A PHYSICAL STUDY OF THE FIREFLY

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CONTENTS.

I. INTRODUCTION.

During the latter part of the summer of 1908 the first attempt was made to measure the radiation from the local species of firefly. The season was late and but little was accomplished beyond the acquisition of some knowledge of the habits of these interesting insects. The following summer, in collaboration with Dr. H. E. Ives,* the spectral energy distribution of the light from the species *Photinus pyralis* was obtained by photographic photometry. Last year an attempt was made to obtain photographically the spectral energy distribution of the species *Photuris pennsylvanica*, which comes earlier in the year. As mentioned elsewhere,† the work was begun too late in the season, and in the course of only a few days this species had disappeared for the year. However, in spite of the lack of sensitiveness of the photographic plates in the red, there was considerable evidence that the light from the *Photuris*, which to the eye appears a greenish blue, is quite monochromatic, being deficient in the yellow and red rays which are prominent in the light of the *Photinus*. Whether the maximum emission is very different in these two genera remained undetermined until this year. The work requires an intimate knowledge of the habits of the various species, the lack of which has been the cause of most of the delays in reaching some conclusion in regard to the various questions under discussion.

One of the foremost problems which now occupies the attention of investigators is the improvement of our methods of illumination. It is recognized that our present methods of light production are of the most primitive type, and yet we seem helpless in the matter. Recognizing our helplessness, we should not hesitate to turn to other animals having photogenic systems which apparently are far more efficient than our own, and try to learn their methods of operation. It may be that in the ultimate analysis the efficiency

*Bull. Bur. Standards, vol. 6, p. 321, 1909.
†Electrical World, **56**, p. 1012, Oct. 27, 1910.

of their lighting systems is no higher than our own (but their fuel supply is evidently different from ours) and to learn that much of their secret may be of value.

Aside from this utilitarian question, there are others of equal importance. For example, we know that closely related species of fireflies emit differently colored light, variously described as blue, green, orange, etc. Is this color-variation a subjective phenomenon, resulting from the variation in color sensibility of the eye with variation in intensity,* or is it an objective reality? If the latter, then what are the laws governing the light emission? It is almost too much to hope to solve this problem in the near future, but it seems possible to settle definitely the question whether or not the light differs in composition and hence is "blue," "green," or "orange," as observed. This knowledge is obtained from the spectral energy curves of the light from various fireflies, to be described presently.

Experimenters have become so accustomed to thinking of the artificial production of light as being accompanied by a large amount of invisible radiation that no experiments would be complete without a repetition of Langley's search for infra-red radiation. Accordingly this question has also been given attention in this paper.

In view of the doubt in many investigators' minds as to whether the color of the light from the firefly is due to a variation in intensity rather than to an actual variation in composition, it seemed worth while to attempt to settle the question by making a thorough study of the light emitted by various species of this insect. Accordingly, the photographic work was continued for about four weeks, during which time 152 photographic exposures were made, on two spectrometers differing widely in dispersion, the time of exposure varying from 30 seconds to 5 hours. The time consumed in actual photography, in holding the insects on the spectrometer slit, was over 56 hours.

The histological data is introduced for clearness in discussing the present work, as well as its bearing upon the whole subject. It permits also a discussion of the plausibility of the functions assigned to certain parts of the photogenic organs as viewed from a physical standpoint and more especially from the optical properties of materials.

While much has already been done on the light of the firefly, much more remains undone, all of which no doubt will have direct bearing on the manner of light production in animals. Among the important problems awaiting solution are (1) whether, in animals having luminous organs emitting light of different colors, the maxima of emission are different; and (2) whether the maximum emission in any one photogenic cell is the same when the light is emitted from the living animal and when the photogenic material is excited to light emission by an oxidizing agent after the luminous organs have been dried.

Heretofore we have been led to think that "light" must be accompanied by infra-red radiations; and we seem utterly unable to turn away from this idea. The various investigations of the firefly have without doubt opened up a new line of thought in regard to the emission of heat and light.

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*Knab., Canadian Entomologist, 37, p. 238, 1905. Molisch, Leuchtende Pflanzen, Jena, 1904.

II. HABITS OF THE VARIOUS SPECIES INVESTIGATED.

At first thought it may seem aside from the main problem to discuss such details, but successful work can be done only after learning the habits of these insects. Not being familiar with the subject at the start, the results given here are the outgrowth of four summers of personal experiences in the field, and it is hoped that they may be useful to others who may be led to undertake similar work. A recent paper by McDermott* is in practical agreement with the experiences herein described.

The insects were caught by means of a net made of white cheesecloth attached to a light wooden handle about 1.5 meters long. The white cloth is easily seen and avoided by the insects, but it is more easily handled in the dark.

The habits of the *Photuris pennsylvanica* are markedly different from the various species of *Photinus*. The *Photuris* inhabits damp ground along wooded brooks and rivers, and in the daytime it seems to rest in the trees as well as in the grass, from which it does not emerge until after it has become quite dark. It flies high, at great speed, gives a quick flash, and the next moment may be repeating the flash 10 to 20 meters away. The color of the light is a rich bluish-green. Because of the darkness, it usually is impossible to see these insects except when they flash. At times, however, when in flight, a faint glow is visible which is easily followed with the net. Late at night they become more quiet and often may be found, flashing, on grass stems and on golden-rod. When struck to the ground, they run about flashing violently (just the opposite from the *Photinus*) and hence are easily located. Late in the season they seem to rest, without flashing, among the underbrush. Many specimens were caught by beating the brush and taking advantage of their flashing when disturbed and on the ground.

One compensation for the difficulties in catching the *Photuris* was in finding that they are strong and hardy, not being easily crushed; and that they could be kept for days in large glass beakers (12 × 18 cm.) containing clean moist sod, the top being covered with cheesecloth. They are carnivorous, eating their dead comrades. In captivity they kill and eat the *Photinus*. The *Photinus pyralis* are not so easily kept, but are more plentiful and more easily obtained. In the previous work on the latter, they were caught and the photographs made the same night. In the present work, half the night was spent in catching the *Photuris*, and usually the photographing of the light was done in a dark room on the following day.

In the *Photuris* the light organs of the female are almost as large as those of the male. The females outnumber the males by about 15 to 1, so that one catches but few of the latter.

The *Photinus pyralis* is plentiful everywhere in this locality. It comes out at dusk, when it can be seen and easily caught. It flies low, hovers about the grass, apparently searching for the female. This species is more delicate than the *Photuris*, is easily injured, and is not so easily kept in captivity. The light organ in the female is very small, and from her habit of remaining in the grass, occasionally flashing, and from the fact that the males outnumber the females by about 15 to 1, the captured specimens of this species were mostly males. The flash is a long fulmination of yellowish light.

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*McDermott, Canadian Entomologist, Nov. 1910.

The *Photinus scintillans* and the *Photinus consanguineus* were found together among shrubbery, in small isolated spots of an acre or less in area. The *scintillans* is only about 3 to 5 mm. long and is therefore very difficult to handle. On the spectrometer slit it would flash but a few times, when fortunately it would emit a rich glow. A female *scintillans* was caught while flying about during the daytime. As in the female *pyralis*, the light organ occupies one-third of the ventral area of the third abdominal segment. Both male and female have the appearance of diminutive *pyralis*, the color of the wings being more grayish.

The *consanguineus* is somewhat larger than the *scintillans* and can be made to flash for a longer time before it begins to glow. Both of these species become active early in the evening, but cease their flashing some time before dark. The flash is a beautiful orange-red, which is emitted at long intervals. The fewness of these two species and the infrequency of the flash made it difficult to obtain specimens in sufficient number for the requirements of the present work. In work like the present it is necessary to have a large number of insects to last three hours. Only once was work undertaken (this on the small spectrograph to be described subsequently) with less than a dozen insects, and of this number only two were very active.

III. COMPOSITION OF THE LIGHT OF FIREFLIES.

The question of the composition or "color" of the light emitted by various species of fireflies is of considerable interest, and may prove of great importance in the theory of radiation. The color of the light may vary according to the species that produces it and from different parts of the body the same animal may emit different-colored light. For example, *Photinus pyralis* has two small light organs, L' L', Fig. 1, on the last abdominal segment which emit light of a decidedly more greenish color than the light emanating from the rest of the luminous organs.

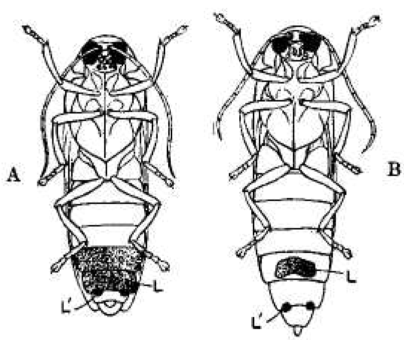

FIG. 1.—*Photinus pyralis*.
A = male. B = female. L and L' = luminous organs.

It would be interesting to know whether the maximum emission is different in the two luminous organs or whether this greenish color in L' L' is simply a question of intensity. In the *Photinus pyralis* it appears to be a low-intensity effect. Whether there is an actual variation in the composition of the light emitted by any one luminous organ is of considerable interest, as this would show that not only the act of emitting the light, but also the composition of the light, is under control of the insect. Whether there is such a variation in the composition, subject to the control of the insect, would be difficult to establish.

It is evident, from visual observations, that the range of variation in color of the light of any one species, whether or not it is under control, must be very limited in extent. Occasionally, however, one finds specimens of a given species in which the light seems to differ from the accustomed color. This is especially true of the *Photinus consanguineus* and *scintillans*. For example, while photographing the light from *Photinus consanguineus* a specimen was found in which the flash appeared a deeper reddish-yellow than that usually observed. To the eye it appeared as though the photogenic material extended into the adjacent dark segment, and as though the color of the light emanating from the line of intersection of the second luminous segment with the adjoining dark segment was of a more reddish tinge than the light coming from the other parts of the luminous segments. This was probably caused by absorption of the yellow and blue light in passing through the slightly brownish integument joining the segments. The extension of the luminous organs under the dark segments would explain the reddish light sometimes observed in insects. Several other specimens were observed in which, while photographing, the light changed from an orange to a decidedly reddish-yellow hue. The illumination was so weak that it was extremely difficult to keep the insects in place on the spectrometer slit, and it is therefore evident that this change in color was not due to the physiological effect of low intensity on the retina; for in that case the light should have appeared greenish.

As so much importance has been attached to the physiological effect of lights of different intensities upon the retina, notes were made of the appearance of the light emitted by various species. After sitting in a dark room from two to four hours, in which fireflies of all degress of activity were handled, it was an easy matter to study this effect. The observations extend over several weeks and are in complete agreement. They show that for the same genus at low intensities the light is more bluish than at high intensities, which is the physiological phenomenon. Examined side by side, after being in darkness for three hours, the glow of *Photinus pyralis* appeared more yellow than that of *Photuris pennsylvanica*, and the flash of the latter appeared bluer than the glow of the former. This evidently can not be explained on the basis of physiological optics. The glow from *Photinus consanguineus* was at all times greenish to yellowish, while the flash was a reddish-yellow. This evidently is the physiological effect of variation in intensity. However, when we compare the latter with *Photinus pyralis* and find that its light is reddish-yellow in spite of the fact that it is barely sufficient to illuminate the spectrometer slit, while the light of *Photinus pyralis* is greenish-yellow and is of sufficient intensity to read the time on a small watch dial, it is evident that there is an actual difference in the light emitted by the various genera and species of fireflies.

After one has done field work for several summers, has handled hundreds of these insects, and has observed the viciousness with which the *Photuris pennsylvanica*, in captivity, kill and devour the smaller species, e. g., *pyralis* and *scintillans*, one concludes that, if for no other purpose, the difference in the color of the light is useful as a distinguishing mark of the different species.