1-6-1. Organic Photoreactions

Overview

Chemistry of organic photoreactions is a field that explores novel reactions and molecular functions through the use of excited states and radical species generated when organic molecules absorb light. Light serves as a mild and selective energy source, enabling unique reaction pathways that proceed via short-lived, high-energy intermediates without relying on scarce elements. As a result, applications are expected in fine chemical synthesis, photocatalysis, drug delivery, and molecular devices, and interdisciplinary research is being actively pursued from fundamental science to applied technology.

Current Status and Frontiers

Organic photochemistry is a discipline that utilizes light energy to promote molecules into excited states, thereby opening reaction pathways inaccessible in the ground state. Upon light absorption, molecules are excited to singlet or triplet states, acting as short-lived but highly energetic intermediates. This property allows reactions that are thermally forbidden by the Woodward–Hoffmann rules to become feasible. A prime example is the [2+2] photocycloaddition, which, though thermally forbidden, has long been recognized as a landmark of organic photochemistry.

In recent years, the field has advanced beyond simple cyclizations and isomerizations toward more precise and controllable reaction design. Notably, photocatalysis and photoredox catalysis (Pac et al.) now allow the generation of radical and cationic species under mild visible-light conditions, enabling novel bond formations and molecular transformations (Fukuzumi, MacMillan). This progress has realized regio- and stereoselective control in the synthesis of pharmaceuticals and functional molecules, which was previously unattainable. Furthermore, photocatalytic systems employing metal complexes or organic dyes are enhancing sustainability and reproducibility, positioning photochemistry as a pillar of green synthesis.

The forefront of organic photochemistry, however, extends beyond synthetic methodology. Photobiological applications, such as the spatiotemporal control of biological activity, are drawing great attention. Phototriggered drug delivery enables the release or activation of drugs with high selectivity and non-invasiveness (Klán). Recent advances in two-photon excitation in the near-infrared region allow spatiotemporal control deep within tissues, facilitating precise concentration

PPG: Photolabile protective group ; **Drug**: drug

jumps in neuroscience and signal transduction research (Abe). By designing photoremovable protecting groups with π-conjugated systems or donor–acceptor structures, two-photon absorption can be enhanced, permitting localized release of active molecules.

Optogenetics, meanwhile, is a technology that controls the activity of specific cell populations using light-sensitive proteins such as opsins. Gero Miesenböck proposed the optical control of neurons in 1999 and demonstrated it in 2001, pioneering the field. Subsequent developments enabled the genetic introduction of light-gated channels such as ChR2, which allow spatiotemporal manipulation of neural circuits (Deisseroth). This technology has produced groundbreaking results in neural circuit analysis, behavioral control, and disease models. For example, optical control of prefrontal cortex neurons produced antidepressant effects in mouse models, and studies are underway on restoring vision in patients with retinitis pigmentosa using optogenetic methods.

References

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Future Perspectives and Directions

In the future, the integration of precisely designed photoresponsive molecules from organic photochemistry with optogenetics is expected to enable drug delivery and neural circuit manipulation in deep tissues. By exploiting two-photon excitation and highly engineered photoactive compounds, applications in medicine, materials science, and biology will further expand.

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