



Chilling Out, Warming Up



How Animals Survive Temperature Extremes

By Brian Rohrig

Animals have some amazing adaptations that help them live in even the most hostile environments. Consider camels, for instance. They can thrive in some of the hottest and driest places on Earth. Their legs don't get burned when they kneel on hot sand due to thick leathery patches on their knees. They can survive for an entire week without water but, at the same time, they can drink 32 gallons of water at once. Their body temperature ranges from 93 °F to 107 °F, so they don't need to sweat very often and can conserve water this way. The spongy bones in their noses absorb any excess moisture to keep every drop of water in, so the air they breathe out is dry air. In addition to camels, other animals' adaptations are equally remarkable. How do they do it? Chemistry helps!

Warm-blooded or cold-blooded?

The most important adaptation is how animals regulate their body temperature. Animals can be either warm-blooded or cold-blooded.

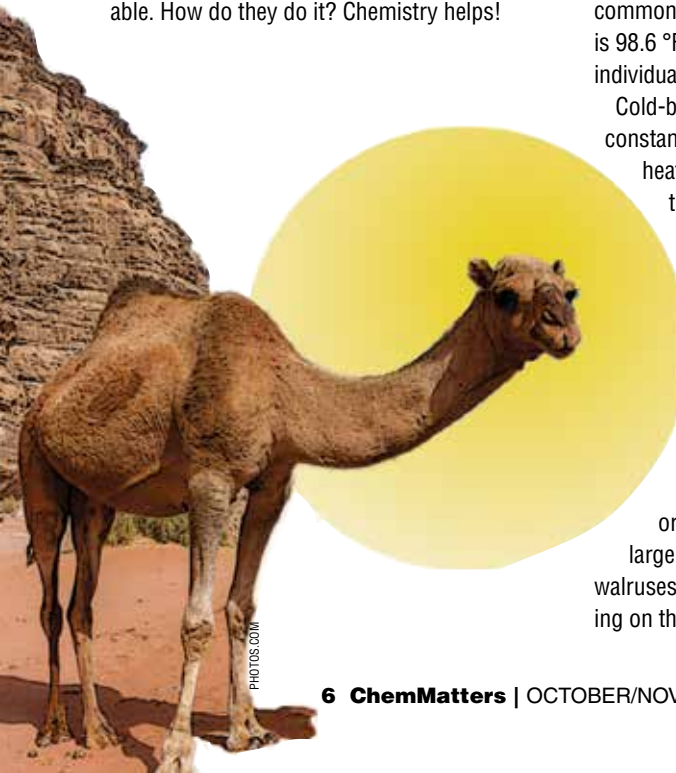
Warm-blooded animals, which are mostly birds and mammals, need to maintain a relatively constant body temperature. The body temperature of most mammals ranges from 97 °F to 103 °F, while birds have an average body temperature of 105 °F. For humans, the commonly accepted average body temperature is 98.6 °F (even though it may vary among individuals).

Cold-blooded animals do not maintain a constant body temperature. They get their heat from the outside environment, so their body temperature fluctuates, based on external temperature. If it is 50 °F outside, their body temperature will eventually drop to 50 °F, as well. If it rises to 100 °F, their body temperature will reach 100 °F.

In most instances, the size and shape of an organism dictate whether it will be warm-blooded or cold-blooded. Think about some large animals—elephants, whales, and walrus. Their volume is so large that relying on the outside environment to heat them

up would be inefficient and would slow their response times, putting their survival at risk. For that reason, nearly all large animals are warm-blooded.

What about all the birds and mammals that are not large, such as mice and sparrows? The other factor—body shape—comes into play here. Small warm-blooded animals tend to have a rounded shape, which ensures that the interior of an organism stays warm the longest time possible. Most cold-blooded organisms have either an elongated or a flat shape. If you look at a typical fish, their bodies tend to be flat when viewed head-on from the front. Snakes, lizards, and worms tend to be long and slender. These shapes ensure they can heat up and cool down rapidly.



Elephants toss dirt on themselves to cool off.

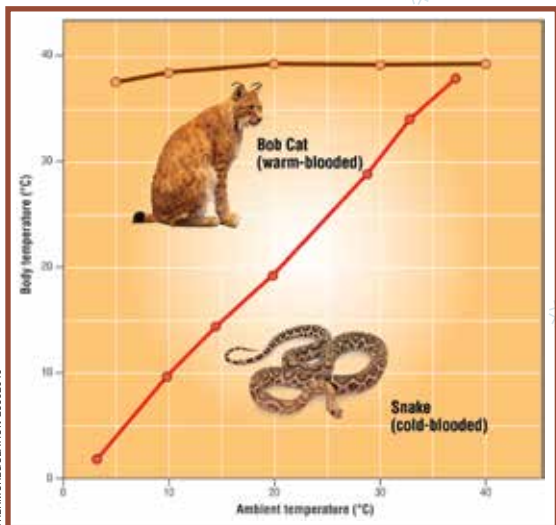


Figure 1. Body temperature vs. ambient temperature for warm-blooded animals and cold-blooded animals.

Within a given species, animals tend to be larger in colder climates and smaller in warmer climates, an observation known as Bergmann's rule. For example, whitetail deer in the southern part of the United States tend to have a smaller body size and less overall mass than whitetail deer in the far northern states.

There are exceptions but, overall, this rule holds true, for the following reason: As the

volume of an object decreases, the ratio of its surface area to its volume increases. In other words, the smaller an animal is, the higher the surface area-to-volume ratio. These animals lose heat relatively quickly and cool down faster, so they are more likely to be found in warmer climates. Larger animals, on the other hand, have lower surface area-to-volume ratios and lose heat more slowly, so they are more likely to be found in colder climates.

Generating energy

Warm-blooded animals require a lot of energy to maintain a constant body temperature. Mammals

and birds require much more food and energy than do cold-blooded animals of the same weight. This is because in warm-blooded animals, the heat they lose is proportional to the surface area of their bodies, while the heat they produce is proportional to their mass. This means that larger warm-blooded animals can generate more heat than they lose and they can keep their body temperatures stable

more easily. Smaller warm-blooded animals lose heat more quickly. So, it is easier to stay warm by being larger.

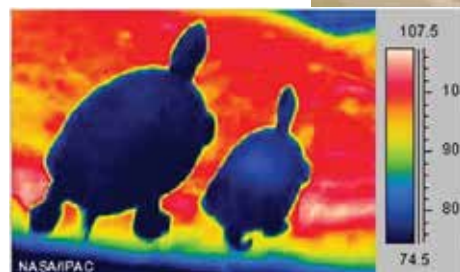
This energy produced by warm-blooded animals mostly comes from food. Food represents stored chemical energy (potential energy), which is converted into other forms of energy within the body when the food is metabolized. Metabolism refers to all the chemical reactions in the body.

The metabolism of food within the body is often referred to as internal combustion, since the same byproducts are generated as during a typical combustion reaction—carbon dioxide and water. And like combustion reactions, metabolic reactions tend to be exothermic, producing heat.

For a warm-blooded animal, food is not just a luxury—it is a matter of life and death. If food is not available for energy, the body's fat is burned. Once fat reserves are used up, death is imminent if a food source is not found. The smaller the warm-blooded animal, the more it must eat—relative to its body size—to keep its internal furnace stoked. That's why most songbirds fly south for the winter.

On the other hand, cold-blooded animals require less energy to survive than warm-blooded animals do, because much of the energy that drives their metabolism comes from their surroundings. It is common to see turtles basking in the sun on rocks and logs. They are not trying to get a suntan, but rather are revving up their metabolism. The sun gives them an energy boost. Muscle activity in cold-blooded animals depends on chemical reactions, which run quickly when it is hot and slowly when it is cold (because the reacting molecules move faster when temperature increases).

Some reptiles, such as the python, can go a year without eating, because they do not use food to produce body heat. And if they lie still, they use little energy, so they can afford to eat little.



These turtles just walked out of a pool of cool water. Notice how cold they still are.

Heating Up a Cold-Blooded Elephant

Cold-blooded animals have either an elongated or flat shape, which helps them soak up the sun and get warm when it is hot outside. *But why would it take longer for a large animal to warm up?* In other words, if an elephant was cold and it wanted to warm up? *Think of it this way:* Imagine you are trying to defrost a steak in your microwave.

After a few minutes, the outside is warm, but the inside is still cold or frozen. This would be similar to trying to heat up a cold-blooded elephant. The outside of our cold-blooded elephant would heat up pretty quickly, but it would take forever to absorb enough energy from the environment to heat up the inside.

—Brian Rohrig



Cold-blooded animals have a disadvantage compared to warm-blooded animals: There is a certain temperature below which their metabolism just won't work. The reason is that all chemical reactions slow down as the temperature is lowered, so at low temperatures, all the chemical reactions in an organism slow down.

You may notice that few cold-blooded animals are active in the winter, and the farther north you go, the rarer they become. By contrast, warm-blooded animals are present in a wider variety of environments and for a longer part of the year than cold-blooded animals.

Hibernation

For warm-blooded animals that don't migrate, one way to survive the winter is to sleep through it. Hibernation is a great strategy that enables animals to conserve energy when food is scarce. During hibernation, body temperature drops, breathing and heart rate slow, and most of the body's metabolic functions are put on hold.

It is almost as if the warm-blooded animal becomes cold-blooded, as its body temperature drops considerably. But they are still alive, and they live off their fat reserves. Hibernation for extended periods of time is accomplished only by those animals that can store a great deal of body fat, such as bears, groundhogs, and chipmunks. A black bear loses 15% to 30% of its weight while hibernating.

Cold-blooded animals hibernate, too. But they need to store less fat than warm-blooded animals because they require less

energy. Turtles and frogs bury themselves in mud under lakes and ponds for up to six months at a time, and, for all practical purposes, they appear dead. There are no external signs of life.

When many cold-blooded animals hibernate, something interesting happens at the cellular level. The fluid around the cells, but not in the cells, is frozen solid. As water freezes outside the cell, water from within the cell is drawn out through osmosis.



Short-Term Hibernation

Some animals, such as hummingbirds, undergo a short-term hibernation known as torpor. Their nightly torpor is an energy-saving mechanism, as their tiny bodies lose heat rapidly. They must feed constantly during the day to keep their body temperature up and maintain their incredibly fast metabolism. **They eat two to three times their body weight every day! If they didn't enter torpor at night, they would die, because their bodies would lose too much heat due to their large surface area-to-volume ratio.** They also lack the insulating down feathers that many birds have, resulting in heat loss.

—Brian Rohrig

Osmosis is a process in which water moves across a semipermeable membrane—in this case, the cell membrane—from an area of low solute concentration to an area of high solute concentration.

As water freezes outside of the cell, the solute concentration increases because the quantity of liquid water decreases while the amount of solutes stays the same. As a result, water flows out of the cell to equalize the concentrated solution outside of the cell (Fig. 2).

At the same time water is leaving the cells, glucose migrates into the cells in copious amounts. As a result, the concentration of dissolved solutes within the cell increases—a lot. The glucose acts as a natural antifreeze, as any solute will lower the freezing point of a given solvent—in this case, water. The presence of high concentrations of solutes in the cells allows animals, such as frogs, to hibernate at temperatures below freezing

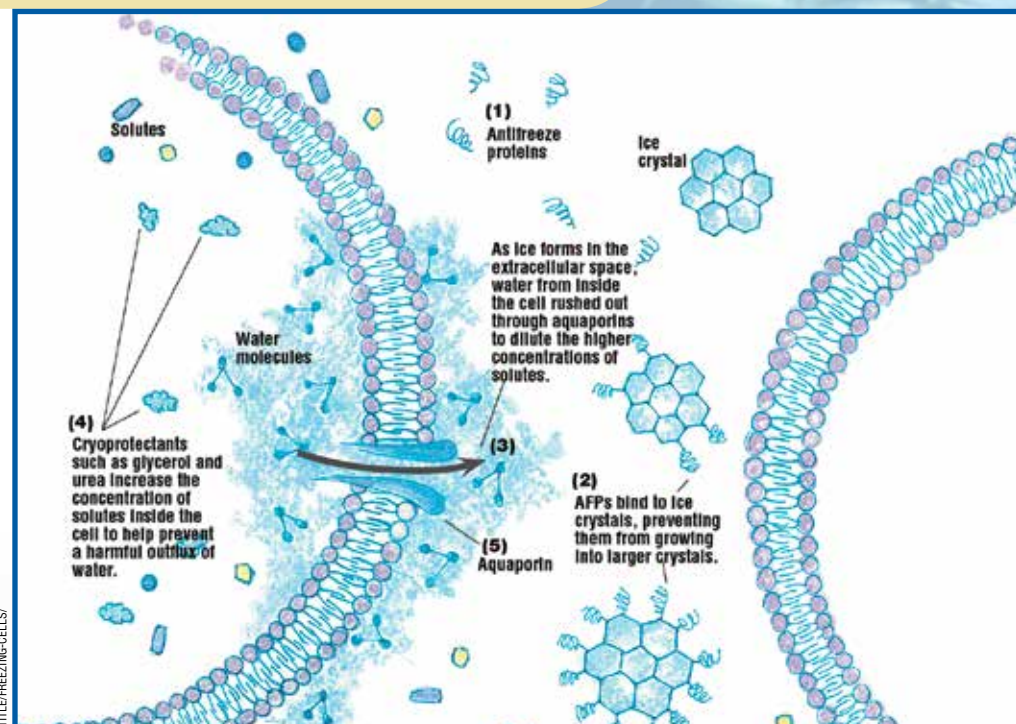


Figure 2. Some cold-blooded animals have found ways to counteract the formation of ice, which can damage their tissues and potentially kill them. For example, antifreeze proteins (1) bind to the surface of ice crystals outside the cells to prevent these ice crystals from growing (2). As these ice crystals form, water flows out of the cells to compensate for the increasing concentration of solute in liquid water outside the cells (3). Inside the cells, compounds called cryoprotectants (4) increase the concentration of solutes, preventing further water loss and cell damage. Proteins on the cell membranes, called aquaporins (5), allow water and some cryoprotectants to flow inside the cells.

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and still survive. While the water around the cells is frozen, the water in the cells is not. If water within a cell were to freeze, the cell membrane would rupture, killing the cell.

Keeping warm

When it gets cold outside, you put on more clothes. Your winter coat does not keep out the cold, but rather keeps in the heat. (Cold itself doesn't exist—it is simply the absence of heat; see the article titled "Why Cold Doesn't Exist," on p. 10.) Birds and mammals also rely on insulation to prevent heat loss. The most effective insulation traps air, since air is one of the best insulators. Wool tends to be warm because its fibers are curled, effectively trapping air and keeping you (and sheep) warm. Birds fluff up their feathers when they want to stay warm, since fluffing introduces air.

For mammals without hair, insulation is accomplished by blubber, a thick layer of fat tissue which helps to insulate an animal's body because fat does not transfer heat as well as muscle and skin. This blubber may be two feet thick in some whales! Whales, tuna, dolphins, and other warm-blooded marine animals also rely on another ingenious method to conserve heat. To prevent excessive heat loss from extremities such as fins and flippers—which are not well insulated—aquatic animals rely on a "countercurrent heat-exchange method," in which the arteries that carry warm blood away from the heart are positioned directly against the veins that carry cool blood to the heart. So, the warmer blood leaving the heart through the arteries warms the cooler blood entering the heart through the veins.

In contrast to birds and mammals, lizards, frogs, snakes, and other cold-blooded animals

do not need insulation—it would only slow down heat transfer into their bodies.

Keeping cool

When you get hot, what's the first thing that happens? You start to sweat. The average adult has 3 million sweat glands. Evaporation is an endothermic phase change, meaning it must absorb energy to occur. This energy is drawn from your body, making you cooler.



Anytime you lose energy, your body will feel cool. Evaporation requires energy because forces of attraction between water molecules—called intermolecular forces—need to be overcome when water goes from a liquid to a gas.

The energy that goes into overcoming these attractive forces comes from your body.

Do animals sweat? Most don't, but some do.

Dogs sweat mainly between the pads on the bottom of their paws. One notable exception is the American Hairless Terrier, which has sweat glands all over its body, illustrating the fact that fur tends to inhibit sweating because if the sweat can't evaporate, it doesn't help in the cooling process.



American Hairless Terriers have sweat glands all over their body, but not hair or fur.

Kangaroos and lions keep cool by licking their forearms.



Cats have sweat glands not only on the pads of their feet, but also on their tongues! When a cat licks

itself, it may not be only to keep clean, it could also be to cool itself, because the saliva on their fur evaporates. Kangaroos will lick their forearms for the same reason.

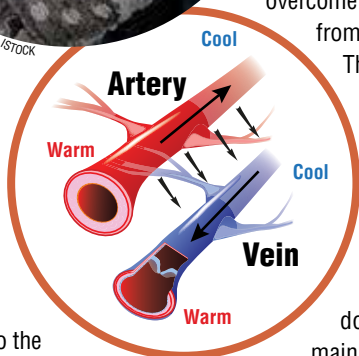
The key to surviving in hot climates is not only to keep your body from overheating but also to prevent water loss. Animals that are adapted to desert life are not heavy sweaters. Because water is scarce, they cannot afford to lose water by sweating. Also, a great deal of water is lost through breathing out, so desert animals expel dry air, reabsorbing the water in their breath before it has a chance to be expelled.

The ability of animals to survive in extreme environments is quite remarkable. Whether it is in the freezing corners of Siberia or the sizzling hot desert of the Sahara, animals have found ways to adapt and thrive, and how they do it will never cease to amaze us! *CM*

SELECTED REFERENCES

- Denny, M.; McFadzean, A. *Engineering Animals: How Life Works*: Harvard University Press: Cambridge, MA, 2011.
- Mone, G. 20 Things You Didn't Know About... Hibernation. *Discover*, March 2013, p 74.
- Streever, B. *Cold: Adventures in the World's Coldest Places*, Little, Brown and Company: New York, 2009.
- Streever, B. *Heat: Adventures in the World's Fiery Places*, Little, Brown and Company: New York, 2013.

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