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Green Chemistry: A Safer Approach for Synthetic Chemistry

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ABSTRACT

Green chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical product. Green chemistry efficiently utilizes (preferably renewable) raw materials, eliminates waste and avoids the use of toxic and/or hazardous reagents and solvents in the manufacture and application of chemical products. Green chemistry aims to protect the environment not by cleaning up but by inventing new chemical processes that do not pollute. It is a rapidly developing and an important area in the chemical sciences. Green chemistry is an essential approach to chemical product design and manufacturing that prioritizes the health and safety of both humans and the environment. By following the principles of green chemistry, we can develop innovative solutions that reduce our reliance on toxic substances and minimize the impact of chemical processes on the planet. As we continue to face environmental challenges, green chemistry will play an increasingly important role in driving sustainable innovation and protecting our natural resources. It is up to all of us to embrace this approach and work towards a cleaner, healthier future for generations to come. This paper focuses on the aspects of green chemistry as a safer approach for synthetic Chemistry.

INTRODUCTION:

Chemistry has provided valuable materials in the form of medicines, food products, cosmetics, dyes, paints, agrochemicals, biomolecules, high-tech substances like polymers, liquid crystals and nanoparticles. The success of the modern pharmaceutical industry is based on remarkable achievements of organic synthesis over the last century[1]. However, the down side is that many of these synthetic methodologies were developed in an era when the toxic properties of many reagents and solvents were not known and the issues of waste minimization and sustainability were largely not recognized[2]. Also the processes on industrial scale involve many chemical reactions using huge quantities and wider varieties of smaller molecules, reagents, solvents, acids, alkali, etc. These chemical processes not only produce the required products but also large quantities of undesired and harmful substances in the form of solids, liquids and gases and have become the biggest challenge that chemistry has to face. So, the pressing need for the synthetic chemists is to minimize chemical pollution[3]. To accomplish the goal of designing and executing an environmentally benign synthetic protocol, green chemistry provides a way out by addressing one basic environmental problem: the problem of pollution[4].

Green chemistry is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical product[5]. Green chemistry efficiently utilizes (preferably renewable) raw materials, eliminates waste, and avoids the use of toxic and/or hazardous reagents and solvents in the manufacture and application of chemical products. Green chemistry aims to protect the environment not by cleaning up, but by inventing new chemical processes that do not pollute. It is a rapidly developing and an important area in the chemical sciences[6]. Green Chemistry is primary pollution prevention rather than waste remediation. Green chemistry is a new way of looking at organic synthesis and the design of drug molecules, offering important environmental and economic advantages over traditional synthetic processes. Pharmaceutical companies are increasingly turning to the principles of green chemistry in an effort to reduce waste, reduce costs and develop environmentally benign processes.

In developing green synthetic strategies, one needs to concentrate on avoiding environmentally noncompatible reagents, solid-state synthesis and modification of synthetic routes to decrease the number of steps and increase the overall yield, usage of newer catalysts and simplification of classical procedures of reaction. Commercial applications of green chemistry have led to novel academic research to examine alternatives to the existing synthetic methods. The fundamental idea of green chemistry is that, the designer of a chemical is responsible for considering what will happen to the world after the chemical agent is put in place. It is helpful to chemists and chemical engineers in research, development and production for development of more eco-friendly and efficient products which may also have significant financial benefits.

BRIEF HISTORY OF GREEN CHEMISTRY

In 1990 the Pollution Prevention Act was passed in the United States. This act helped to create a modus operandi for dealing with pollution in an original and innovative way. This paved the way to the green chemistry concept. Paul Anastas and John Warner coined the two letter word "green chemistry" and developed the twelve principles of green chemistry[7]. In 2005 Ryoji Noyori identified three key developments in green chemistry: use of supercritical carbon dioxide as green solvent, aqueous hydrogen peroxide for clean oxidations and the use of hydrogen in asymmetric synthesis.

The 12 Principles of Green Chemistry[3,6]

1. Prevention: It is better to prevent waste than to treat or clean up waste after it has been created.
2. Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Less Hazardous Chemical Syntheses: Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Designing Safer Chemicals: Chemical products should be designed to affect their desired function while minimizing toxicity.
5. Safer Solvents and Auxiliaries: The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. Design for Energy Efficiency: Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. Use of Renewable Feedstocks: A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. Reduce Derivatives: Unnecessary derivatization (use of blocking groups, protection/deprotection, and temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Design for Degradation: Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. Real-time analysis for Pollution Prevention: Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. Inherently Safer Chemistry for Accident Prevention: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

The Role of Catalysis[3,6]

The waste generated in the manufacture of organic compounds consists primarily of inorganic salts. This is a direct consequence of the use of stoichiometric inorganic reagents in organic synthesis. Pharmaceuticals manufacture is widely using 'stoichiometric' technologies. e.g. stoichiometric reductions with metals (Na, Mg, Zn, Fe) and metal hydride reagents ($LiAlH_4$, $NaBH_4$), oxidations with permanganate, manganese dioxide and chromium (VI), etc. This could be efficiently replaced by substitution of classical stoichiometric methodologies with cleaner catalytic alternatives. Biocatalysis has many advantages in the context of green chemistry, e.g. mild reaction conditions and often fewer steps than conventional chemical procedures because protection and deprotection of functional groups are often not required.

GREEN SOLVENT

One of the green solvents is supercritical carbon dioxide. Supercritical carbon dioxide refers to carbon dioxide that is in a fluid state while also being at or above both its critical temperature and pressure yielding rather uncommon properties. Supercritical carbon dioxide has been used as a processing solvent in polymer applications such as polymer modification, formation of polymer composites, polymer blending, microcellular foaming, particle production, and polymerization.

Green Guidelines experiments in Laboratory

1. Experiments should involve the use of eco-friendly and easily available reagents in bulk quantities at very cheap price.
2. Minimize the use of sophisticated instrumentation techniques like high-pressure system, evacuated system, inert atmosphere using argon, etc.
3. Avoid tedious experimental procedure like longer reaction time, reaction at high temperature etc.
4. All organic chemistry experiments (preparation, separation of mixture of compounds, identification of functional groups etc.) should preferably be conducted in semi-micro or micro-scale. Thin-layer chromatography (TLC), spectroscopic techniques (UV, IR and wherever available NMR) should be methods of choice for determining purity, functional groups and structure elucidation.
5. Identity of compounds should be preferably done by TLC behavior of the compounds prepared.

GLOBAL RECOGNITION OF GREEN CHEMISTRY

- Australia: The Royal Australian Chemical Institute (RACI) presents Australia's Green Chemistry Challenge Awards.
- Canada: The Canadian Green Chemistry Medal is an annual award given to any individual or group for promotion and development of green chemistry.
- Italy: Green Chemistry activities in Italy centre on inter-university consortium known as INCA. In 1999, INCA has given three awards annually to industry for applications of green chemistry.
- Japan: In Japan, The Green & Sustainable Chemistry Network (GSCN), formed in 1999, is an organization consisting of representatives from chemical manufacturers and researcher.
- UK: In the United Kingdom, the Crystal Faraday Partnership, a non-profit group founded in 2001, awards businesses annually for incorporation of green chemistry.
- USA: United States Environmental Protection Agency (EPA).

- Nobel Prize: The Nobel Prize Committee recognized the importance of green chemistry in 2005 by awarding Yves Chauvin, Robert H. Grubbs, and Richard R. Schrock the Nobel Prize for Chemistry for "the development of the metathesis method in organic synthesis."

CONCLUSION

Green chemistry addresses such challenges by opening a wide and multifaceted research scope. Thus allowing the invention of novel reactions that can maximize the desired products and minimize the waste and byproducts as well as the design of new synthetic schemes that are inherently, environmentally, and ecologically benign. In conclusion, green chemistry is an essential approach to chemical product design and manufacturing that prioritizes the health and safety of both humans and the environment. By following the principles of green chemistry, we can develop innovative solutions that reduce our reliance on toxic substances and minimize the impact of chemical processes on the planet. As we continue to face environmental challenges, green chemistry will play an increasingly important role in driving sustainable innovation and protecting our natural resources. It is up to all of us to embrace this approach and work towards a cleaner, healthier future for generations to come.

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