In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

Applying Reuse and Reduce in an Undergraduate Organic Laboratory: Sustainable Practices*

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Amidst the Covid-19 pandemic, we have planned a strategy for our institution which aims towards reuse and reduce principles of Green Chemistry. Organic preparations in the undergraduate curriculum can be utilized for other sister laboratory experiments such as recrystallization, determination of physical constants (m.pt) and detection of extra elements, detection of functional group and in qualitative analysis. The product of preparation can also be subjected to a second synthesis. This approach will reduce the amount of chemicals needed for carrying out experiments other than organic preparations. This paper illustrates a few organic preparations which can be reused for other companion laboratory exercises. This approach may set a model towards sustainability for other undergraduate laboratories.

Keywords
Reuse, reduce, sustainable practices, undergraduate, organic chemistry, laboratory experiments.

Introduction

Laboratory work has a significant impact on the environment as it involves the consumption of energy, resources and chemicals. As

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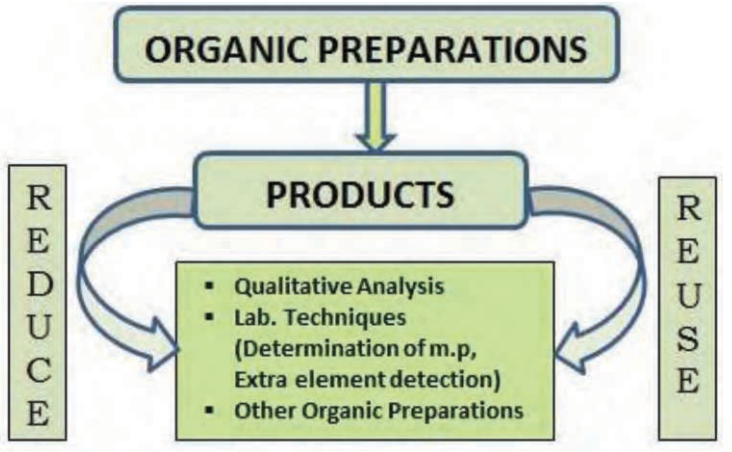

Flow Chart.

chemists, apart from innovating eco-friendly protocols, we should strive to reduce, reuse and recycle in the laboratory [1]. Such strategies for managing a laboratory minimize environmental impact. The strategic tier is to reuse material and avoid the purchase of surplus chemicals. Practices that implement this strategy include purchasing only what is needed, keeping chemical inventories to prevent the purchase of duplicates, and reusing excess materials. Ordering the minimum quantity of chemicals required and reusing substances are also effective means of minimizing the generation of hazardous waste. We at Delhi University have designed a protocol that involves the utilization of products of organic preparations for other practical exercises of the curriculum. We have taken three organic preparations whose products will serve as principal compounds for other laboratory exercises.

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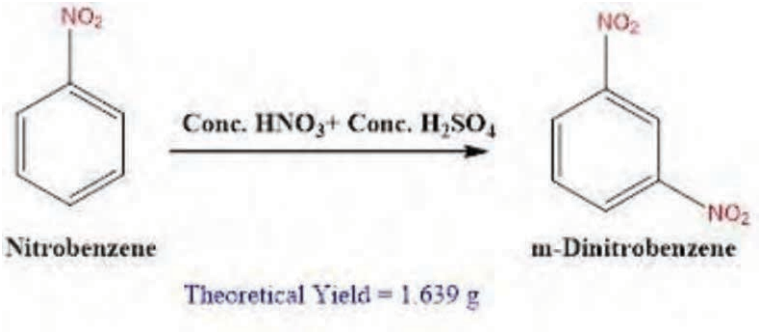
Reuse and Reduce Through Organic Preparations

Synthesis of an organic compound needs a lot of materials and input of energy. As a consequence, reduction and reuse are the most effective ways by which we can save natural resources, protect the environment and save money. In the following section, three routine organic preparations have been considered, which if shared for other exercises, can effectively cut down the annual



Scheme 1. Preparation of m-dinitrobenzene from nitrobenzene.

budget for the purchase of specific compounds.

Nitration of Nitrobenzene

Nitration of nitrobenzene to yield m-dinitrobenzene (*Scheme* 1) is one of the essential experiments in the undergraduate curriculum. It yields m-dinitrobenzene as the sole product. Experimentally 1 mL of nitrobenzene on nitration yields 1.64 g of m-dinitrobenzene. The product, if stored, can be reused, and as such, its purchase can be reduced. After preparation at the term's end, the product is usually thrown by the students as waste. In a class of 60 students, approximately 50 g of m-dinitrobenzene can be obtained, which can be reused and utilized as described in subsequent sections.

Reuse:

m-dinitrobenzene obtained in nitration of nitrobenzene may be further used in following laboratory experiments:

- Preparation of m-nitroaniline
- Melting point determination
- Recrystallization
- Identification of functional group(s)
- Qualitative analysis of organic compounds

Annually two bottles of m-nitrobenzene are purchased for INR 1500 @ 500 g per bottle (LOBA Chemie). This purchase can be avoided or reduced as it can be obtained via nitration of nitrobenzene.

Reduce:

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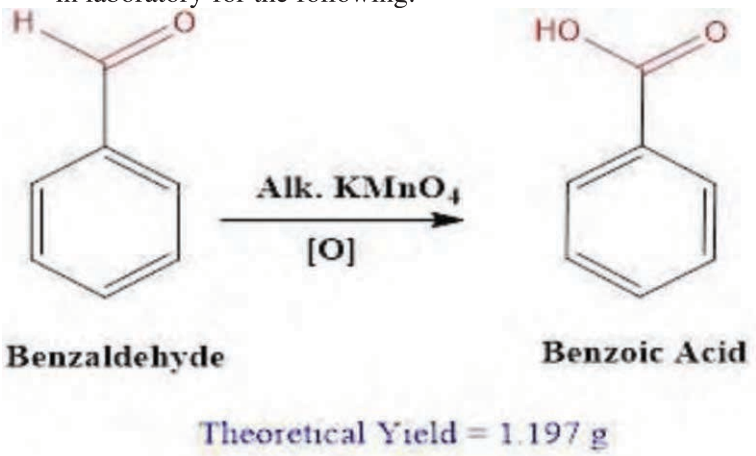
Oxidation of Benzaldehdye

Benzoic acid is obtained by the alkaline oxidation of benzaldehyde (*Scheme* 2), which is a fundamental compound utilized for the majority of laboratory exercises. This compound obtained during oxidation can be reused for other exercises, including the preparation of derivatives of benzoic acid such as benzamide. 1 mL of benzaldehyde on alkaline oxidation affords 1.2 g of benzoic acid. A sufficient amount of benzoic acid can be prepared by a class of 60 students which can be stored and put to reuse for further exercises such as recrystallization, determination of melting point, functional group analysis, etc., as stated in laboratory courses.

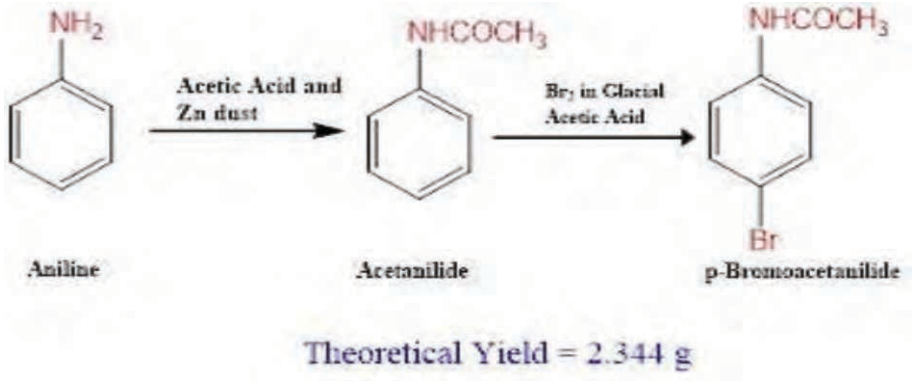
Benzoic acid is obtained by the alkaline oxidation of benzaldehyde (*Scheme* 2), which is a fundamental compound utilized for the majority of laboratory exercises. This compound obtained during oxidation can be reused for other exercises.

Reuse:

Benzoic acid obtained via oxidation of benzaldehyde can be reused in laboratory for the following:



Scheme 2. Alkaline oxidation of benzaldehyde.



Scheme 3. Synthesis of p-Bromoacetanilide from aniline.

1. Preparation of benzamide and other derivatives
2. Melting point determination
3. Recrystallization technique
4. Qualitative analysis

Reduce:

Annually approximately 6–8 bottles of benzoic acid are purchased for INR 380 @ 500 g bottles (LOBA Chemie). The quantity of benzoic acid to be purchased can be reduced so as to meet only the necessary requirement.

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Preparation of p-Bromoacetanilide

p-Bromoacetanilide is synthesized in a two-step reaction where aniline is first acetylated to acetanilide followed by bromination to afford p-bromoacetanilide (*Scheme* 3.) This conversion involves the study of two reactions, namely acetylation and bromination. The products of these two reactions can also be utilized for further laboratory exercises.

Reuse:

Acetanilide and p-Bromoacetanilide—the two products can be reused in laboratory for the following:

1. Preparation of p-nitroacetanilide
2. Extra element detection
3. Melting point determination
4. Recrystallization technique
5. Qualitative analysis

Laboratory Practices for Greening up the Laboratory

In addition, the following steps are advised so as to minimize the environmental impact of the lab.

- Reduce the scale of reagents/substrate to a minimum wherever feasible.

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- Experiments should be encouraged towards teamwork.
- Chemicals should be ordered according to the needs.
- Sharing of excess and unexpired chemicals should be allowed.
- Products of organic synthesis in laboratories should be saved for further use in unused and empty bottles of chemicals.

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- Identification of greener methodologies over conventional methods.
- Reuse of solvents through filtration and distillation techniques.

Conclusion and Future Outlook

Reusing a substance is considered the best way to reduce waste. By incorporating the above strategies, an institution with almost 100 students enrolled on a chemistry course can save up to 15–20% of the funding granted for the purchase of chemical compounds in a year. This proactive and voluntary improvisation step in environmental awareness can help towards the sustenance of

the environment for future generations. As educators, it is our primary responsibility to promote such little changes which can lead to a great impact.

Suggested Reading

[1] 1. G Bistulfi, Reduce, reuse and recycle lab waste, *Nature*, 502, 170, 2013. https://doi.org/10.1038/502170a