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COHERENCE OF THE LIGHT FROM THE INDIAN FIREFLY ASYMMETRICATA CIRCUMDATA

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Abstract: Numerous investigations conducted on firefly bioluminescence over the past few decades have improved our knowledge of the intriguing phenomenon that produces light. Different studies have also demonstrated the influence of external environmental elements on the light emitting reaction. In this article, interference fringes from the light of the Indian firefly *Asymmetricata circumdata* produced using a Michelson interferometer are presented. The fringes vanish when the path difference of interfering beams equals or exceeds 30 cm, indicating that the light of this firefly species maintains a stable phase up to a path difference of 30 cm.

Keywords: Firefly bioluminescence, Asymmetricata circumdata, Interference, Michelson interferometer, Temporal coherence.

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1 Introduction

Fireflies are an amazing creation of mother Nature that can produce light by their own. They use this light to locate mates or to scare predators or attract preys [1, 2]. A chemical reaction that is approximately 41% efficient [3, 4] is responsible for light production in fireflies. In this reaction, luciferin (a luminophore), luciferase (an enzyme), Mg^{2+}, ATP and molecular oxygen take part. Initially, luciferin gets oxidised to form oxyluciferin in an excited state, which releases visible light during relaxation to ground state [5]. Reaction steps are summarised in Fig. 1.

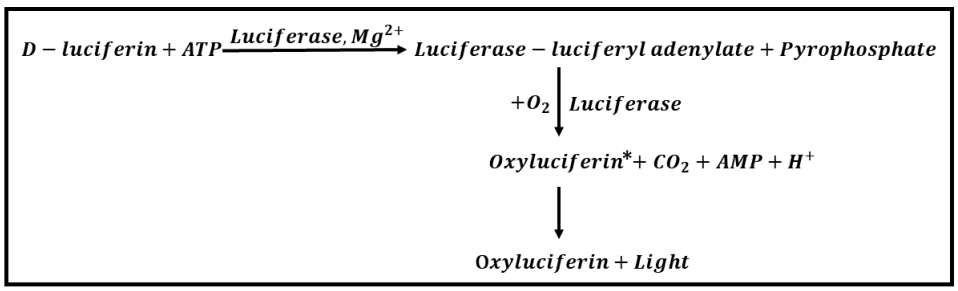

Figure 1: Bioluminescence reaction that produces light in fireflies. Due to its high efficiency, this light is also referred to as cold light.

In the bioluminescence (BL) reaction in fireflies, neural signals regulate whether a flash is emitted or not [6, 7]. The reaction is affected by any external environmental factors. Among different factors, the most influential one is temperature [8–12]. At lower temperatures than normal one, the BL reaction becomes slower- making the reaction start and end very slowly and emits broad flashes [13]. Below a certain low temperature, flash duration increases exponentially and a blue shift of peak wavelength is also discernible. This happens due to cold denaturation of luciferase. Conversely, rate of the reaction becomes faster at higher temperatures. At a certain hot

temperature, a red shift of peak wavelength is visible and shortest flashes are obtained. This is known as thermal denaturation. Above this temperature, flashes again start to broaden. The temperatures ranges for thermal and cold denaturation are species specific. Fireflies keep a safe margin from temperatures at which denaturation happens- they appear at least 5–7$^{\circ}C$ higher than cold denaturation temperature and at least 3–4 $^{\circ}C$ lower than thermal denaturation temperature. Temperatures within these two limits are favourable for fireflies. In the firefly species *Abscondita perplexa* (previously named as *Luciola praeusta*), widely found in northeastern India, the thermal and cold denaturation temperatures are 42 and 11.5–11.0 $^{\circ}C$, respectively [12, 13], which makes them capable of appearing from March to November just after sunset. On the other hand, for *Schlerotia substriata*, these values are 34 and 10.5–9.0 $^{\circ}C$, respectively [10], making them appear about one to one and a half hour after sunset in the same location. Other external factors affecting BL reaction are magnetic and electric fields. In Japanese firefly species *Luciola cruciata* and *Luciola laterialis*, both the pulse density and frequency were found to increase under the influence of external pulsed magnetic field suggesting that the magnetically induced current inside the firefly affected its nervous system or the photochemical process in the light organ [14]. In static electric field, though the firefly species *A. perplexa* showed no variation in peak-wavelength position, but its flashes broadened twice in males and thrice in females and no variation was observed in alternating field [15]. Therefore, it was concluded that the static electric field probably removed free electrons from the cuticle layer, which in turn carried away some heat from the firefly making it cool, which in turn slowed the reaction rate and made flashes broad. In a recent article, it is reported that biting by a spider alters male flashes to mimic with those of females [16].

Investigations made on the internal structure of the firefly light-emitting organ reveal the presence of uric acid granules, which behave like a cavity similar to that present in a random laser [17]. Another report about a laser-like emission in specimens of the firefly *A. perplexa* is also available [18]. The temporal coherence length measured for this species is 23 cm [19]. *Asymmetricata circumdata* is another firefly species that coexists with *A. perplexa*. Therefore, its coherence property has been measured for comparison.

2 Materials and methods

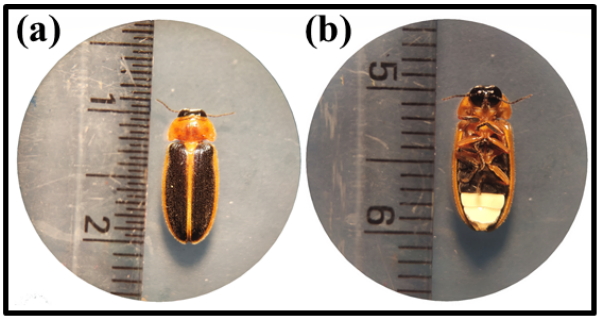

Figure 2: Photographs showing a male specimen of the firefly species Asymmetricata circumdata in (a) dorsal and (b) ventral views. The presence of two white segments in the abdomen confirms it as a male.

Among the four firefly species identified on the Gauhati University campus (26.1540° N, 91.6630° E), *Abscondita perplexa* has the highest population, and *Asymmetricata circumdata* is second in the list, followed by the other two species- *Diaphanes sp.* and *Schlerotia substriata*. Fireflies of the species *A. circumdata* appear 1.5 to 2 hours after sunset and thus are dark-active. It is very difficult to catch females of this particular species. Catching of a few males is somewhat less difficult. A mature firefly is approximately 1 cm long, as shown in Fig. 2. For the experiment, 10 healthy male specimens were collected using a specially designed net. Before the experiment, fireflies were kept in the dark laboratory in a bottle with good air flow. Acclimatised fireflies were then fixed with a beam expander using cotton and sellotape. A Michelson interferometer was used to form interference fringes. The experimental setup is presented in Figure 3. Snapshots of fringes were captured using DSLR (`NIKON D7000`) camera with a lens (`AF-S NIKKOR 24-120 mm 1:4 G ED`).

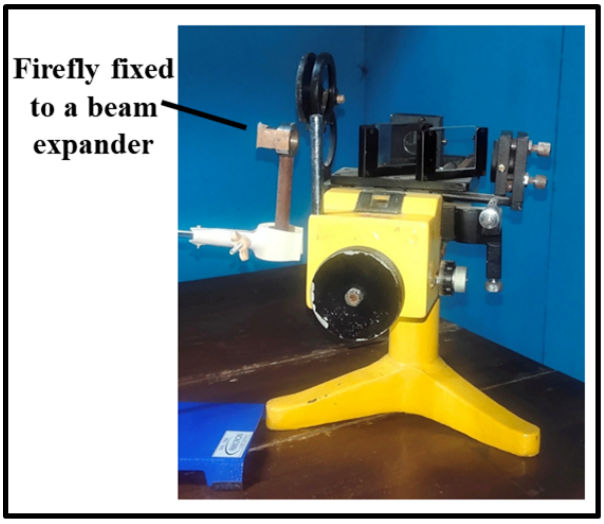

Figure 3: A photograph showing a Michelson interferometer. The point-like light of the firefly is expanded to obtain interference fringes on this interferometer.

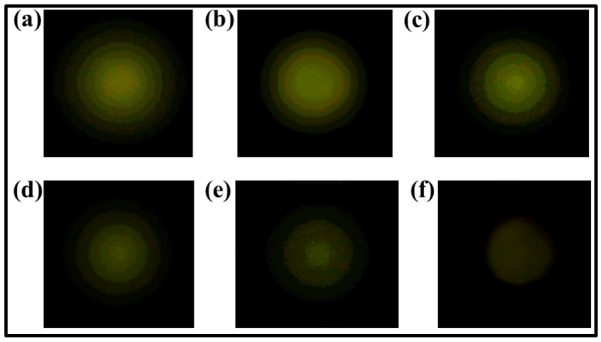

Figure 4: Snapshots of interference fringes at different path differences. (a) Fringes are formed at zero path difference. (b) to (f) Path differences are set at 8, 16, 24, 30, and 31 cm, respectively.

3 Results and discussion

Interference fringes formed at different path differences are presented in Fig. 4. Since firefly light is polychromatic- a mixture of three colours, viz. green, yellow, and red [20]- we get colourful fringes. Due to the overlapping of different ordered fringes for these colours, completely dark fringes are absent. When there is no path difference, the number of rings in the interference fringes is maximum. With increasing path difference, the number of interference rings decreases. It is found that at a path difference of 30 cm, the minimum number of rings is obtained, and interference fringes start disappearing hereafter. No fringes were obtained at a path difference of 31 cm.

4 Conclusion

Light of the firefly *A. circumdata* is found to interfere in a Michelson interferometer to form circular rings. The disappearance of interference rings at a path difference exceeding 30 cm confirms a better coherence length of this species in comparison to that of the species *A. perplexa*. Hence, it can be concluded that the light of *A. circumdata* is much more monochromatic.

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