



## Part II – A Little Background

Water is obviously very important to life. One example of how organisms can utilize water to survive is *evaporative cooling*. Evaporative cooling lowers an organism’s body temperature through the evaporation of water from respiratory or external surfaces. The fastest-moving water molecules (those with the greatest kinetic energy) gain enough energy to leave a surface. This lowers the average kinetic energy of those water molecules left behind, and in turn lowers temperature. Evaporative cooling is particularly important in large animals (organisms with relatively large volumes relative to small surface areas). Additionally, evaporative cooling increases the relative humidity of an environment, due to increasing the level of water vapor present.

### Questions

3. Evaporative cooling, like many biological adaptations, is an emergent property stemming from the basic chemical properties of molecules. Explain some properties of water that allow for evaporative cooling to take place.

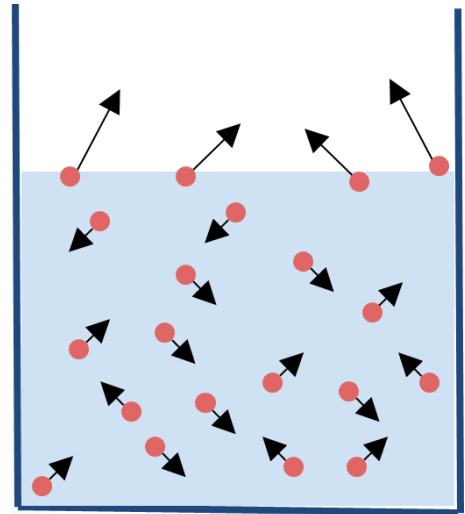


Figure 1. During evaporation, more energetic molecules escape, leaving less energetic molecules behind.

4. Evaporative cooling is a product of evolution that has evolved in some organisms for use under certain environmental conditions. Circle the organisms or conditions below that you think are most likely to use evaporative cooling.

<i>Large body size</i>	<i>Small body size</i>
<i>Terrestrial organisms</i>	<i>Flying organisms</i>
<i>Warm climate</i>	<i>Cool climate</i>
<i>Water sources scarce</i>	<i>Water sources plentiful</i>

## Part III – How Grasshoppers Stay Cool

Unfortunately, Dr. Prange's experiment was rejected. The physiology department had already committed resources to working with specific strains of lab mice; it did not want to risk the chance of contamination with any wild type species. Dr. Prange did not want to give up on his experiment, so he suggested to the physiology department that he use grasshoppers instead. Grasshoppers were readily available, easily bred in captivity, and Dr. Prange saw this as the path of least resistance. The department approved, and Dr. Prange began his experiment on behavioral temperature regulation in the *Schistocerca nitens* species of grasshopper.

Prior to Dr. Prange's experiment, scientists held the belief that, because of their small body size and limited water reserves, grasshoppers (i.e., quiescent insects) were incapable of using evaporative cooling to regulate their body temperature. It was assumed that insects would exclusively rely on behavioral adaptations to keep cool. This phenomenon was well documented and observed.

To begin his experiment, Dr. Prange placed a grasshopper in the warm side of the alternative chamber, which was set to maintain a temperature of around 50 °C. This temperature was generally held to be lethal to an insect. Dr. Prange started the timer and began documenting the grasshopper's behavior. After more than a half hour, he noted that the grasshopper had not moved or shown signs of distress; he assumed it was dead. Dr. Prange reached into the chamber to retrieve the grasshopper, and to his great surprise, it jumped away. Dr. Prange hypothesized that either the grasshoppers had an unusual tolerance for heat, or they were utilizing a cooling mechanism.

### Questions

- From the data acquired in Prange's experiment (Figure 2), determine the temperature that leads to a significant difference between body temperature and air temperature (i.e., greater than about 2 °C difference).
- As Dr. Prange suggested, the grasshoppers appear to be using some other cooling mechanism(s) besides behavior. Give two examples of cooling mechanisms that grasshoppers in the study might be using.

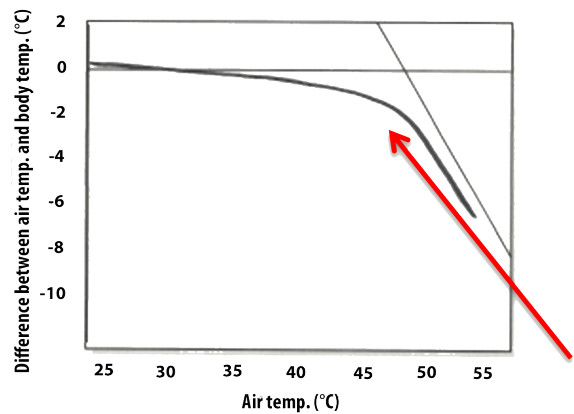


Figure 2. Significant difference between body and air temperature in grasshoppers. Adapted from Prange (1990).

## Part IV – What’s Going On Here?

Dr. Prange decided to take this experiment a step further. He wanted to know mechanistically how the grasshoppers were able to keep their body temperatures low enough to withstand lethal environmental temperatures. He developed these two hypotheses:

*Hypothesis 1:* The grasshoppers reduce their body temperature by decreasing their metabolism.

*Hypothesis 2:* The grasshoppers reduce their body temperature by using an evaporative cooling mechanism.

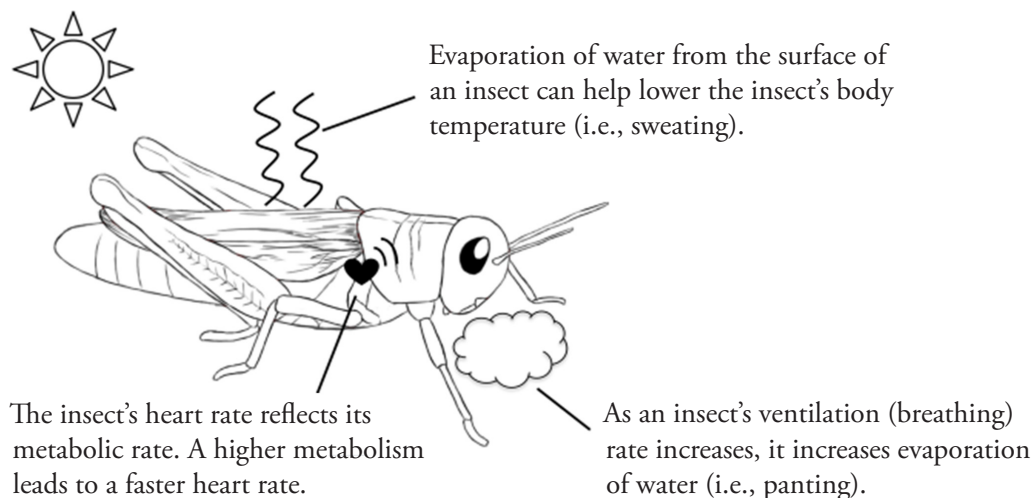


Figure 3. Possible cooling mechanisms in a grasshopper.

Dr. Prange used specific instruments to record the grasshopper’s heart rate, ventilation (breathing) rate, and evaporative water loss. He compared these with the organism’s body temperature in the three graphs below (Figure 4). From his findings, the ventilation rate increased drastically around a temperature of 45 °C (left graph). The figures for heart rate and evaporative water loss are also shown below.

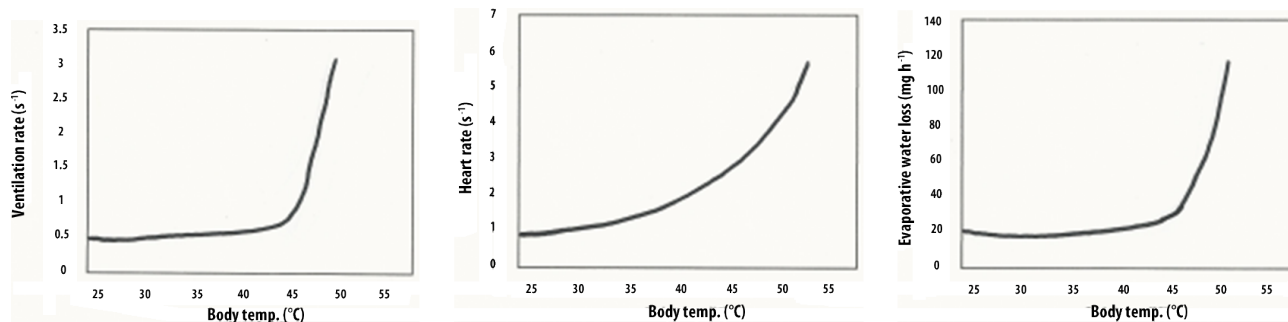


Figure 4. Grasshopper heart rate, ventilation rate, evaporative water loss. Adapted from Prange (1990).

### Questions

- From the graphs in Figure 4, does the increase in ventilation rate appear to be most likely related to an increase in metabolic need (heart rate), or an increase in the amount of water evaporation? Explain your reasoning.

8. Compare the graphs in Figure 4 to the graph in Figure 2. What appears to happen to grasshoppers at a temperature of around 48–50 degrees?
9. From Dr. Prange's study, can it be supported that the grasshoppers were using evaporative cooling? Why or why not?

*\*Bonus\**

10. Water has an unusually high heat of vaporization ( $\sim 40\text{kJ/mol}$ ), allowing it to be used for evaporative cooling. What do you think would happen if a different compound was used for evaporative cooling—for example, methane ( $\sim 8\text{kJ/mol}$ )?

## References

- Asres, A. and N. Amha. 2014. Physiological adaptation of animals to the change of environment: a review. *J. Biology, Agriculture, and Healthcare* 4(25): 146–51.
- Prange, H. 1990. Temperature regulation by respiratory evaporation in grasshoppers. *J. Exp. Bio.* 154: 463–474.