THE COLOUR OF THE LIGHT EMITTED BY LAMPYRIDÆ.

BY W. W. COBLENTZ, WASHINGTON, D. C.

The light emitted by various animals has been described as being "blue," "bluish," "green," "yellowish," "orange-coloured," "red," etc. In view of the doubts* as to whether this colour is a subjective phenomenon, resulting from the variation in colour sensibility of the eye with variation in intensity, or whether it is an objective reality, it seemed of interest to attempt to settle the question by subjecting the light to physical analysis by means of instruments which are unbiassed in the matter. One can, of course, examine the light visually by means of a spectroscope and note that in some cases it is "bluer," and on other cases it "extends further toward the red," etc., but to those familiar with the vagaries of the human eye, such a record is useless. The proper instrument to use is a bolometer, but because of the lack of sensitiveness of such an instrument and because of the intermittence of the light, the spectral analysis of the light by such means is prohibited. Spectrophotometric comparisons are also precluded. The only satisfactory means available is the photographic plate, which is integrative in its action, and hence well adapted to study weak sources of radiation. The photographic plate must be of a special kind, sensitive to all parts of the visible spectrum. The nearest approach to this condition is the Wratten and Wainwright "Panchromatic" plate, which is sensitive, in a variable degree, to all frequencies from the ultra-violet far into the red. The method is really a species of spectro-photographic photometry, in which the light of the fire-fly and that of a standard source are photographed, after which the "densities" of the negatives are compared, in a manner to be described presently.

The apparatus used consisted of a large prism spectrograph of one meter focal length, giving a long spectrum, and a small spectrograph, of triple achromatic lenses, 6 cm. diameter and 18 cm. focal length, which had a much greater light-gathering power, hence useful in photographing the weak radiations in the red. The method of procedure consisted in holding the insects in the fingers, one or two at a time, over the spectrometer slit. This required an exposure varying from one to five hours on the large spectrograph, and from one to sixty minutes on the small

*Knab.—CANADIAN ENTOMOLOGIST, 37, p. 238, 1905

Molisch.—Leuchtende Pflanzen, Jena, 1904.

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spectrograph to obtain satisfactory negatives of the various species of fire-flies. The photographing was done in a dark room. Over 150 negatives were taken, over 56 hours being spent in holding the insects in place. The plates, being sensitive to red light, were developed and fixed in a perfectly dark room. The numerous details in the work will be published in the complete paper.

Prints from negatives of the light of *Photuris pennsylvanica* and of *Photinus pyralis* are given in fig. 23, from which it is evident that the light of the *Photinus pyralis* does not extend so far into the blue ($\lambda = .5015\mu$)

FIG. 23.—a, spectrum of "4 Watt" carbon glow lamp; b and d, spectrum of fire-fly, *Photinus pyralis*; c, spectrum of fire-fly, *Photuris pennsylvanica*; d, helium vacuum tube spectrum, used for comparison.

as, and that it extends farther toward the red ($\lambda = .6678\mu$) than does the light of the *Photuris pennsylvanica*.

In addition to the negatives of the fire-fly light, a series of photographs (see fig. 23), were obtained of the spectrum of a standard comparison lamp (carbon glow lamp operated on four watts per candle) when exposed for 2, 4, 6, 8, 12, 20, 30, 60, 120 and 240 seconds.

The "densities" or "blackening" of the photographic plates were then measured by means of a Marten's polarization photometer, mounted on a small comparator, in such a manner that strips 1.5 high and 1 mm. long were compared against the clear unexposed plate. These "densities," i.e., the amount of light absorbed, were then plotted to scale, as indicated in

fig. 24, where the horizontal scale is the wave length. In this illustration

FIG. 24.—Density curves of photographic plates of
Photuris pennsylvanica X—X—X—X

Photinus pyralis ϕ — ϕ — ϕ — ϕ

Glow Lamp — — — — —

the heavy black lines give the effect of the light of *Photuris pennsylvanica* (X—X—X—X, •—•—•—•, ϕ — ϕ — ϕ — ϕ), of *Photinus pyralis* (θ — θ — θ — θ), and of the carbon glow lamp (— — — — —).

This illustration, in itself, is an ample demonstration that the light of the *Photinus pyralis* is much richer in red and yellow rays than is the *Photuris*; for the curves intersect, and all those of the *Photinus*, whatever the density, lie to the right of those of the *Photuris* of equal density. But we can go a step farther by comparing densities of the negatives. It is assumed that the density or the effect of the light upon the photographic plate is proportional to the time of exposure. This is, of course, not true for very long exposures, and hence the highest parts of the curves are not used in this work. For convenience I have taken the four seconds glow lamp density curve as my unit. Hence the 8 seconds density curve represents 2 units, the 12 seconds density curve represents 3 units, etc. Turning now to the fire-fly curves we see that the upper, heavy, density curve of *Photuris pennsylvanica* intersects the 4 seconds density curve of the glow lamp at $.52\mu$ and at $.592\mu$; i.e., at these two points, the two

curves have the same density, which in magnitude, by our arbitrary scale, is 1 unit. At $.532\mu$ and at $.572\mu$ this same *Photuris* curve intersects the 8 seconds density curve of the glow lamp, and hence, on our arbitrary scale, photometric value at these two points is 2 units. At the intersections with the 20 seconds density curve of the glow lamp the photometric value is 5 units, etc. These photometric values, 1, 2, 5, etc., or ratios of densities, are plotted to scale in fig. 25. The dotted curve in this illustration is plotted from Langley's photometric values of *Pyrophorus noctilucus*.

FIG. 25.—Ratio of densities of photographic plates :
 $\frac{\text{fire-fly light}}{\text{glow lamp light}}$

The fire-fly curves have now been compared against a standard source and their maxima are entirely different. It is of interest to note that the glow worm (larva of the *Photuris pennsylvanica*) has its maximum at practically the same place as has the adult insect. In these curves the various circles (o, ó, ô), etc., indicate that the resultant curve is the composite of numerous "density" curves. (See fig. 23.) The photographic

plate is very sensitive in the region of $.59\mu$, and it is difficult to eliminate this effect in the fire-fly curves. The hump in the curve of the light from the glow worm and of *Photinus consanguineus* at $.59\mu$ is, therefore, not considered of real significance. The curves of these two samples were obtained from the photographs taken with the small spectrograph.

Knowing the distribution of energy in the spectrum of the glow lamp, given in fig. 26, it is possible to determine the spectral energy distribution

FIG. 26.—Spectral energy curves of fire-flies and glow lamp.

of the fire-fly by multiplying the energy values of the glow lamp by the ratio of densities, $\frac{\text{fire-fly light}}{\text{glow lamp light}}$ at each wave length. The resultant curves are given in figs. 26 and 27. In fig. 26 the spectral energy curve of the *Photuris pennsylvanica* and of the *Photinus pyralis* are plotted to the same scale in the blue-green. An integration of these two curves shows that for the same emissivity in the blue the energy curve of the *Photinus pyralis* is 2.83 times that of the *pennsylvanica*. To the eye it is apparent that the illuminating power of the *Photinus* is far greater than that of the *Photuris*.

The results of the study of the candle-power, radiation and temperature measurements will be described at some future time, and it will be

FIG. 27.—Spectral energy curves of fire-fly and glow worm.

sufficient to add that in a healthy fire-fly the abdominal segments containing the photogenic organ are at a higher temperature than the dark segments, whether or not the flashing is in progress.

In conclusion, it may be added that for the first time we have substantial evidence that the colour of the light of various fire-flies is different; the maximum emission of the

Pyrophorus noctilucus being at 538μ .
Photuris pennsylvanica " " 552μ .
Photinus pyralis " " 567μ .
Photinus consanguineus " " 578μ .

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