Scientists Investigate How Fireflies Emit Different Colors of Light

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Scientists have discovered that the light-emitting luciferin molecule in fireflies can produce different colors of light depending on different polarities inside the molecule. Image credit: Wikimedia Commons.

(PhysOrg.com) -- There are more than 2,000 species of fireflies around the world, many of which are best known for their bioluminescence. Fireflies, which are not flies but beetles, produce flashes of light in order to communicate with each other and to attract mates. The color of light emitted by the luceferin molecule in fireflies can range from red to yellow to green. However, the chemical and physical origin of firefly color variation is not well understood.

In a recent study, a team of scientists has proposed a new explanation for firefly color modulation in the Japanese Genji-botaru firefly that contrasts with previous explanations. Using recent X-ray data and theoretical simulations, the researchers suggest that the wavelength of the emitted light depends on the polarity of the microenvironment in the firefly's light-emitting molecules. Lead author Isabelle Navizet from Beijing Normal University and University Paris-Est, along with coauthors from the Chinese Academy of Sciences, Université d'Aix-Marseille, and Lund University, have published their results in a recent issue of the Journal of the American Chemical Society.

Fireflies emit light from chemical reactions that occur in their lower abdomens. The emitted light arises from the oxidation of the organic substrate luciferin, catalyzed by an enzyme called luciferase. This series of complicated reactions also involve the participation of ATP (adenosine triphosphate) molecules and magnesium ions.

Previously, researchers proposed that the key to understanding the bioluminescence color variation was the size of the luciferase protein cavity. The idea is that a larger cavity allows more energy loss than a smaller cavity, so a larger cavity leads to the emission of lower-energy red light, while a smaller one emits higher-energy yellow and green light.

However, using new experimental data and simulations, Navizet and coauthors found that this theory doesn't adequately explain the color modulation. Instead, their results suggest that the polarity of the luciferase protein cavity could be responsible for different colors. The cavity's polarity can be adjusted by changing the number of water molecules and protein residues inside the cavity. The mutations of the residues involved in this H-bond network can lead to different polarizations acting on the luciferin and can change the color of the emitted light accordingly.

"We've shown that the light wavelength does not depend on the rigid or loose structure of luciferase but on the water H-bond network inside the cavity," coauthor Ya-Jun Liu of Beijing Normal University told PhysOrg.com. "Mutations of luciferase on residues involved in this network should modulate the color."

As Liu explained, understanding the relationships between the luciferase structure and the bioluminescence may have several applications.

"Due to its high sensitivity and extreme specificity for ATP, luciferases are used as markers for the investigation of various biochemical processes in vitro and in vivo," Liu said. "Knowing the modulation mechanism in fireflies can suggest which mutation to perform in order to produce mutants with specific light wavelengths. For example, in mammalian cells which absorb shorter wavelengths, red-light emitting luciferin-luciferase systems are useful. Knowing the mechanism of the modulation of the emission light and the sensibility to external factors such as pH, solvation, etc., is also important for luciferases as biosensors."

More information: Isabelle Navizet, Ya-Jun Liu, Nicolas Ferre, Hong-Yan Xiao, Wei-Hai Fang, and Roland Lindh. "Color-Tuning Mechanism of Firefly Investigated by Multi-Configurational Perturbation Method." J. Am. Chem. Soc. Doi:10.1021/ja908051h