THE INFLUENCE OF STARVATION ON THE THERMAL DEATH-POINT ON INSECTS

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(With Two Text-figures.)

Previous work (Mellanby, 1932) has shown that insects may be killed at temperatures above the normal by various factors. There is no definite "thermal death-point" above which they are killed instantly, and below which they survive in a normal manner. Various factors contribute to the death of insects, and in different circumstances different factors are limiting. If the temperature is above 40° C. the heat is sufficient to kill many species. The actual lethal temperature depends on the length of the exposure, and may also be influenced by atmospheric humidity. Below 40° C., in moist air, the heat is usually the limiting factor, but in dry air insects which cannot conserve the water in their bodies die from desiccation.

Further experiments have shown that starvation is a factor which may influence the thermal death-point. Experiments made with the human body-louse, *Pediculus humanus corporis* de G., and with the mosquito, *Culex fatigans*, illustrate this point, and are here described.

TECHNIQUE.

The apparatus was, in essentials, similar to that used in the previous experiments (Mellanby, 1932). It consisted of a tank of water, which could be controlled at any temperature; into this tank jars of about 500 c.c. capacity were placed, containing 40 c.c. of the appropriate mixture of sulphuric acid and water to keep the air at a definite humidity. The jars, which were totally submerged, had three tubes leading into them. Through one, fresh air (with the correct moisture content) could be blown, and the air which it displaced escaped through another. The insects were introduced through the third tube, which was considerably broader than the others (16 mm. internal diameter).

The insects were placed in special containers which allowed as free contact as possible with the air. For the lice shallow zinc troughs were made, 50 mm. long, 10 mm. broad and 5 mm. deep. The insects were placed inside a trough, which was then covered over with bolting silk, sufficiently fine to prevent newly hatched larvae from escaping. The troughs were introduced into the jars on the ends of glass rods. The mosquitoes were placed in cylindrical cages of phosphor-bronze gauze. The

cages were 50 mm. long and 10 mm. broad, and they also were introduced on the end of glass rods. It was possible to remove the insects from the apparatus whenever required.

EXPERIMENTS WITH *PEDICULUS HUMANUS.*

In the previous paper experiments with adult lice are described. These were found to be able to survive a temperature of 46·5° C. for 1 hour, but were killed by a temperature one degree higher; the humidity of the air did not affect the survival temperature. When exposed for 24 hours they were able to survive 38° C. when the air had a relative humidity of 90 per cent., but they only survived 33° C. in dry air (relative humidity 0 per cent.).

In the experiments described below, larval lice were used within 12 hours of emerging from the egg. In the first series they were allowed to feed before the experiments began. Batches of twenty larvae were used in each experiment. They were exposed for either 1 or 24 hours to different conditions of temperature and humidity, and the limiting conditions determined. They were found to behave exactly as did the adults in the previous experiments. They survived 46·5° C. for a period of 1 hour, and in the 24 hour experiments survived 38° C. in moist air and 33° C. in dry. The results were consistent with one another, and there was only a difference of one degree between the temperature at which twenty lice in a batch survived and the temperature at which they were all killed.

Next, unfed larvae were used. When exposed for 1 hour they were found to be able to survive the same temperature as adults or larvae which had fed. But when they were exposed for periods of 24 hours, quite different results were obtained. The larvae died at lower temperatures, and the thermal death-point was not sharply defined. Fig. 1 is a graphical representation of the results obtained. Each rectangle represents the results obtained under one set of conditions of temperature and humidity. The black portion of the rectangle represents the percentage of the larvae which were killed, and the white portion the percentage which survived. Thus, at 37·6° C., when the relative humidity was 90 per cent., all the larvae were killed, and a black rectangle is shown on the figure. At 34° C. and a relative humidity of 90 per cent., 55 per cent. of the larvae were killed and 45 per cent. survived. The rectangle representing this is blackened over 55 per cent. of its area. Each rectangle represents the sum of the results obtained from a number of different experiments with batches of twenty larvae. As the results were somewhat irregular, it was necessary to use a great number of lice—nearly 2000 were used in all. The dotted line on Fig. 1 shows the highest temperature which similar lice which had fed would survive for 24 hours.

The unfed lice which died in dry air during an exposure of 24 hours' duration to a high temperature dried up, and had obviously been killed by desiccation. But those which died in moist air, at temperatures lower than those fatal to fed larvae, appeared unharmed. They had presumably died from starvation. At high temperatures their rate of metabolism was increased, and their food reserves were insufficient to last them over as long a period as 24 hours. The reason that the results are

irregular, and that the thermal death-point is not sharply defined as it is for fed larvae or adults, is that the individuals started the experiments after a period varying between 0 and 12 hours from the time when they hatched from the egg. Now other experiments have shown that the mean survival time of newly hatched, unfed lice at 30° C. and 90 per cent. relative humidity is 29·6 hours, so a difference in age of 12 hours will make a considerable difference to the survival time of such animals.

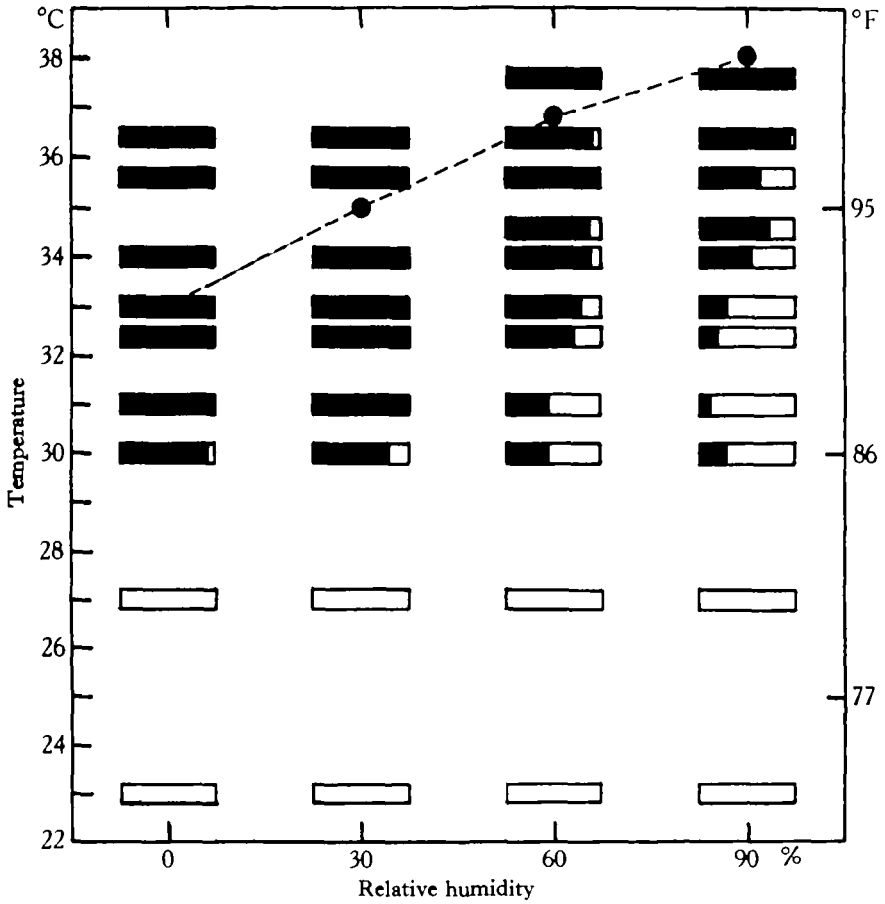

Fig. 1. Results of exposure of larval lice to high temperatures. For explanation see text (p. 49).

It was not found practicable to use larvae which hatched over a shorter period than 12 hours, as that would have meant using smaller batches of individuals, and a great many would have had to be wasted.

EXPERIMENTS WITH *CULEX FATIGANS*.

The *Culex*, which were bred in cages, were caught in glass tubes and blown into the phosphor-bronze containers. This treatment did not injure the mosquitoes, as they survived when kept at room temperature equally well as others which had not

been so treated. The mosquitoes were exposed to the high temperatures in the same way as the lice.

C. fatigans proved to be very susceptible to high temperatures. Newly hatched adults of both sexes, adults fed on water and fruit for several days, and females gorged with blood were able to survive only 39° C. for 1 hour—they were all killed by 40° C. The humidity of the air did not affect the fatal temperature.

Next, adult mosquitoes of both sexes, which had emerged less than 24 hours, were exposed for periods of 24 hours. The results obtained are shown on Fig. 2. The line marked "unfed adults" shows the highest temperature at which *most* of the insects survived. They did not give such regular results in this experiment as they did in the 1 hour experiment, but the line on Fig. 2 represents limiting con-

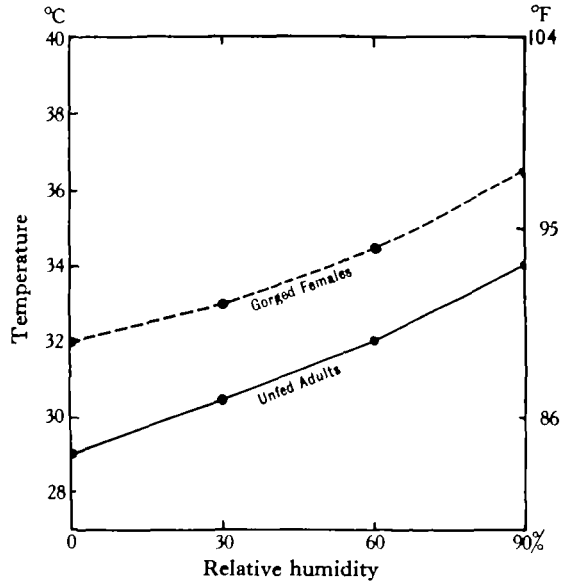

Fig. 2. Results of exposure of adult *Culex fatigans* to high temperatures. The lines represent the limiting conditions under which the insects could survive for 24 hours.

ditions for more than 75 per cent. of the mosquitoes. A very few individuals survived up to a degree above the temperature indicated, and some died at lower temperatures. It was thought that the survival temperatures were so low because the newly emerged adults were not properly hardened. Adults which had been kept several days, feeding on fruit (adults may be kept for weeks in this way) were used next. They gave even more irregular results, but none survived any higher temperatures than did the newly emerged mosquitoes. Many died at lower temperatures, and some in about the same range. This indicates that this species does not become more resistant as time goes on after emerging—in fact it seems to become less resistant.

Next, female *C. fatigans* were allowed to feed on a canary. It was found convenient to use individuals which had emerged a week, as these fed most readily. The females which gorged were used in the experiments. They gave results which

are quite different from those obtained with the other *Culex*. The results are summarised by the curve marked "gorged females" on Fig. 2. These insects were able to survive considerably higher temperatures than the other mosquitoes, and the results were more regular. The curve approximates to that obtained with the lice which had fed on blood. The reason that the *Culex* which have not taken a blood meal cannot survive high temperatures appears to be that they have small food reserves. The following experiment proves this. Some adult mosquitoes which had not gorged with blood were supplied with fruit and water, and kept at 36° C. They survived for several days. Others which were kept at the same temperature with water alone survived for a longer period than mosquitoes kept in air with a 90 per cent. humidity without water, but they were all dead within 36 hours. The humidity of the air did not affect the mosquitoes which had water to drink. Evaporation from the drinking dish will keep the air near to it saturated, so the external humidity will not be that to which the insects are subjected. Water alone is not sufficient to keep the mosquitoes alive for long at high temperatures, though lack of it soon proves fatal. A blood meal is not necessary to increase the females' resistance to high temperatures—any food will suffice. When the females gorge on the canary, they take sufficient blood to last themselves for a long period. They feed more sparingly on fruit, and cannot survive long at high temperatures without repeated feeds.

DISCUSSION.

Insects may be killed by high temperatures both directly and indirectly. One cause of death is the effect of the heat, and another is desiccation—the evaporative power of the air is greater at high than at low temperatures, and this can prove fatal to insects which cannot conserve the water in their bodies. The experiments described in this paper show that a third factor—starvation—may cause the death of insects at high temperatures which would have survived longer periods at lower temperatures. It is well known that the rate of metabolism of insects can be accelerated by raising the temperature, and that death from starvation frequently occurs in a shorter time at high than at low temperatures. It is not usually realised that starvation may affect the thermal death-point. There are several unfavourable conditions influencing the insects in the different experiments, and the limiting factor is not always the same. The lice and the mosquitoes which have fed on blood are subjected to two unfavourable conditions—heat and desiccation. In moist air, the heat was the limiting factor, while in dry air desiccation killed the insects at temperatures considerably below those at which the heat alone would have caused death. The unfed insects had also to contend with starvation. With the newly hatched, unfed lice, starvation proved to be the limiting factor in the 24 hour experiments (see Fig. 1). With the *Culex*, the limiting factor was also starvation, but the absence of drinking water influenced the results. Insects which had no large reserves of food (*i.e.* blood) died at high temperatures from the lack of food and water before they were affected by the heat itself.

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SUMMARY.

Experiments are described in which newly hatched larval lice (*Pediculus humanus corporis*) and adult *C. fatigans* were exposed to high temperatures. The humidity was controlled, and the exposures lasted for either 1 or 24 hours.

Larval lice, whether fed or unfed, withstood 46·5° C. for 1 hour, while the *Culex* were much less resistant—they only withstood a temperature of 39° C. The humidity of the air did not affect these results.

When exposed for 24 hours, larval lice which had fed withstood 38° C. in moist air. They only withstood 33° C. in dry air, as they were killed by desiccation at higher temperatures. Mosquitoes (*C. fatigans*) which had gorged gave similar results. They survived 37° C. for 24 hours in moist air, and only 32° C. in dry.

Unfed lice or mosquitoes behaved differently, as they could not withstand such high temperatures for periods of 24 hours. This was because they had small food reserves, and at high temperatures their rate of metabolism was so increased that they died of starvation.

REFERENCE.

MELLANBY, K. (1932). *Journ. Exp. Biol.* **9**, 222–31.