Twelve Principles of Green Chemistry

Green Chemistry has emerged as an important aspect of all chemistry Green Chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Green Chemistry is based on Twelve Principles

Principles of Green Chemistry

1: Waste Prevention

It is better to prevent waste than to treat or clean up waste after it has been created. Thus, chemical processes should be optimised to produce the minimum amount of waste possible.

A metric, known as **the environmental factor** (**E factor**), was developed to gauge the amount of waste a process created, and is **calculated by simply dividing the mass of waste the production process produces by the mass of product obtained.**

Lower valvue of E factor indicates better results. Other methods of assessing amounts of waste, such as comparing the mass of the raw materials to that of the product, are also used.

2: Atom Economy

Atom economy is a measure of the amount of atoms from the starting material that are present in the useful products at the end of a chemical process. Thus, synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

Side products from reactions that aren't useful can lead to a lower atom economy, and more waste. In many ways, atom economy is a **better measure of reaction efficiency than the yield of the reaction; the yield** compares the amount of useful product obtained compared to the amount you'd theoretically expect from calculations. Therefore, processes that maximise atom economy are preferred.

3: Less Hazardous Chemical Synthesis

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 effect their desired function while minimizing their toxicity**. The design of **safer chemical targets requires a knowledge** of how chemicals act in our bodies and in the environment. In some cases, a degree of toxicity to animals or humans may be unavoidable, but alternatives should be sought.

5: Safer Solvents & Auxiliaries

Many chemical reactions require the use of **solvents** or other agents in order to facilitate the reaction. They can also have a number of hazards associated with them, **such as flammability and volatility**. Solvents might be unavoidable in most processes, but they should be chosen to **reduce the energy needed** for the reaction, should have **minimal toxicity**, and should be **recycled** if possible.

6: Design for Energy Efficiency

Energy-intensive processes are unacceptable in green chemistry. 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 (e.g., chemicals derived from biological sources) rather than depleting whenever technically and economically practicable. For example petrochemicals are non-renewable resources which are employed as starting materials in a range of chemical processes can be depleted.

8: Reduce Derivatives

Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste. Alternative methods must be developed which do not require the such groups for example enzymes which are highly specific.

9: Catalysis

The use of catalysts can enable reactions with higher atom economies. Catalysts themselves aren't used up by chemical processes, and as such can be recycled many times over, and don't contribute to waste. They can allow for the utilisation of reactions which would not proceed under normal conditions, but which also produce less waste.

10: Design for Degradation

Organic pollutants do not decompose and can accumulate in the environment for example halogenated compounds (DDT). Where possible, these chemicals should be replaced with chemicals that are more easily decomposed by water, UV light, or micro-organisms. Chemical products should be designed so that at the end of their function they decompose into harmless degradation products and don't have adverse impacts on the environment.

11: Real Time Pollution Prevention

Monitoring a chemical reaction as it is occurring can help prevent release of hazardous and polluting substances due to accidents or unexpected reactions. With real time monitoring, warning signs can be spotted, and the reaction can be stopped or managed before such an event occurs.

12: Safer Chemistry for Accident Prevention

Working with chemicals always carries a degree of risk. However, if hazards are managed well, the risk can be minimised. This principle clearly links with a number of the other principles that discuss hazardous products or reagents. Where possible, exposure to hazards should be eliminated from processes, and should be designed to minimise the risks where elimination is not possible.