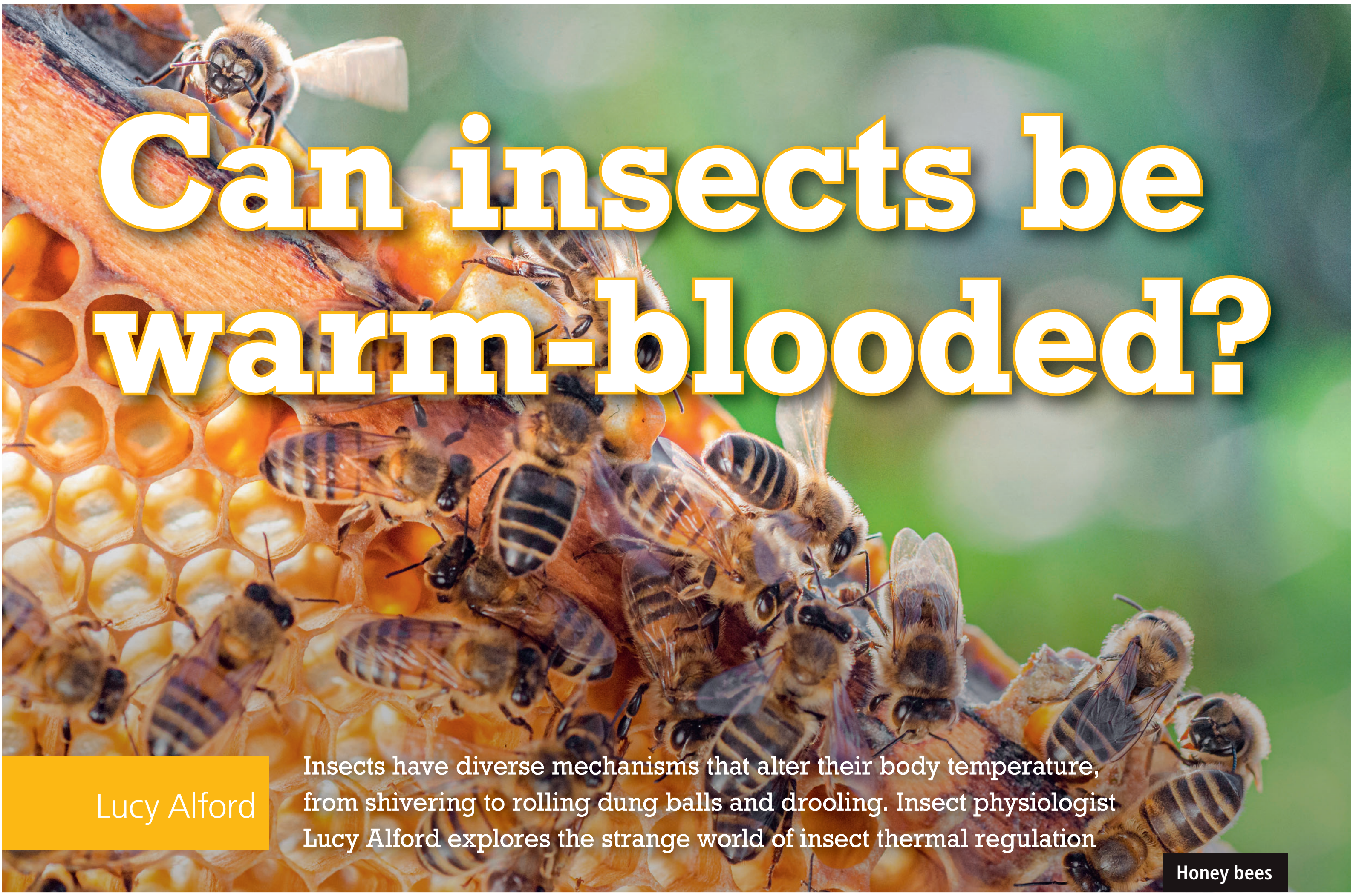
Can insects be warm-blooded?



Lucy Alford

Insects have diverse mechanisms that alter their body temperature, from shivering to rolling dung balls and drooling. Insect physiologist Lucy Alford explores the strange world of insect thermal regulation

Honey bees

EXAM LINKS

AQA: Principles of homeostasis
OCR A: Temperature control
OCR B: Control of body temperature
Pearson Edexcel A: Mechanisms of thermoregulation
Pearson Edexcel B: Temperature regulation
WJEC Eduqas: Concept of homeostasis

Temperature is an important **abiotic factor**. It affects the activity and distribution of animals. Animals differ in how they maintain their body temperature in relation to the environment around them. This allows us to classify all animals as either **endotherms** or **ectotherms**.

Endotherms have physiological mechanisms that maintain a stable body temperature, irrespective of the environmental temperature. We typically think of them as warm-blooded animals, such as birds and mammals. However, most animals are ectotherms. These animals we typically think of as cold blooded, and include insects, reptiles, amphibians and fish. Ectotherms have limited physiological control over their body temperature and, as a result, their internal body temperature is determined by the environmental temperature around them.

Ectotherms

Although ectotherms lack physiological mechanisms that control their body temperature, many can maintain a relatively constant body temperature using behaviour. This is known as **behavioural thermoregulation**. Since the temperature of the environment varies from place to place, an ectotherm may occupy specific locations within the environment to produce a favourable body temperature. For example, a butterfly may bask in the sun until its body is warmed to a suitable temperature. Once the butterfly gets too warm, it may instead seek shade to cool itself. The butterfly can also alter the area of its body exposed to the sun by changing its basking posture and orientation in relation to the sun.

Certain species of blowfly engage in drooling behaviour as an unusual method of

Box 1 Drooling to keep cool

Blow flies engage in a bizarre behaviour to keep cool on a hot day. They drool. The flies create a droplet of saliva that hangs from their mouthparts. As this droplet begins to evaporate, heat is lost to the surrounding air via evaporative cooling. When the droplet of saliva has cooled, the fly then sucks the droplet back up. This drool–cool–suck behaviour is repeated multiple times and can help cool the fly's body temperature by up to 4°C.

Through studying blowflies using X-ray imaging, Denis Andrade and colleagues at São Paulo State University have shown that the droplets are sucked back into the buccopharyngeal cavity, helping to keep the brain cool and prevent dangerous overheating.

TERMS EXPLAINED

Abiotic factor An environmental variable that can influence where organisms live. Examples include temperature, light intensity, soil pH and soil moisture.

Behavioural thermoregulation The maintenance of a relatively constant body temperature by use of behaviour, for example basking and sheltering.

Ectotherm An animal that is dependent on external sources of heat to warm its body.

Endotherm An animal that generates heat to maintain its body temperature.

Mechanical efficiency A measure of the ability of a system to perform a task without wasting energy.

Thermal generalist An animal able to function over a wide range of body temperatures.

Thermogenesis The generation of heat in a living organism.

Thermoregulation The ability of an animal to maintain a body temperature within certain boundaries.

thermoregulation (see Box 1). However, a major limitation of behavioural thermoregulation is that it is dependent upon the opportunities for heating and cooling available in the environment. A cold, cloudy day in winter offers few opportunities for an ectotherm to warm its body temperature. For this reason, ectotherms are **thermal generalists** and must be able to function over a range of body temperatures.

Box 2 Thermogenesis and the production of heat

In placental mammals, including humans, heat is generated by shivering **thermogenesis** and non-shivering thermogenesis. During shivering thermogenesis, antagonistic muscles contract randomly and the muscles quiver, as opposed to generating purposeful movement. Adenosine triphosphate (ATP) is hydrolysed and heat is generated.

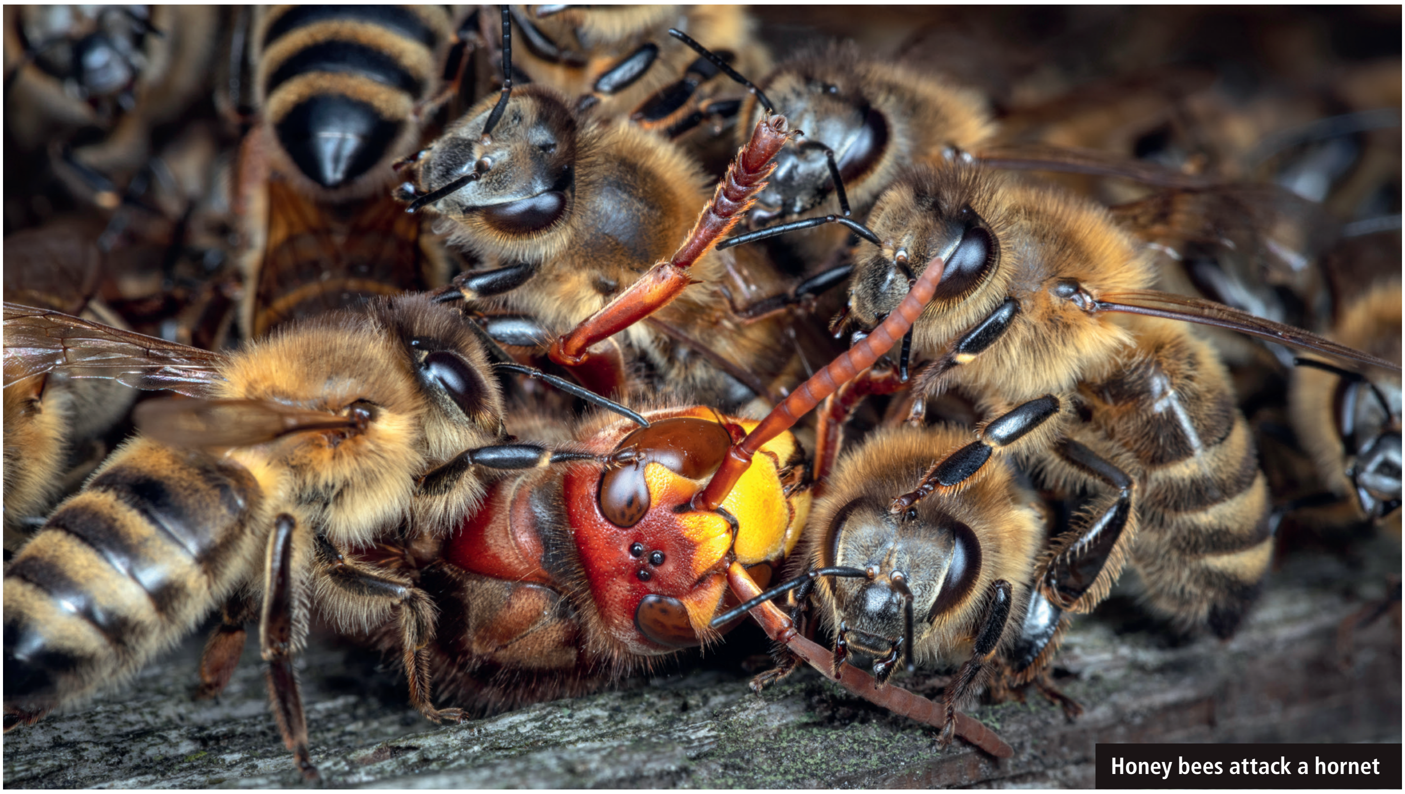
Non-shivering thermogenesis does not involve muscle contractions and instead involves brown adipose tissue (BAT) or brown fat, which is highly vascularised (see pp. 26–29) and rich in mitochondria. During non-shivering thermogenesis fat metabolism is altered to produce heat instead of ATP. The high vascularisation of BAT ensures that heat is effectively transferred away from the site of production to warm the body.

Endothermy in insects

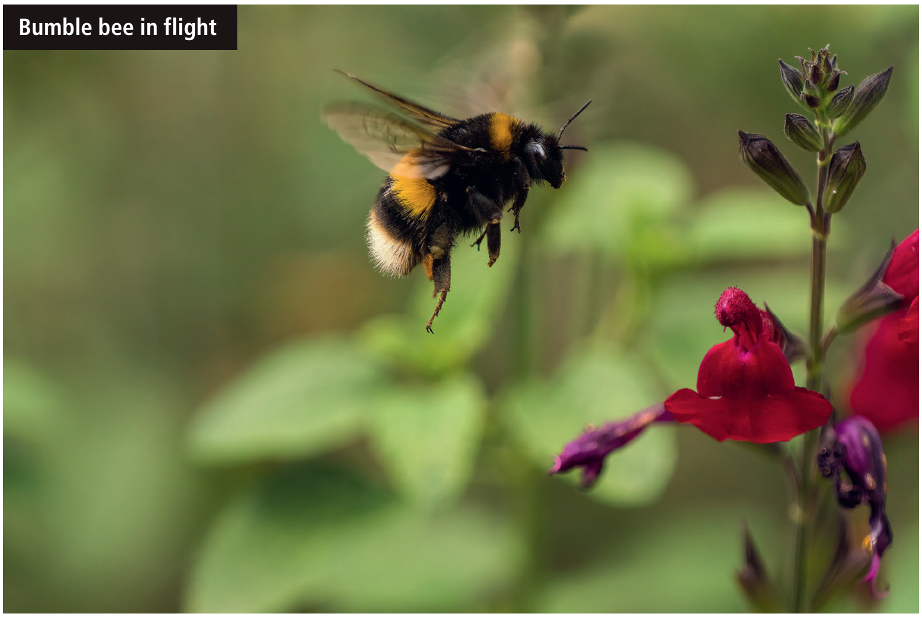
Most invertebrates are ectotherms. They become inactive when environmental temperatures become too low to allow activity. But some insects can increase their body temperature by releasing heat from metabolic reactions, and then using the circulatory system to redistribute this heat around the body (see Box 2). This allows the insect to be active even when environmental temperatures are low.

Such endothermic insects use the heat released by contraction of their flight muscles to raise their body temperature. Insect flight muscles are among the most metabolically active tissues known, although their **mechanical efficiency** is only around 20%. The remaining 80% of the energy expended during flight is released as heat, and it is this heat that can be used to raise body temperature.

Small insects, such as fruit flies and midges, have a high surface area-to-volume ratio. This means that most of the heat released by their flight muscles is lost to the environment. As a result, their body temperature in flight is close to the environmental temperature. However, for larger insects, such as some species of bees, wasps, butterflies, beetles and dragonflies, most of the heat released by their flight muscles is retained and used to increase their


Honey bees attack a hornet

Bumble bee in flight



body temperature substantially higher than the ambient temperature. During flight, the temperature of flight muscles can rise 20–30°C above the external environmental temperature.

Preparing for take off

Although larger insects can generate and retain heat during flight, their muscles will only produce sufficient lift for flight to occur if they are warm. This creates an interesting dilemma because, at low ambient temperatures, no flight is possible to generate the initial heat required for flight to occur.

In the absence of flight, therefore, how do insects generate the heat required to warm the flight muscles and enable take-off? They do this by engaging in a pre-flight warm-up. Opposing flight muscles are activated in a different pattern, contracting simultaneously instead of alternately as they would during flight. This behaviour is known as shivering because the contractions of the wing muscles give the appearance that the wings are shivering. Bumble bees need a thoracic temperature above 30°C before their flight muscles can generate sufficient lift for flight to occur. Shivering enables the bumble bees to raise their temperature to the required 30°C even when environmental temperatures are as low as 3°C.

Not only is the metabolic release of heat exhibited by endothermic insects highly effective at generating the body temperatures required for flight, it is also extremely efficient at maintaining a constant temperature, even when environmental temperatures vary greatly. Worker bumble bees, for example, can maintain a temperature of 32–33°C while foraging, even when the air temperature is, say, 9°C or 24°C. Likewise, the tobacco hawkmoth can maintain its temperature when flying at 38–43°C, whether the air temperature is 12°C or 35°C.

Metabolic release of heat can also happen during activities other than flying. In such cases, the primary source of heat remains the flight muscles. However, instead of being used to fly, the flight muscles are used to shiver. Crickets, for example, can generate heat and become endothermic while they sing, and dung beetles can become endothermic while rolling dung balls.

Thermoregulation

By altering the intensity of shivering, an endothermic insect can control the amount of heat released, and therefore has fine control over its body temperature. This is **thermoregulation**. When air temperatures drop, an endothermic insect can increase the intensity of shivering to increase the release of heat and counteract the cooling effect of declining air temperature.

Some solitary insects are even capable of using the heat released by shivering to incubate their young. Bumble bee queens, for example, overwinter

PRACTICE EXAM QUESTIONS

1 Distinguish between ectothermy and endothermy. [2 marks]

2 When under attack from a hornet, around 500 worker bees surround and engulf the hornet in a ball. The honey bees use metabolic heat to raise the temperature inside the ball to 46°C. The concentration of carbon dioxide within the ball also increases sharply.

a Briefly describe how metabolic heat is released by the honey bees. [2 marks]

b Explain why the concentration of carbon dioxide within the ball increases. [2 marks]

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Go online for the answers at www.hoddereducation.co.uk/bioreviewextras

RESOURCES

BBC video showing Japanese honeybees killing a hornet: **https://tinyurl.com/bees-vs-hornet**

Dragonfly shivering: **https://tinyurl.com/insect-shiver**


Red admiral butterfly basking


Dung beetle rolling a dung ball

alone and rear their first brood in spring without the help of a colony. By shivering her flight muscles, the queen can generate heat in her thorax and redistribute this heat to her abdomen. The queen incubates her brood by pressing her warm abdomen against them. When the temperature drops, the queen increases the amount of heat released by intensifying the rate of shivering.

Just as solitary insects can finely control their body temperature by varying the intensity of shivering behaviour, so too can social insects, such as bees and wasps, which work together as a colony to finely control the temperature inside their hives and nests. The honey bee (*Apis mellifera*), for example, requires a hive temperature of 32–36°C for their brood to successfully develop. To achieve such fine control over hive temperature, when the environmental temperature outside the hive gets too cold, worker bees cluster together and shiver to raise the internal hive temperature.

In contrast, when the environmental temperature outside the hive gets too warm, worker bees disperse within the hive and fan their wings in a coordinated manner to bring in fresh air from outside to cool the hive. If the environmental temperature gets warmer still, worker bees collect water and spread it within the hive. The water then evaporates into the airstream generated by the worker bees fanning their wings, leading to evaporative cooling. This regulation of hive temperature is so effective and efficient that a honey bee hive can be maintained at around 32–36°C, even when the air temperature outside falls to –30°C or rises to +50°C.

Heat and hive defence

Some social insects work collectively using metabolic heat as a form of defence. The Japanese honey bee is one such example. The giant hornet represents a major threat to Japanese honey bees. The hornet will capture the brood of the honey bees to feed its own larvae.

When under attack from a hornet, around 500 worker bees surround and engulf the hornet in a ball. The honey bees use metabolic heat to raise the temperature inside the ball to 46°C. Carbon dioxide levels also increase sharply. Under conditions of high carbon dioxide, the temperature of 46°C is fatal to the hornet. In contrast, under the same conditions, the lethal temperature for the honey bee is 50–51°C, thus enabling the honey bees to survive the attack.

Although insects are commonly assumed to be ectothermic and at the mercy of environmental temperatures, some larger insects are capable of endothermy and show impressive levels of thermoregulation. Whether using metabolic heat to incubate young, or coordinating shivering on a mass scale to warm the hive or kill the enemy, the applications of insect endothermy are truly impressive.

Points for discussion

- How might climate change impact an insect's ability to thermoregulate?
- Why aren't all insects capable of endothermy?

KEY POINTS

- Endothermic animals can generate heat to warm and maintain their body temperature.
- Ectothermic animals have limited control over their body temperature. Their body temperature is determined by the environmental temperature.
- Ectotherms can regulate their body temperature and maintain a relatively constant temperature by changing their behaviour.
- A few insects are capable of generating heat via metabolic heat production, and are therefore endothermic.
- Some social insects can act cooperatively and use metabolic heat production and behaviour to control hive temperature.

Dr Lucy Alford is an insect physiologist from the University of Bristol. She is interested in identifying and developing environmentally friendly ways of controlling pest insect populations and restoring beneficial ecosystem services in agricultural landscapes.