REFLECTION OF ULTRAVIOLET LIGHT FROM THE WING SURFACE OF THE CABBAGE BUTTERFLY, *PIERIS RAPAE CRUCIVORA* BOISDUVAL (LEPIDOPTERA : PIERIDAE)

By

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INTRODUCTION

As is well known, there is sexual difference in coloration of wings of butterflies. The difference is resulted from structure or quality and quantity of pigments of wing scale.

Regarding the wings of the Pierid butterflies, the sexual difference in optical property was found by several authors (LUTZ 1933, MAKINO, *et al.* 1952, MAZOKHIN-PORSHNIAKOV 1957, OBARA and HIDAKA 1968, 1970). Further it was reported that the difference played the most important role in the release of courtship activity of *Pieris rapae crucivora* (OBARA and HIDAKA 1964, 1968, 1970).

The optical property of the wing surface is generally measured by LUTZ's photographic method, in which the wing casted with ultraviolet light passing through UV-filter is photographed, whereas there is another method to research it using spectroscopy.

The optical property obtained by the above methods was measured only by the perpendicular direction to the wing surface.

In the present paper, an account is given of the results on the reflection of ultraviolet ray measured from various angles to the wing surface in *Pieris rapae crucivora.*

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MATERIALS AND METHODS

The fresh males and females of *Pieris rapae crucivora* collected from field in 1973 were used for the materials.

Each of their wings fixed on a black paper was casted by the ultraviolet light having the main wavelength of 354mμ and the light reflection was measured from various angles by Goniophotometer (G-P meter) as seen in the previous papers (TAKIZAWA and KOYAMA 1969, 1970, 1972). The filter used for making ultraviolet light was UV-DIA (Toshiba-type) and the photomultiplier tube set on the photoreceptor was R212 (Hamamatsu Television).

The reflection intensity of the wing was measured from each reflex angle (ϕ_r) from 0° to 80° with 5° interval after keeping incident angle (ϕ_i) as 45°.

A value of reflection coefficient (%) was calculated by the ratio between the reflection intensities of the wing and of the standard plate (paraglass).

RESULTS

A. REFLECTION INTENSITY

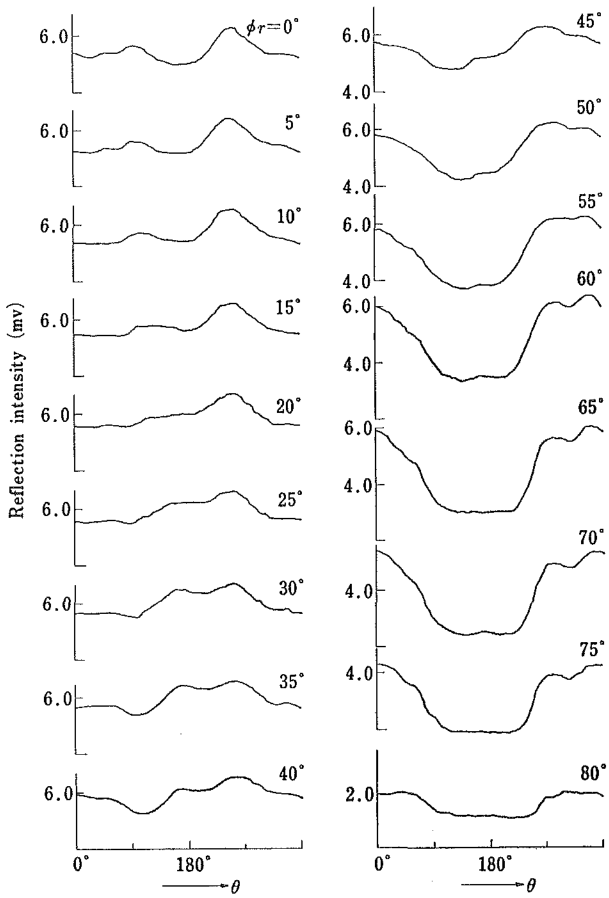

Fig. 1 Reflection intensity from upper side of fore-wing in female
ϕr : Reflex angle, θ: Rotation angle of sample stage These abbreviations are used in the following figures.

1. Upper side of fore-wing

In the female (Fig. 1), the maximum value of the reflection intensity is as large as 6.4~6.7mv at $\phi_r=0°\sim20°$, though the value decreases gradually as ϕ_r becomes larger and finally reaches 2.0mv at $\phi_r=80°$.

As the wing rotated horizontally, two peaks appear at $\theta=90°$, 270° in the reflection intensity curves (I-θ curves) when $\phi_r=0°\sim15°$. The peak at $\theta=90°$, however, disappears with increasing of ϕ_r, and later makes a large trough from $\phi_r=45°$ to 80°.

Such a feature seems to be caused by some surface structure of the wing, because I-θ curve should be straight, if the wing surface would be entirely flat.

In the male (Fig. 2-A), the reflection intensity (0.48 mv) is highest at $\phi_r=0°\sim5°$ in the male wing, and shows almost a constant value of 0.35~0.44

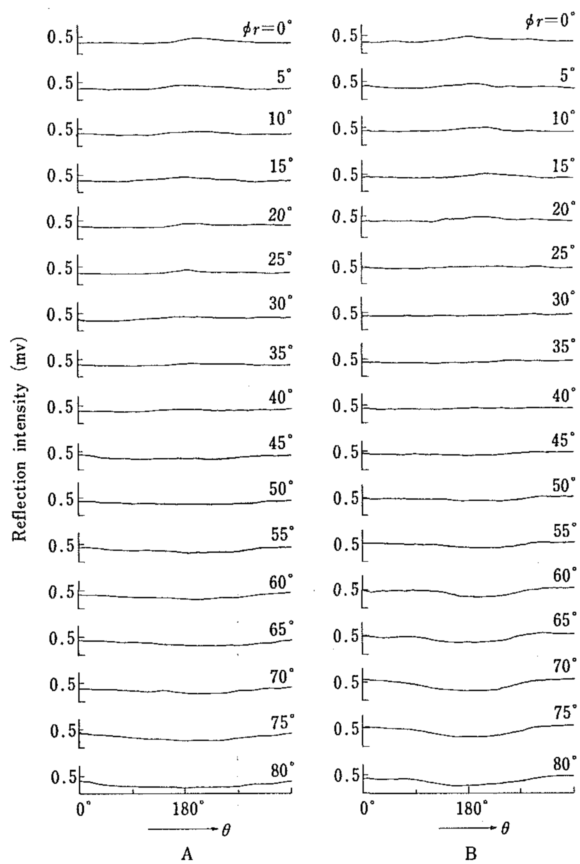

Fig. 2 Reflection intensity from upper (A) and under (B) sides of fore-wing in male

mv at $\phi_r=10°\sim75°$.

The minimum intensity is almost a constant value of 0.28mv with exception at $\phi_r=80°$, when it falls into 0.14mv.

The maximum and the minimum intensities are greatly smaller in the male than in the female.

The peak observed in I-θ curve in the female is difficult to detect in the male.

2. Under side of fore-wing

In the female (Fig. 3), the maximum intensity shows the highest value of 5.1mv at $\phi_r=25°$, from which the value decreases gradually till $\phi_r=70°$, and at last reaches 2.5mv at $\phi_r=80°$. The minimum value changes from 3.6 mv to 1.2mv as ϕ_r becomes larger. The maximum and the minimum values

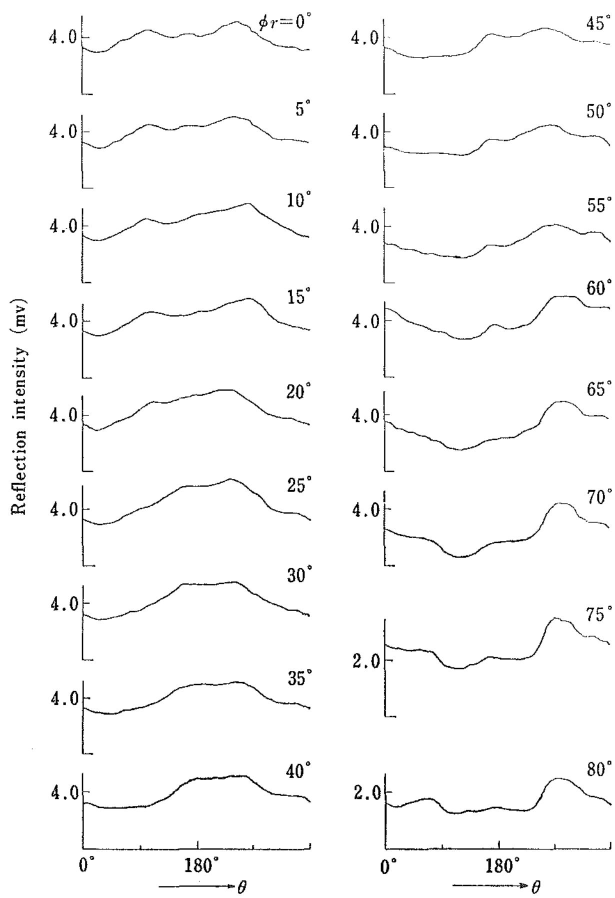

Fig. 3 Reflection intensity from under side of fore-wing in female

are remarkably smaller than those of the upper side of the wing (Fig. 1).

The changing phase of I-θ curve takes almost the same tendency as in the upper side of the wing, excepting that troughs seen from $\phi_r=65°\sim80°$ when $\theta=90°\cdot270°$ are fainter than those of the upper side of the wing.

In the male (Fig. 2–B), the maximum value of the intensity keeps almost a constant range of 0.6~0.8mv. It is a little larger than that in the upper side of the fore-wing, although it is significantly small as compared with that in the under side of the female wing (Fig. 3). The minimum value takes an invariable range of 0.4mv at $\phi_r=0°\sim55°$, reducing gradually from $\phi_r=60°$ and falls into 0.22mv at $\phi_r=80°$.

As is apparent in Fig. 2–B, I-θ curve taking a flattened shape differs very much from that in the female which has a distinct peak.

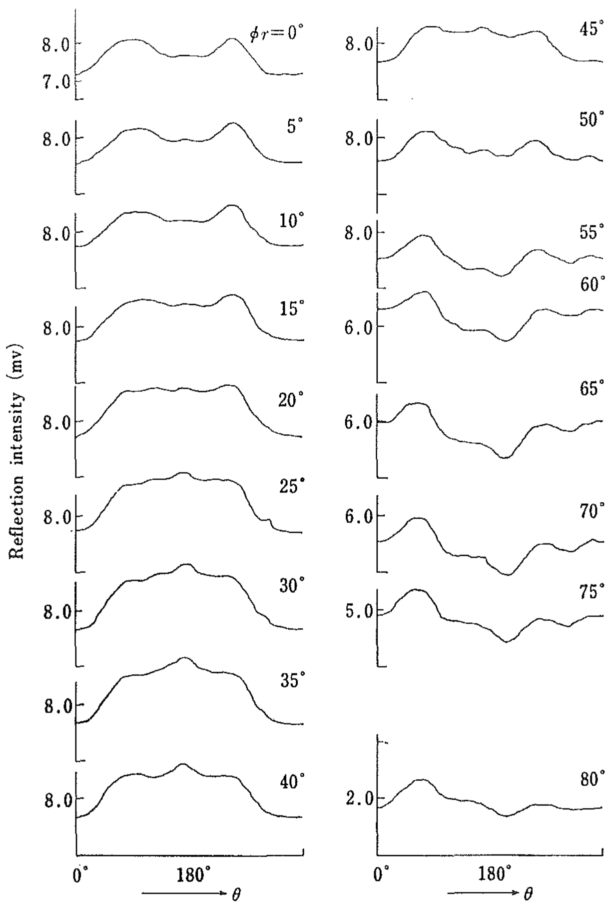

Fig. 4 Reflection intensity from upper side of hind-wing in female

3. Upper side of hind-wing

In the female (Fig. 4), the highest intensity is 9.7mv at $\phi_r=30°\cdot35°$, but takes a decreasing tendency from $\phi_r=40°$ and falls into the lowest value of 0.2mv at $\phi_r=80°$.

The lowest intensity ranges 6.8~7.5mv at $\phi_r=0°\sim15°$, though it becomes smaller as ϕ_r increases and finally reaches 1.4mv when $\phi_r=80°$.

A changing phase of I-θ curve shows almost the same as that in the fore-wing, though it is slightly different at $\phi_r=25°\sim45°$ in having one peak at $\theta=180°$.

In the male (Fig. 5-A), the largest and smallest values of the reflection intensity are higher to some extent than those of the upper surface in the fore-wing (Fig. 2-A). The largest intensity ranges 0.56~0.64mv when $\phi_r=0°\sim45°$, and takes a value of 0.20~0.56mv when $\phi_r=50°\sim80°$. The smallest

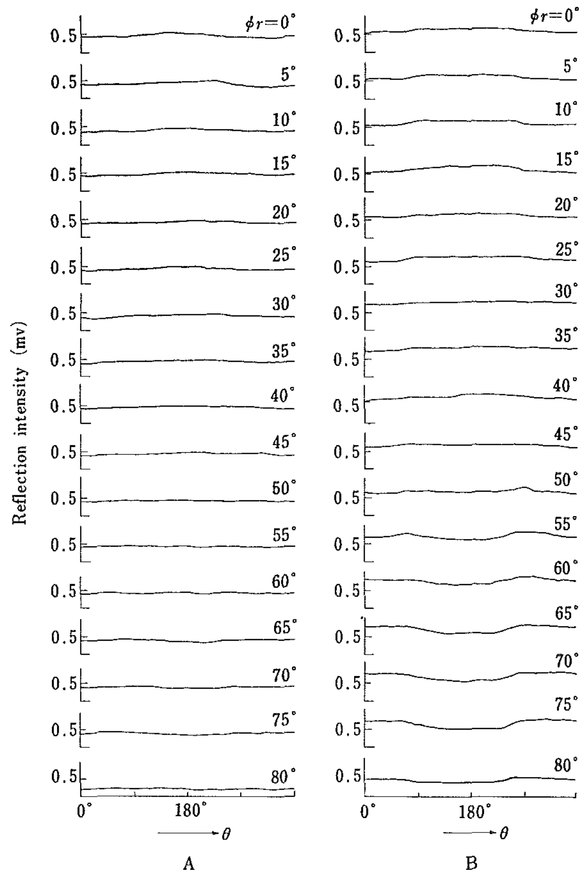

Fig. 5 Reflection intensity from upper (A) and under (B) sides of hind-wing in male

intensity is as large as 0.34~0.44mv at $\phi_r=0°\sim55°$ and later gradually becomes smaller to fall into 0.12mv at $\phi_r=80°$.

The changing feature of I-θ curve resembles that in the upper surface of the fore-wing.

4. Under side of hind-wing

In the female the maximum intensity is highest (9.3mv) at $\phi_r=25°\cdot30°$, and later becomes smaller as ϕ_r increases and at last reaches 2.9mv at $\phi_r=80°$ (Fig. 6).

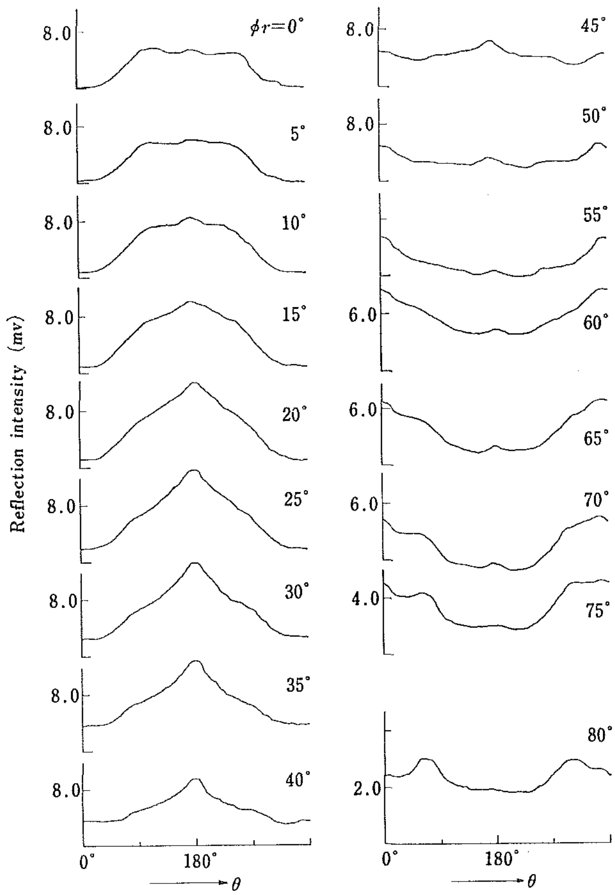

Fig. 6 Reflection intensity from under side of hind-wing in female

The minimum intensity ranges 6.0~6.7mv at $\phi_r=0°\sim45°$, and reduces gradually from $\phi_r=50°$ to fall into 1.8mv at $\phi_r=80°$.

Each single peak which appears at $\theta=180°$ from $\phi_r=10°$ to 40° in I-θ

curve is produced more remarkably than that of the upper surface (Fig. 4).

In the male (Fig. 5–B), the intensity is largest (about 1.0mv) at $\phi_r=55°$ when $\theta=270°$, though each I-θ curve is so much flattened. Further the minimum intensity keeps almost a constant value of about 0.7mv from $\phi_r=0°$ to $55°$. It decreases as ϕ_r increases and reaches 0.27mv when $\phi_r=80°$.

The changing feature of I-θ curve bears a close resemblance to that of the under surface of the fore-wing (Fig. 2–B).

B. REFLECTION INDEX

1. Upper side of fore-wing

In the female, a relationship between the reflex coefficient (Rc) and the reflex angle is illustrated in Fig. 7.

The value of Rc is 45% at $\phi_r=0°$ and reaches the highest value (about 50%) at $\phi_r=25°$, from which it decreases gradually with increment of ϕ_r,

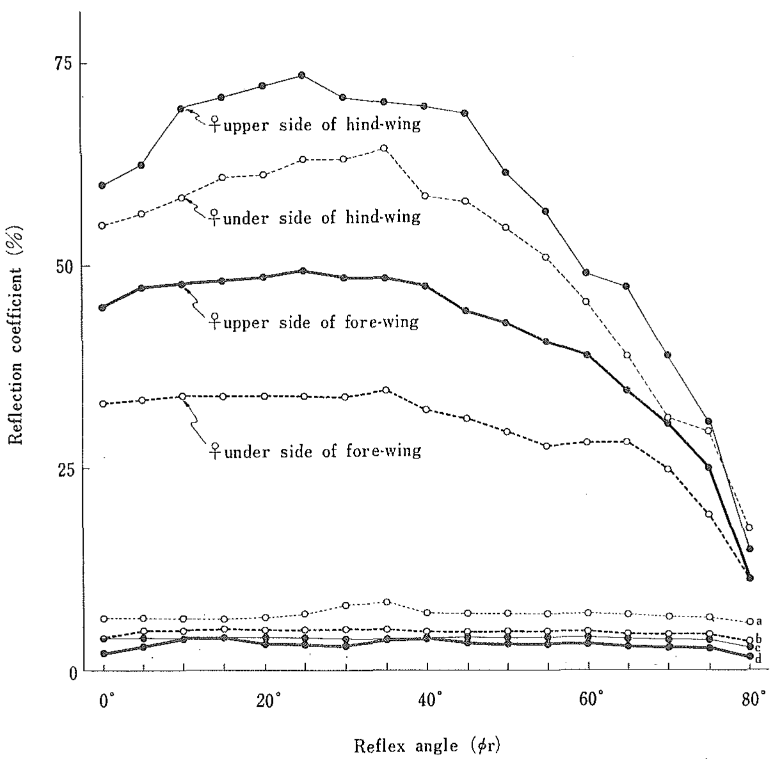

Fig. 7 Reflection coefficient at each reflex angle in wings
a~d: Male, a : Under side of hind-wing, b : Under side of fore-wing
c : Upper side of hind-wing, d : Upper side of fore-wing.

falling into the lowest value (11.5%) at $\phi_r=80°$.

In the male, Rc curve seems to be almost straight. The average value of Rc is about 3.5%.

2. Under side of fore-wing

In the female, Rc value is 33% at $\phi_r=0°$, persisting a constant value (34%) when $\phi_r=10°\sim30°$ and it takes the highest (35%) when $\phi_r=35°$ (Fig. 7).

The value reduces gradually from $\phi_r=40°$ toward 80°, reaching 11.5% when $\phi_r=80°$, which is equal to that of the upper side. Roughly estimated, each value of Rc is smaller 10∼15% than that of the upper side, respectively.

In the male, Rc keeps almost a constant value of 5% regardless of the reflex angles. Each value is slightly large as compared with that of the upper surface (Fig. 7).

3. Upper side of hind-wing

In the female, the value of Rc is 60% at $\phi_r=0°$, increasing as ϕ_r becomes larger and takes the maximum value (74%) at $\phi_r=25°$ (Fig. 7), from which it traces a decrement curve. Finally, the value falls into the minimum when $\phi_r=80°$.

The highest value is greater 25% than that of the upper surface of the fore-wing.

In the male, Rc forms almost a straight line, keeping an average value of 4%, which is imperceptibly larger than that (3.5%) of the upper surface of the fore-wing (Fig. 7).

4. Under side of hind-wing

In the female, the maximum value of Rc (about 65%) occurs at $\phi_r=35\%$. It is larger than that of the under side of the fore-wing (Fig. 7). The highest value stands at the same ϕ_r (35°) as in the under side of the fore-wing.

In the male, Rc curve is almost straight, but a faint peak is seen at $\phi_r=30°\cdot35°$, differing from the other Rc curves in the male. The value of Rc (about 7.5%) is maintained with constancy, which is largest among the other Rc values in the male wings.

CONSIDERATION

As well known, the ground color of wings of the Pierid butterflies is recognized as white by human eyes. According to photographs taken by ultraviolet light, however, it has been confirmed that the wings of the female look whitish coloration caused by strong reflection of ultraviolet ray, while those of the male takes blackish coloration caused by absorption of the ray (LUTZ, 1933). In addition, MAKINO *et al.* (1952) have been concluded that the mechanism of this phenomenon is due to the difference of pterin content between the male and the female wings by a chemical analysis of the wings of *P. rapae crucivora.*

In the light of the results obtained from the present study, both the reflection intensity and the reflection coefficient (Rc) of ultraviolet light are significantly larger in the female wings than in the male wings. In the female wings, however, the both values show a great difference in the upper and the under surfaces. In the male wings such a difference is difficult to see, except for the under surface of the hind-wing. The fact is coincided with the results obtained by OBARA and HIDAKA (1968, 1970). They reported that the male and the female wings of *P. rapae crucivora* were distinctly different with each other as regards the near-ultraviolet light (maximum transmission around 360mμ) and the sexual difference of optical property was significant on the mating behavior.

As shown in Fig. 7, the position of the peak of Rc curve in the female wings differs between the upper surface and the under surface; it appears at $\phi_r=35°$ in the former, while at $\phi_r=25°$ in the latter. This fact may be arisen by some structural difference between the upper surface and the under surface of the wing. Why Rc curves appear to be straight in the male wings while moutain-like shaped in the female wings remains to be unsolved in the present study, though the authors presume that it depends upon the optical property of substance contained in the wing.

The result, however, that in the male Rc value is highest with a faint peak in the under side of the hind-wing (Fig. 7) seems to accept OBARA and HIDAKA's proof (1968, 1970), in which only the under side has a weak reflection property (5%) to the short wave from 300 to 400mμ. Further the fact that Rc value falls into the minimum (ca. 13%) when $\phi_r=80°$ in the both sides of the female wing suggests to have some relation to the mate-refusal posture of the female in *P. rapae crucivora* (OBARA, 1964).

As above-mentioned the reflection property of the wings in *P. rapae crucivora*, especially in the female, is different according to the reflex angle (ϕ_r) of light.

The angle, therefore, when the male approaches to the female, will provide an important meaning to the mating behavior of *P. rapae crucivora.*

From such a point of view, ecological observation will be requested for analysis of the courtship behavior of the butterfly.

SUMMARY

In the present paper, an account is given of the results on the light reflection from the wings of the cabbage butterfly, *Pieris rapae crucivora* Boisduval. Ultraviolet ray (max. transmission around 354mμ) was used for the experiment. The light reflections coming from various angles of the wings were measured by Goniophotometer.

1. The reflection intensity in the female wings increased from the reflex angle (ϕ_r) 0° to 35°, and decreased gradually as ϕ_r became larger.

In the male wings, however, it took almost a constant value (0.5mv) regardless of ϕ_r, though the largest value (0.7mv) was recorded from the under surface of the hind-wing.

2. In the female wings, the reflection intensity curve (I-θ curve) had two peaks at the rotation angles (θ) 90°・270° when $\phi_r=0°\sim15°$. The first peak seen at $\theta=90°$ disappeared with increasing of ϕ_r, and there a large trough was formed from $\phi_r=45°$ to 80°. The trough formation was most remarkable in the upper and the under sides of the fore-wing.

3. In the female a changing phase of I-θ curve in the upper and the under sides of the hind-wing showed nearly the same as that in the fore-wing, whereas it is slightly different from the fore-wing at $\phi_r=25°\sim45°$ in having one peak at $\theta=180°$.

4. In the male each I-θ curve took a flattened shape differing far from that in the female.

5. The reflection coefficient (Rc) calculated from the reflection intensity showed a great difference between the female and the male wings. It was largest in the upper side of the hind-wing in the female.

6. Rc value could be arranged orderly such as ♀ hind-wing> ♀ fore-wing>♂ hind-wing>♂ fore-wing.

Such a difference is believed to facilitate the meeting of individuals of the opposite sex.

7. Rc curve was greatly different between the female and the male wings. In the former it took a mountain-like shape, on the contrary almost a straight in the latter.

8. The peak of Rc curve appeared at $\phi_r=35°$ in the upper surface and at $\phi_r=25°$ in the under surface of the female wing. The difference seems to be dependent upon the optical property of substance contained in the wing.

9. As above-mentioned the light reflection from the wings differs significantly according to the reflection angle of light. Ecological observation, therefore, from such a point of view, will be requested for analysis of the

mating behavior of the butterfly.

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