos of dyed cloth).

Quantitation

Both Crystal Violet and Malachite Green are commercially available. Using a Spec-20 spectrophotometer, it is possible to construct standard curves for dilute, acidic (HCl) aqueous solutions of these dyes. The Crystal Violet was read at 500 nM. The Malachite Green was read at 425 nM. For Crystal Violet, the plot was essentially linear from A = 0.118 at 0.002 mg/mL to A = 0.580 at 0.10 mg/mL. For Malachite Green, the plot was essentially linear from A = 0.22 at 0.005 mg/mL to A = 1.10 at 0.026 mg/mL.

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For Crystal Violet, the total volume of the reaction was 65 mL. A 1.0-mL aliquot was diluted with water to 100 mL in a volumetric flask. A 6.0-mL aliquot of this solution diluted with water to 100 mL gave A = 0.25 ± 0.01, indicating a total yield of 0.54 g (32% yield based on the limiting reagent, diethyl carbonate) of Crystal Violet hydrochloride.

For Malachite Green, the total volume of the reaction was 65 mL. A 1.0-mL aliquot was diluted with water to 100 mL in a volumetric flask. A 1.0-mL aliquot of this solution diluted to 100 mL gave A = 0.11 ± 0.01, indicating a total yield of 1.54 g (68% yield based on the limiting reagent, methyl benzoate) of Malachite Green hydrochloride.

Waste Disposal: All excess dye mixtures should be transferred to the chemical waste container.

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Literature Cited

Convergent Synthesis of Betaine-30, a Solvatochromic Dye

An Advanced Undergraduate Project and Demonstration

Bruce R. Osterby1 and Ronald D. McKelvey
University of Wisconsin—La Crosse, La Crosse, WI 54601

Solvatochromism is used to describe a pronounced change in the position of a UV–vis absorption band with a change in solvent polarity. Betaine-30 (2,6-diphenyl-4-(2,4,6-triphenylpyridinium)phenolate) has one of the largest effects ever observed. The compound is red in methanol, violet in ethanol, blue in isooamy alcohol, green in acetone, and yellow in anisole, thus covering the whole visible range (1). This corresponds to a range for λ\text{max} of some 357 nm. The solvatochromism probably derives from solvent stabilization of the polar ground state relative to the less polar charge-transfer excited state.

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\end{align*}
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Betaine-30 makes an impressive demonstration, and a picture of the dye in various solvents has recently been included in an organic textbook (2). The multistep synthesis provides students with experience working on a small scale. If only the demonstration is of interest, betaine-30 is available from Aldrich.

The syntheses and solvatochromic properties of betaine-30 and related compounds came out of the PhD theses of Rechard et al. and have been described in the primary (3–5) and secondary (1) literature. The synthesis is convergent, which offers two advantages. Each branch can be run on a modest scale, and a reasonable amount of betaine-30 can still be obtained. The synthesis can be run as a team project, with different students working on each branch. The overall synthesis of betaine-30 is shown in Figure 1.

The first branch involves the synthesis of 2,4,6-triphenylpyrylium hydrogen sulfate. This is prepared by an acid-catalyzed condensation/cyclization with chalcone and acetophenone. Chalcone is commercially available but can also be made by a crossed aldo condensation (6). The mechanism of the second reaction provides an interesting challenge, especially because it involves an unexpected oxidation/aromatization step at the end. Our version of the mechanism is shown in Figure 2. The second branch is the synthesis of 4-amino-2,6-diphenylphenol. This can be synthesized from 2,6-diphenylphenol by nitration followed by reduction.

The convergent step in the synthesis is a mechanistically interesting opening/recyclization reaction to produce betaine-30. We have shown our version of the mechanism in Figure 3. The reaction is interesting to run as well because the mixture becomes ink-black. Recrystallizing dark crystals from a dark solution is a new experience for most.

The synthetic scheme can be expanded to include the condensation to produce chalcone (6) and the synthesis of 2,6-diphenylphenol.2 Including these reactions emphasizes the importance of condensation reactions in organic synthesis.

We have used this as an independent study project and also as a group project in an advanced synthesis lab. In both cases, students were able to get reasonable yields and reproducible results. NMR spectra and melting points confirmed the structures of products.

Demonstration

The solvatochromic effect can be easily demonstrated by simply dissolving betaine-30 in a variety of solvents. Quantitation is not critical. An effective method is to put a pinch in the bottom of test tubes or Erlenmeyer flasks and then add the (colorless) solvents to them with mixing.

22,6-Diphenylphenol was temporarily not available from Aldrich. Therefore, the authors devised a two-step synthesis from 1,3-diphenyl-2-propanone and acrolein. For details, contact the authors.