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Studies on Diapause in *Actias* Moths (Lepidoptera, Saturniidae)  
V. Photoperiod and Thermoperiod as Time Cues  
for Adult Eclosion

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**Abstract** In *Actias artemis* BREMER et GREY photoperiod and thermoperiod provided time cues for adult eclosion. There was, however, a difference in the timing of adult eclosion between the summer and the overwintered generations. In the former, most individuals emerged without any clear peak during several hours before lights-off or temperature drop, but in the latter, the emergences were concentrated within a few hours. The transmission of light through the unpigmented "window" and the adjacent pigmented parts of the cuticle were effective in timing the adult eclosion in both generations, but the overwintered pupae were more sensitive to a low intensity of light than the summer ones.

**Introduction**

Termination of diapause in the pupae of *Actias* moths (*Actias artemis* and *Actias gnoma*) is controlled by photoperiod, and light through the unpigmented portion of the facial cuticle "window" is highly effective (MIYATA, 1974).

The present work has been carried out to examine the significance of light and temperature as time cues for emergence rhythms and the light transmission through the window and adjacent pigmented area of cuticle.

**Materials and Methods**

All experiments were performed on pupae of *Actias artemis* BREMER et GREY. Adult moths were collected in late June in Kanagawa Pref., Japan. The offspring larvae were reared on cherry leaves in short (12L 12D) or long (16L 8D) photoperiods at natural air temperature.

After pupation, the diapausing (winter) pupae were chilled for 100 days and then transferred to chambers under controlled conditions of temperature and photoperiod. The non-diapausing (summer) ones were immediately kept in the environmental chambers.

Thermoperiodic treatments were made by removing the plastic case containing pupae from one chamber to another with a different temperature.

Adult emergence was observed at 30 minutes intervals and the number of emergence recorded.

## Results

### 1. *The influence of light on adult eclosion*

Both summer and winter pupae were subjected to a photoperiod of 16 hr light and 8 hr dark (16L 8D) at 25°C.

In non-diapausing (summer) pupae, adult eclosion was observed from 9 hours before to 1 hour after the lights-off (Fig. 1 a). In winter pupae after chilling, it was 9–6 hours before the lights-off (Fig. 1 b).

Clearly, the lights-off or the lights-on stimulus is a factor determining the time

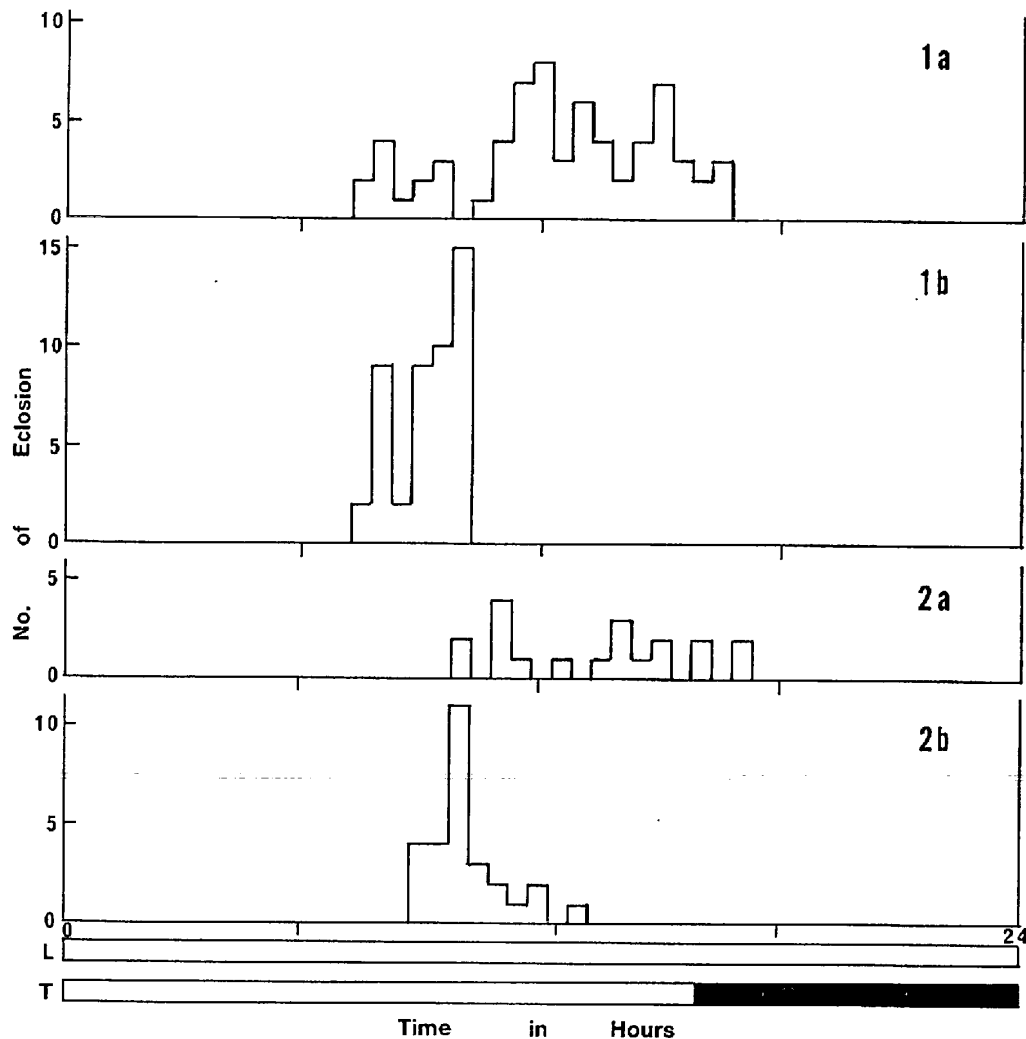


Fig. 1. Temporal patterns of adult eclosion of *Actias artemis* in the summer (non-diapause) (a) and the overwintered (diapause) (b) generations under a 16L 8D photoperiod at 25°C. L: light conditions. T: temperature conditions. Open area shows light (for L) or warm (for T) period, and closed area dark or cool period.

Fig. 2. Patterns of adult eclosion of *Actias artemis* in the summer (a) and the overwintered (b) generations under a thermoperiod of 25°C and 15°C in constant light (1800 lux).

of eclosion.

## 2. *The influence of temperature on adult eclosion*

Both summer and winter pupae were kept in a thermoperiod of 16 hours at 25°C and 8 hours at 15°C in constant light (about 1800 lux).

Eclosion from non-diapausing pupae occurred from 6 hours before to 1 hour after the temperature drop, though the eclosion peak was not obvious (Fig. 2 a). In winter pupae, adults emerged before the temperature drop and the eclosion peak was observed 6 hours before the stimulus (Fig. 2 b).

These results indicate that a thermoperiod exerts a strong gating effect on adult eclosion at least in the winter pupae.

## 3. *Relative importance of temperature and lights-off stimulus*

The interaction between the photoperiodic and thermoperiodic cues was analyzed by combining the two cycles in different phase angles.

First, a temperature drop from 25 to 15°C was coincided with lights-off. Adult eclosion from summer pupae was observed between 10 hours and 1 hour before the lights-off and temperature drop (Fig. 3).

In the next series of experiments, a photoperiod of 16L 8D was combined with a thermoperiod of 16 hr at 25°C and 8 hr at 15°C as before, but the cool phase began 12 hr before the lights-off. Summer pupae eclosed before the temperature drop and again before the lights-off (Fig. 4 a). Chilled winter pupae also gave, (Fig. 4 b), two clear peaks of eclosion — the first peak 4 hours after the temperature drop and the second peak 7 hours after the lights-off.

Therefore, not only light but also temperature can provide stimuli to determine the time of eclosion.

## 4. *Influence of covering the 'window'*

When non-diapausing pupae was constantly kept in darkness at 25°C, adult eclosion occurred rather at random (Fig. 5). The absence of time cue thus lead to arrhythmicity of adult emergence.

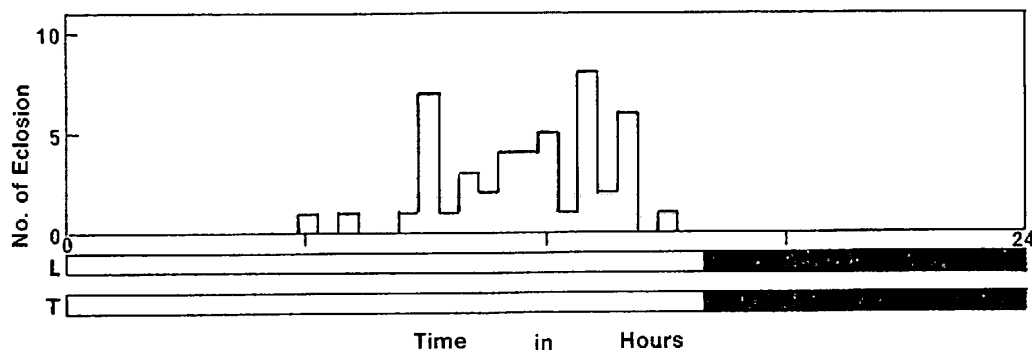


Fig. 3. Adult eclosion of *Actias artemis* in the summer generations under a photoperiod of 16L 8D combined with a thermoperiod of 25°C and 15°C.

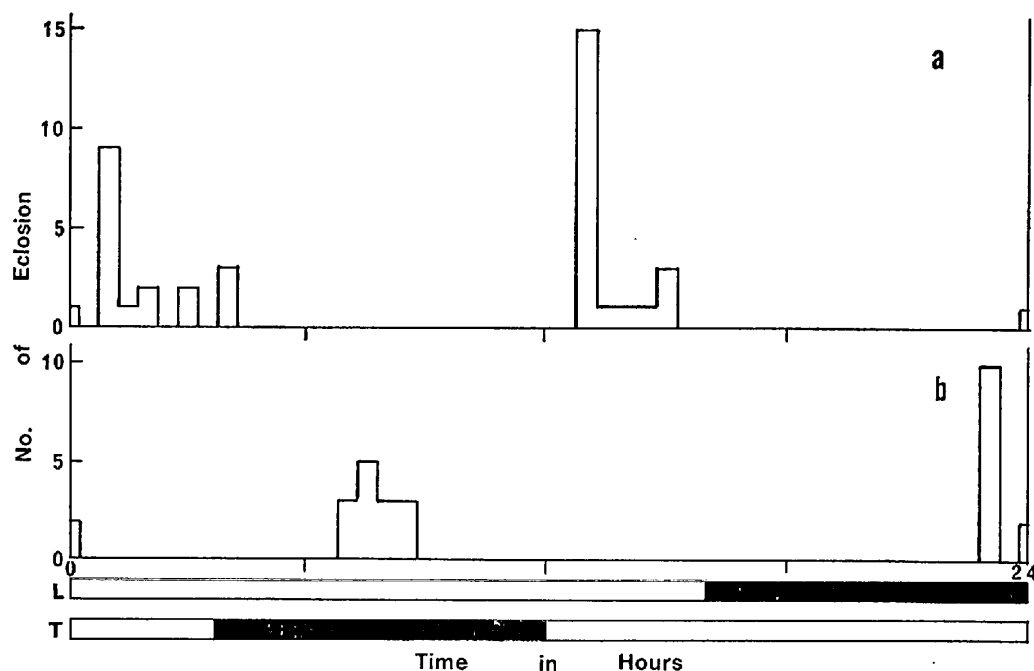


Fig. 4. Adult eclosion of *Actias artemis* in the summer (a) and the overwintered (b) generations under a 16L 8D photoperiod coupled with a thermoperiod of 25°C and 15°C. The cryophase covered hrs 4 to 12 of the photophase.

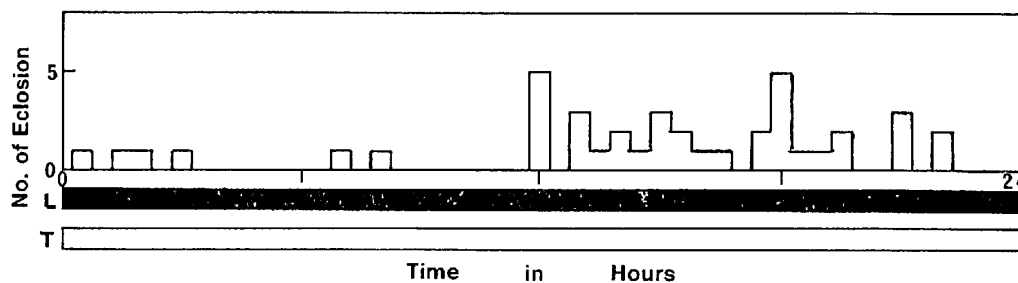


Fig. 5. Adult eclosion of *Actias artemis* in the summer generation under continuous darkness at 25°C.

To assess the light sensitivity of the brain of pupae in timing the adult eclosion, pupae were subjected to conditions mentioned below.

Non-diapause summer pupae were allotted to groups 1 a-1 e and diapause winter pupae to groups 2 a-2 e. Groups 1 a and 2 a were exposed to 16L 8D with 1 lux illumination in the photophase and the facial window was not covered. Groups 1 b and 2 b were exposed to the same photoperiod with 1800 lux and the facial window was painted black. Groups 1 c and 2 c were treated in the same way except that the photophase was provided by 1 lux. Groups 1 d and 2 d received black paint covering the whole facial cuticle (including window) and the groups 1 e and

2 e black paint extending over wings (including the window and facial cuticle). They were exposed to 16L 8D with 1800 lux.

In group 1 a (Fig. 6 a), the adult-eclosion timing was similar to that with 1800 lux photophase (Fig. 1 a) except a few that emerged 11 hours before the lights-off. In group 1 b (Fig. 6 b), a number of individuals emerged in the scotophase and a few in the photophase. They were less synchronized than in group 1 a. In group 1 c (Fig. 6 c), the adult eclosion was more random than in group 1 b. This was the case also in group 1 d (Fig. 6 d) or 1 e (Fig. 6 e) and the eclosion pattern was more or less similar to that in continuous darkness (Fig. 5).

Adults eclosed in group 2 a (Fig. 7 a) 6–8 hours, in group 2 b (Fig. 7 b) 10–6 hours, and in group 2 c (Fig. 7 c) 9–4 hours, before the lights-off. They were well synchronized. In group 2 d (Fig. 7 d) and 2 e (Fig. 7 e), the adults eclosed in the photophase but less synchronized than in groups 2 a, 2 b or 2 c.

### Discussion

In the emergence rhythm of *Hyphantria cunea*, both temperature and light stimuli were effective as time cues (HIRAI 1969, 1972). The present experiments show that adult eclosion of the *Actias* moths is similarly timed by these two stimuli. There is, however, a difference in the response to the stimuli between the summer and winter pupae, and the timing of eclosion in response to the stimuli is more precise in the latter than in the former.

This difference may be related to bird predation and temperature drop in the field. In spring, the pupae after hibernation emerge as adults early in the afternoon before the evening drop of temperature. In summer, the non-diapause pupae emerge over a longer period of time including dusk when the air temperature is still high enough for activity and the predation by birds decreases.

As stated in a previous paper (MIYATA 1974), the unpigmented facial cuticle “window” of the *Actias* pupae enhances the transmission of light in photoperiodic termination of diapause. The present study has shown further that the facial window is effective in the photoperiodic signalling for eclosion, especially when pupae can receive only feeble light. At least in the non-diapausing pupae, the transparent facial cuticle is “the safe device for cocoons in shady situations” as in *Antheraea pernyi* (WILLIAMS, 1969 a).

In the overwintered pupae, covering the facial window with black paint did not appreciably reduce their sensitivity to light even at an intensity as low as 1 lux. This may suggest that light transmitted through pigmented portions around the “window” is more or less effective. In the summer pupae, however, the pigmented cuticle around the window does not seem to be effective in transmission of light. The overwintered pupae are thus more sensitive to a light stimulus than the summer non-diapause pupae. This difference may be regarded as an ecological adaptation. The overwintering pupae are enclosed in thicker cocoons covered with leaf litter

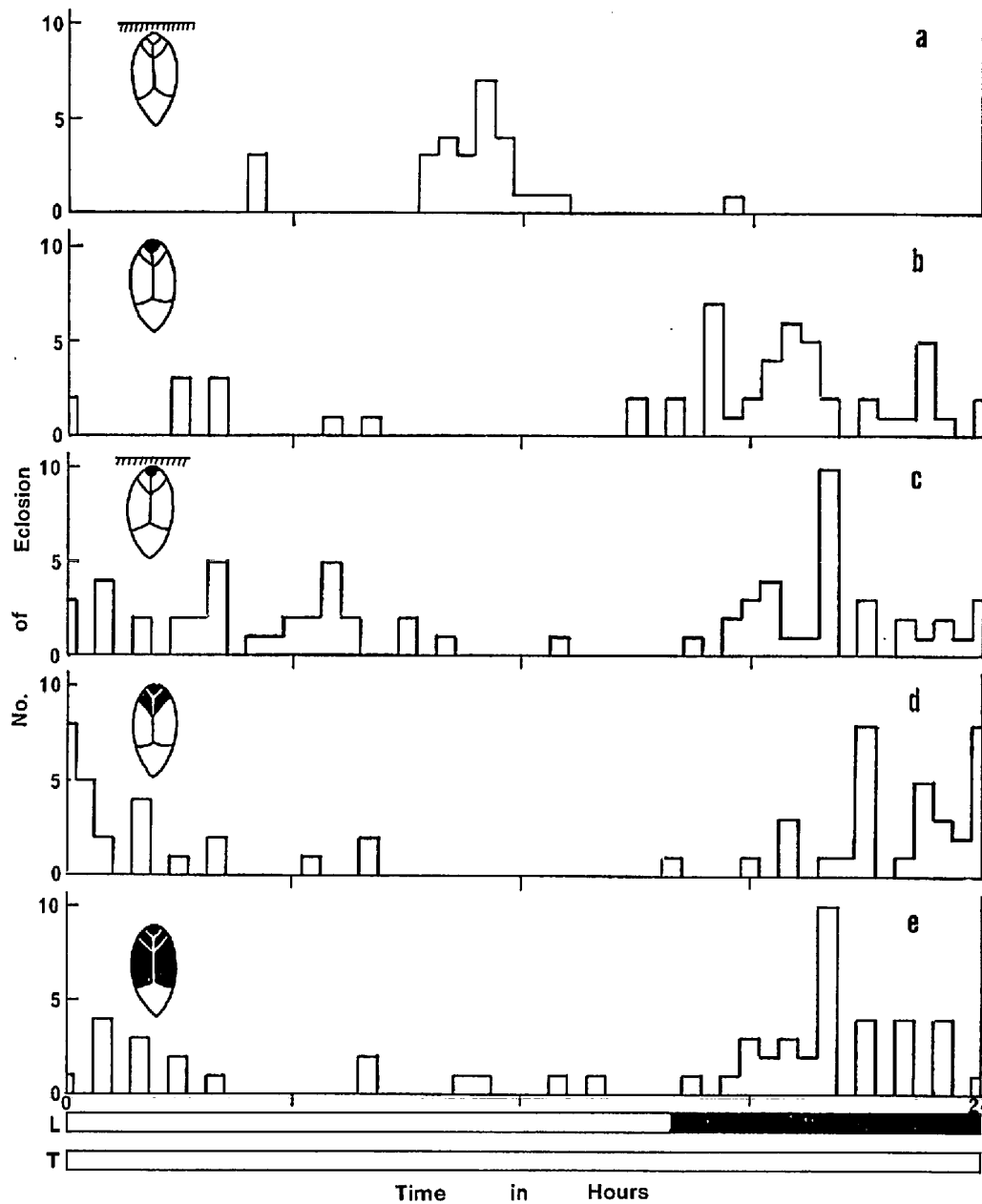


Fig. 6. Effects of covering the facial window with black paint on the timing of adult eclosion of *Actias artemis* in the summer (non-diapause) generation. (a) The facial "window" was exposed with photophase of about 1 lux; (b) the "window" painted black with photophase of about 1800 lux; (c) the same as (b) but with photophase of about 1 lux; (d) the window and adjacent facial cuticle were painted black with photophase of 1800 lux; (e) black-painted area was extended further to cover the wings with photophase of 1800 lux.

on the ground but the summer pupae in thin cocoons wrapped with leaves on twigs.

In *Antheraea pernyi* timing of adult emergence is controlled by light transmitted

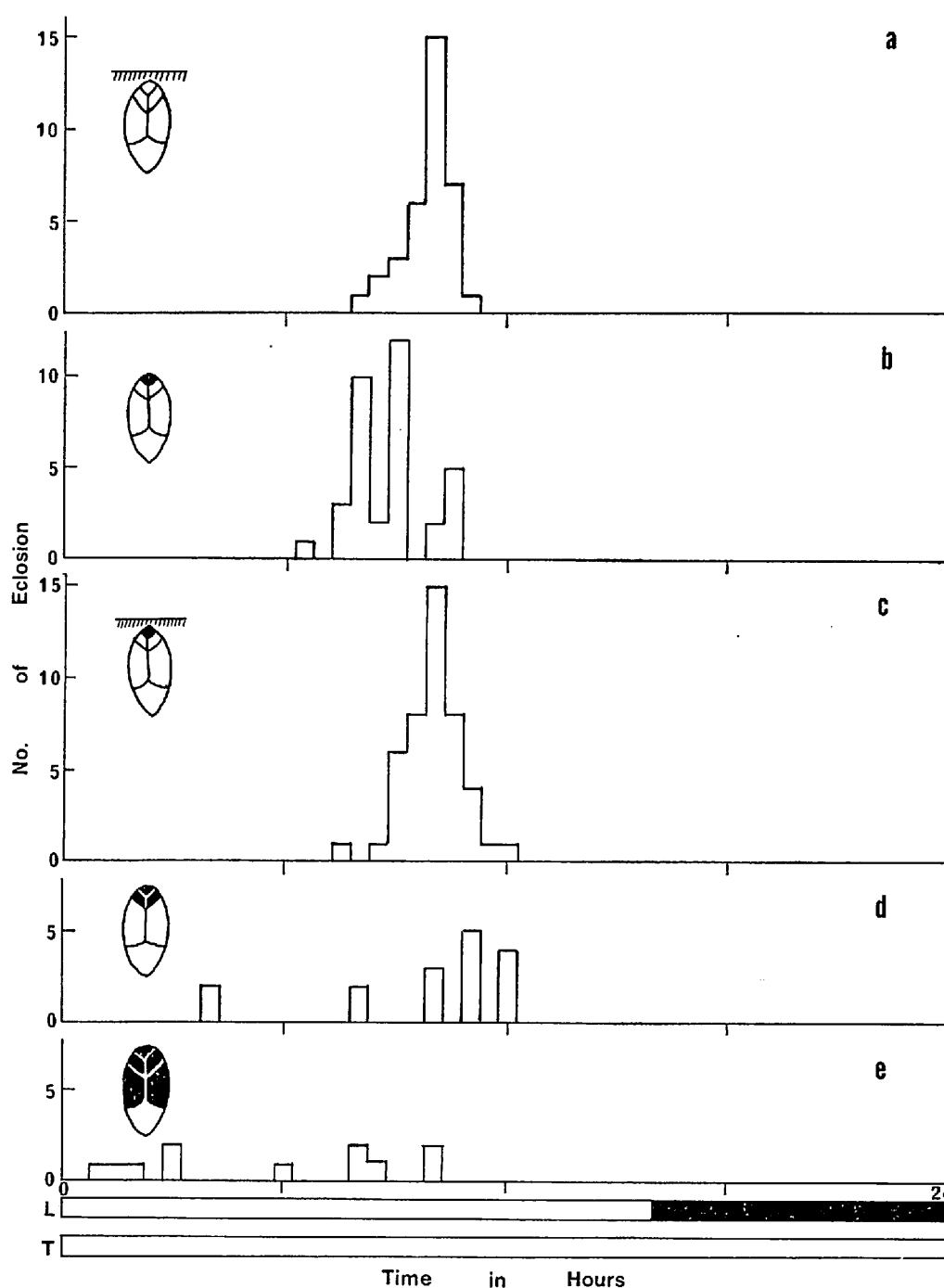


Fig. 7. (a)–(e) show the results of experiments similar to (a)–(e) of Fig. 6, respectively, but with pupae of overwintering generation.

to the pupal brain (TRUMAN & RIDDIFORD, 1970). In the *Actias* pupae also, light transmitted through the window probably acts on the brain controlling the adult emergence. It has not been elucidated, however, whether the summer and winter

pupae are different in the mechanism of time-cue reception or in the response pattern itself.

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