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AN EVAPORATIVE COOLING MECHANISM

IN *PHOLUS ACHEMON* (SPHINGIDAE)

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HEAT PRODUCTION DURING ACTIVITY in moths is well known (Adams and Heath, 1964). These insects are insulated against heat loss by a coat of dense pile (Church, 1960, and therefore, they may experience heat stress during activity in high ambient air temperatures (Heath and Adams, in press). However, some insects evaporate water by increased ventilation when under heat stress (Prosser and Brown, 1961). *Pholus achemon* (Drury) similarly increases the rate of ventilation under heat stress, but has an additional evaporative cooling mechanism.

Observations were made on a single male moth collected near Santa Barbara, California, in the spring of 1962. Although we have not had the opportunity to repeat these observations, the behavior was so striking and consistent as to appear worth reporting.

An iron-constantan thermocouple 0.3 mm. in diameter with long (one meter) and flexible leads was implanted in the thorax. Readings were made on a potentiometer with electronic reference junction, to the nearest ½ °C.

Following implantation the animal was gently prodded. It began beating its wings with low amplitude, a process called shivering (Adams and Heath, 1964) or whirring (Dorsett, 1962). The animal heated at a rate of 7°C. per minute until a thoracic temperature of 39°C. was attained (Fig. 1). The moth then flew briefly, while the temperature rose to 40°. Upon alighting, it sat quietly and cooled. As cooling began a small drop of fluid appeared on the partially extended proboscis (Fig. 2). Rhythmic changes in the drop size indicated that the fluid was being drawn in and out of the mouth.

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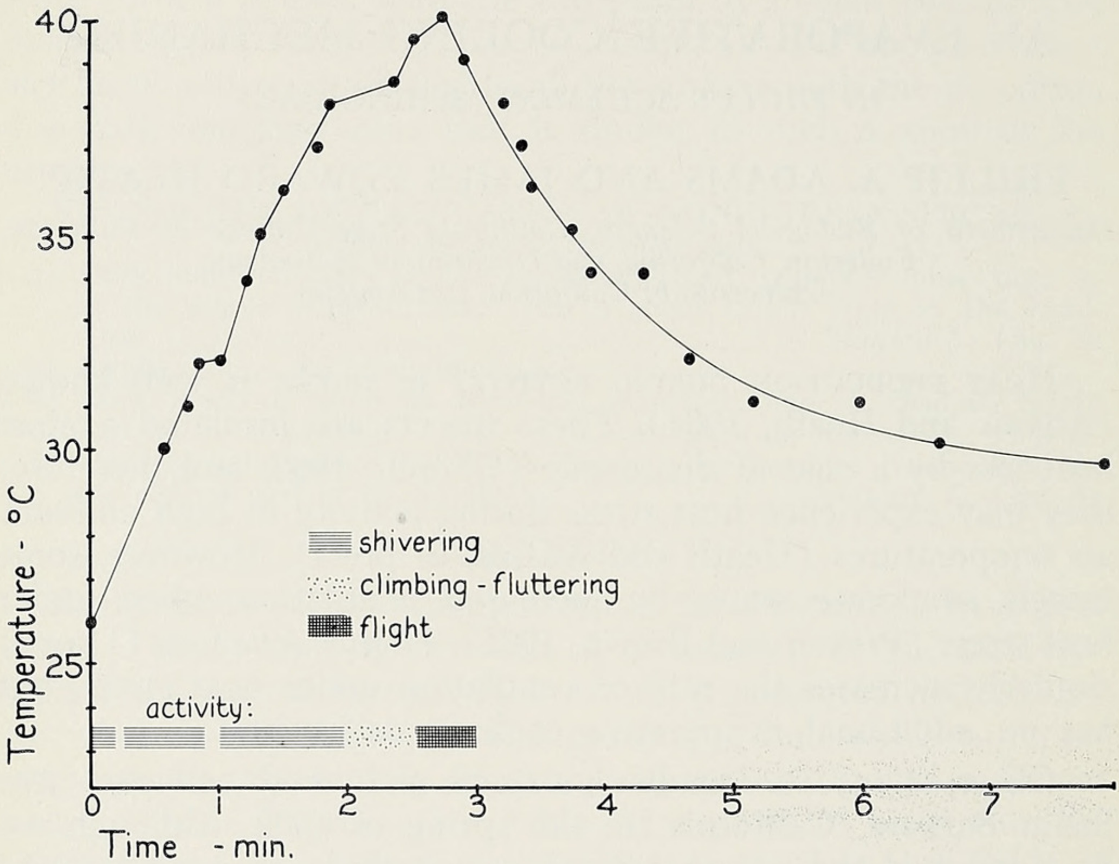

Fig. 1. Changes in thoracic temperature during activity in *Pholus achemon*. Ambient temperature 26°C.

In order to view this event in more detail the moth was heated artificially with an infra-red heat lamp held 30 cm. away. The drop appeared in four successive trials at thoracic temperatures of 40.5°, 41°, 40°, and 42.5°C. The drop size increased as the thoracic temperature rose, reaching a maximum estimated diameter of 3 mm. In each case the drop was withdrawn as cooling began. On the fifth trial no fluid was elicited; rather the animal retreated from the heat source to shade.

Observations on the rate of ventilation showed that vigorous and rapid movements began and continued during the period the temperature was high. A sudden increase in rate occurred at body temperatures of 40°, 41°, 40°, and 42°C. in successive trials, reaching maximum frequencies of 45 - 50 per minute.

Pholus also showed behavioral adjustments to localized radiant heat. At body temperatures above 42°C. the moth markedly changed its posture with respect to the heat lamp. The

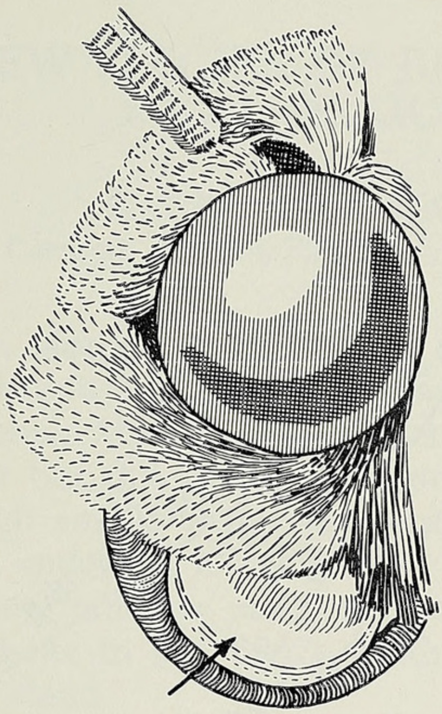

Fig. 2. The head of *Pholus achemon*, showing the location and relative size of the extended drop (arrow).

legs were extended, raising the body above the surface on which it was resting. The antennae were tucked under the wings and the body tilted so that it was shaded by the wings. This behavior was so effective in reducing the rate of heating that it was necessary to move the lamp closer to heat the insect further.

At very high body temperatures the moth moved out of the zone of radiation produced by the heat lamp. This response is called the "maximum voluntary tolerance" in reptiles (Cowles and Bogert, 1944). In six trials this occurred at 40.5°, 41°, 42°, 42°, 42.5°, and 42.5°C. (mean 41.8°C.).

Both pumping of fluid in and out of the mouth and abdominal hyperventilation appear to be effective means of cooling in *Pholus*. Two cooling curves obtained from *Pholus* differ from those of other sphingids, e.g. *Smerinthus* (Figure 3), in that the rate of heat loss is not directly proportional to the thoracic-ambient temperature difference. The cooling curve of *Smerinthus* is predictable from Newton's law of cooling, which states that the rate at which heat is lost to its surroundings by a body is proportional to the difference in temperature between them. Symbolically,

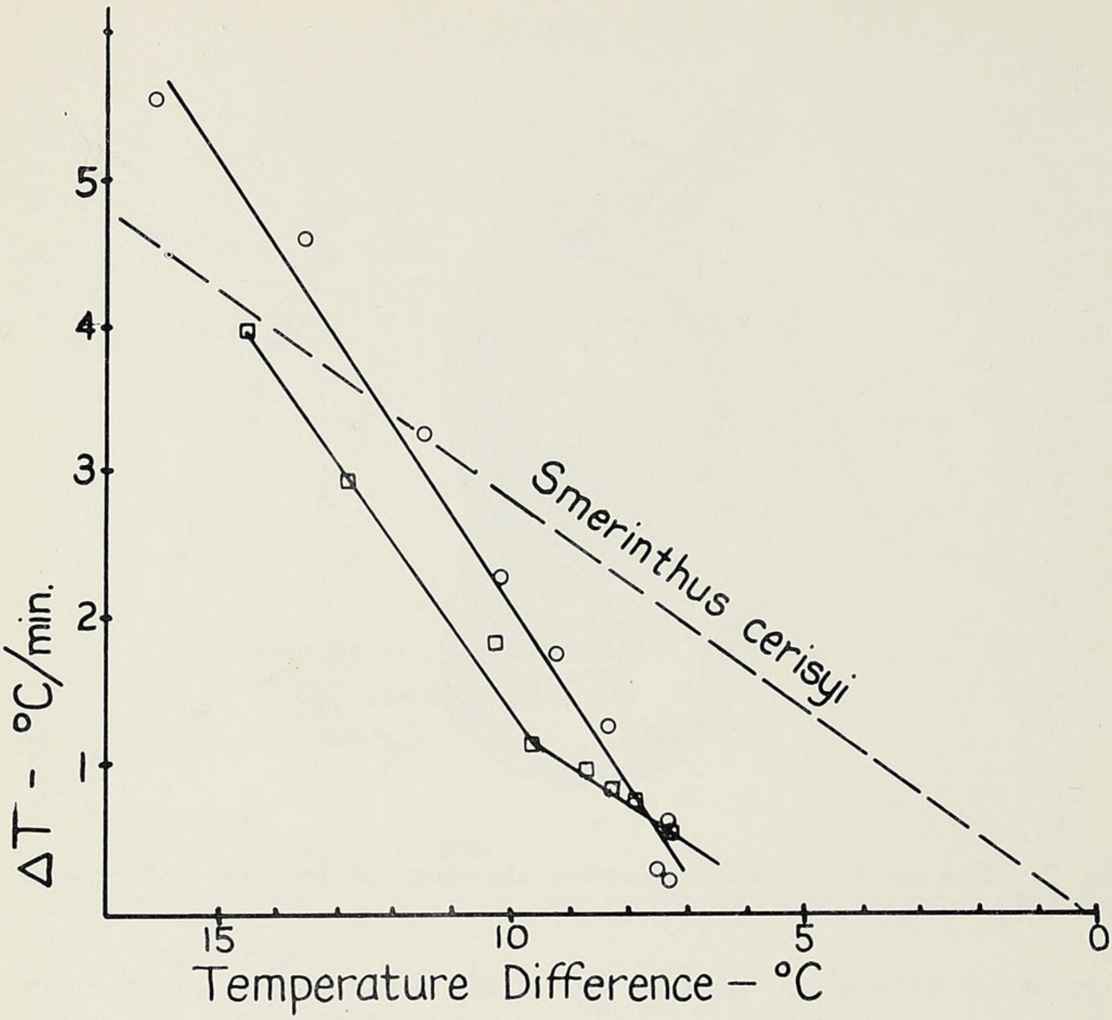

Fig. 3. Two cooling curves of *Pholus achemon*, compared with one of *Smerinthus cerisyi*. Delta T—rate of thoracic cooling; Temperature Difference—between thorax and ambient air.

$$\frac{dH}{dt} = c(t_2 - t_1)$$

where H is heat loss, t_2 the temperature of the hot body, t_1 the temperature of the surroundings, and c a proportionality constant. The higher-than-predicted heat loss in *Pholus* probably results in part from active evaporative cooling.

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