Adaptations for the hot and dry…

In low latitude deserts, daily air temperature may reach 40 – 50 ^{o}C, and surface temperatures may reach 60 – 70 ^{o}C!

Mammals now faced with reverse heat gradient.

More difficult to maintain Tb below Ta than to regulate heat loss when Tb above Ta.

Primary mechanism used by mammals to dump heat is evaporative cooling.

When Ta > Tb, must evaporate water to dissipate heat to environment, no passive flow possible. (580 kcal per liter water)

Some mammals sweat (primates, some ungulates), but fairly limited or absent in most.

Carnivores and some ungulates pant. Evap. water loss from respiratory passages.

Some mammals resort to saliva spreading.

Problem if water limited! Most mammals die if lose >10-20% of body water.

Deserts are an especially challenging environment both because of heat and low availability of water.

High Ta often associated with scarcity of water.

Dry air doesn’t contain enough humidity to form clouds or hold in heat at night, Ta fluctuates more than in humid environments.

Low moisture often means low productivity = low food.

Dehydration causes blood to thicken, no longer effectively circulates through capillaries, can’t transport heat effectively, causes Tb to shoot up.

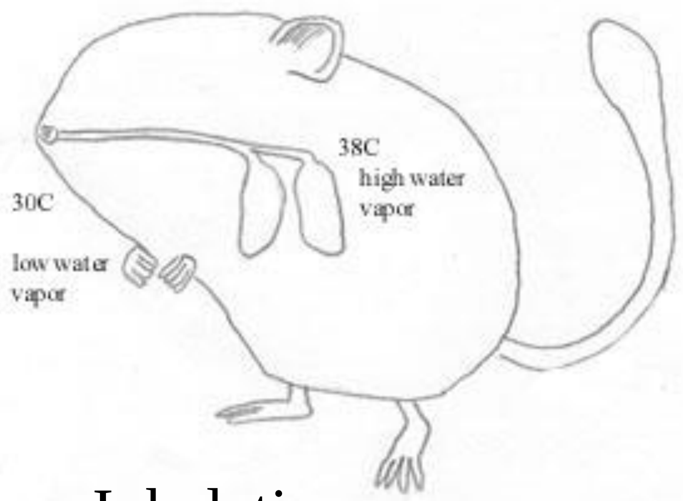
Tb above 43^{o}C can induce brain damage. (109^{o}F)

Death comes quicker by hyperthermia than by hypothermia.

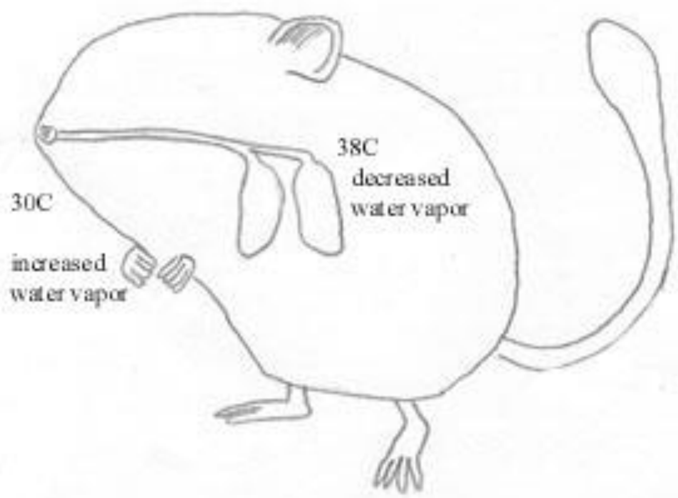
A 50-g kangaroo rat out in the mid-day sun in a hot desert would need to evaporate water equivalent to 13% of its body mass each hour to maintain normal Tb. Without water, would reach lethal limit of dehydration in around 2 hrs.

small mammals in hot deserts: kangaroo rats as an example

1) nocturnal activity (may be more cold-stressed than heat!)
2) uses burrows, relatively stable thermal environment plus blocks entrances during day to keep in humidity
3) relies on pre-formed water in food, and metabolically produced water; cached seeds absorb some water from humidity in burrow
4) super efficient kidneys (urine 5X more concentrated than that of humans, crystalizes on contact with air!)
5) counter-current system in nasal passages conserves water
6) no sweat glands (all rodents)

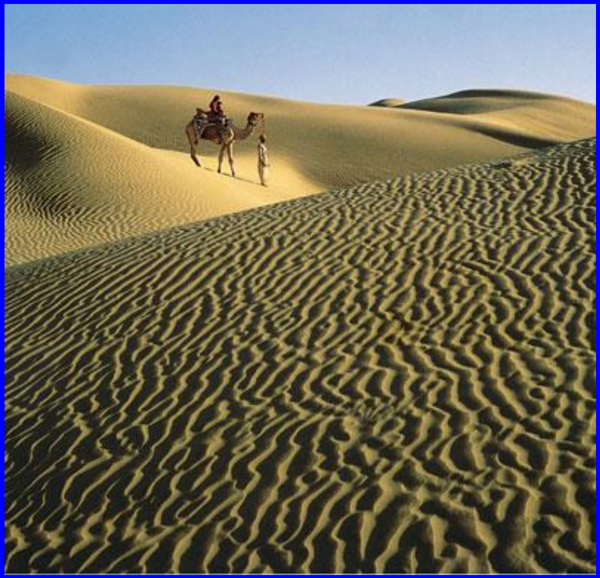


Inhalation



Exhalation

1. Problem: Inhales dry air, loses water from moist lungs
2. However: As air flows over complex nasal passages, gets saturated with water and heats up to 38C. Nasal passages cooled by evap, tissue surface dries; lungs protected.
3. When exhales, warm, moist air from lungs passes over cool, dry tissues in nasal passages, water condenses out and is quickly reabsorbed. Still loses some water, but not as much.



What about large mammals? Can't use burrows, often hard to find shade, out in daytime.

Larger size means greater mobility, can move greater distances to find food, water, shelter.

Lower SA/V means absorb heat more slowly, combined with lower metabolic rate means heat up more slowly.

Still, hot, arid environments pose special challenges to large mammals.

How camels succeed.

1) Heavy coat in winter, sheds in spring but retains hair 5-6 cm long on back, up to 11 cm on hump (like blanket on back...but remember, insulation acts both ways!)

2) Ventral surface, legs w/ hair only 1.5-2 cm

3) Fur surface T may be 70^{o}C, but skin surface only 40^{o}C. Sweat glands under fur also provide evap. cooling... because under fur, evap. mainly from body heat, not solar radiation.

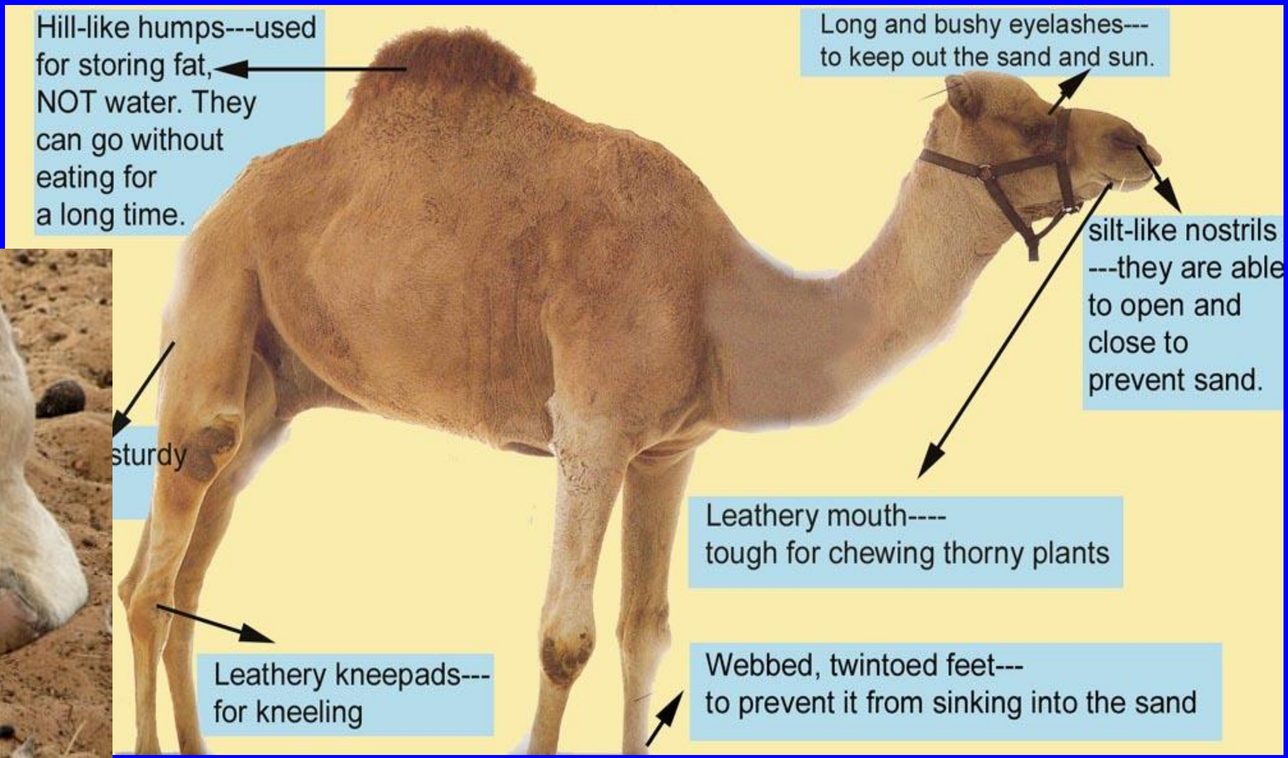
Classic large desert mammal: F 400-450 kg, M 500 kg

When water available, camel relies on evaporative cooling, but needs about 4-5 liters/day to keep Tb in 36-38C range.

4) When water scarce (can't sweat much), tolerates <u>hyperthermia</u> in day, goes <u>hypothermic</u> at night

Tb up to 40.5^{o}C in daytime, down to 34.5^{o}C at night. Going hypothermic at night means takes longer to heat up in daytime. Can tolerate water loss of 25% of body weight (most of any mammal)... mechanism unclear, but maintains plasma volume while water lost from intercellular fluids instead.

Can drink up to 30% of body mass!

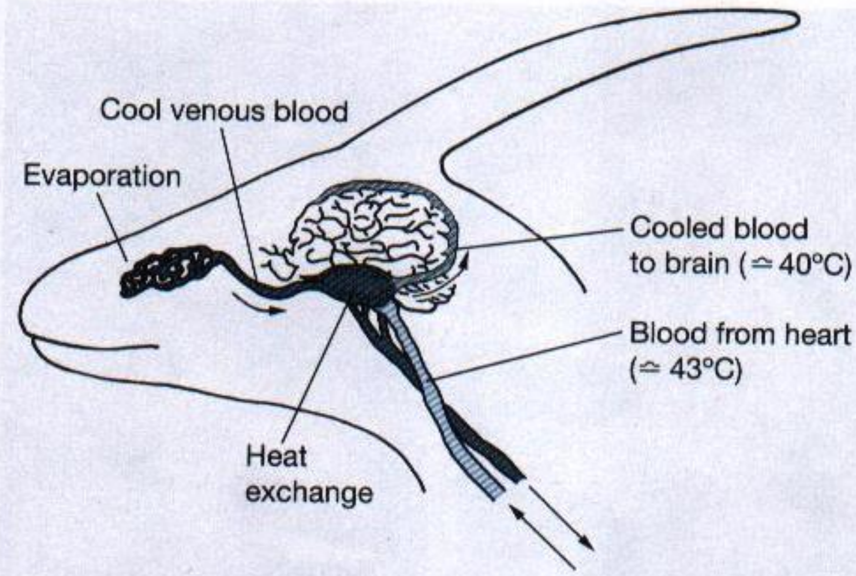


Some large mammals in arid regions have pale, and/or glossy, reflective fur

eland

gemsbok

Large mammals like gazelles, antelopes, oryx often tolerate Tb that gets quite high… up to 45C in *Oryx*. But temperatures above 43C cause brain damage. ???



▲ **FIGURE 22–15** The countercurrent heat-exchange mechanism that cools blood going to a gazelle's brain. Blood leaves the heart at about 43°C (light color) and is cooled to about 40°C by cool venous blood (dark) returning from the nasal passages where it was cooled by evaporation of water.

Tb may rise above 40^{o}C during the day; temperatures above 43^{o}C typically cause brain damage.

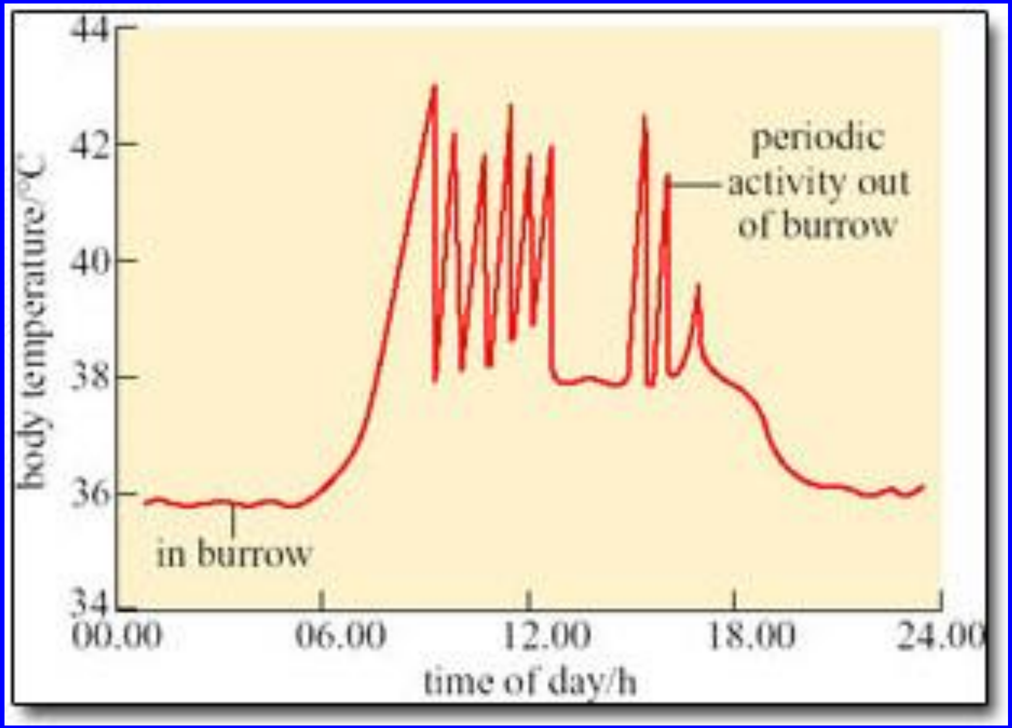
Blood supply to the brain passes via carotid arteries. These break into many smaller arteries (rete mirabilia) as they pass through a venous sinus.

Venous blood in that sinus has been passed through the nasal passages, where it has been cooled by evaporative cooling and is now cooler than Tb.

Keeps brain from overheating, esp. when they run away from predators.

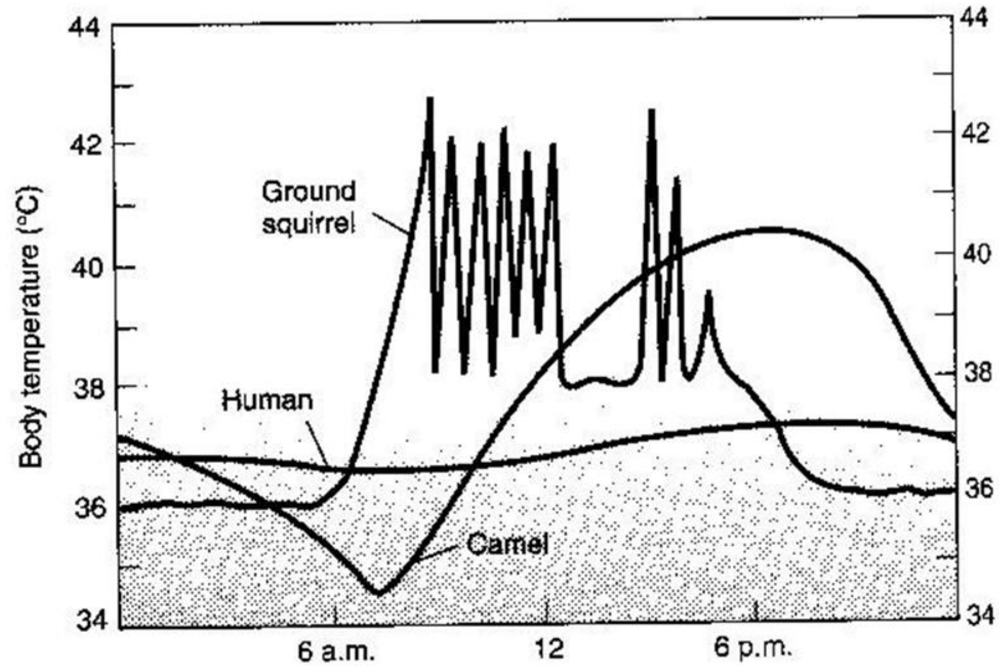
Gazelle brains have a counter-current system to help keep them cool.

antelope ground squirrel



Some small mammals in deserts are diurnal. They rely on short bursts of activity, cooling off in burrows or cool microhabitats. Tolerate short periods of hyperthermia. Activity patterns vary seasonally.

FIGURE 21-11 Daily patterns of body temperature change in three mammals subjected to desert heat. Note that the antelope ground squirrel *(Ammospermophilus leucurus)* goes through a series of heating-cooling cycles during the day, while the camel slowly becomes hyperthermic as the day progresses. *(After Bartholomew, 1964)*



Compare daily body temp fluctuations of a diurnal ground squirrel and a camel!

Thermal windows: areas with low insulation and often high vascularization that can be used to dump heat.

desert jack rabbit

ibex

Why do elephants have such big ears?

The African elephant (above) provides an extreme example of the skin's thermoregulatory function. The front of the animal's ear (left photo) shows the ear's great size relative to its head and body—but very thick skin. Notice the lighter areas—these are highly keratinized patches. The back of the ear reveals very large vessels near the surface of the very thin skin (no light patches). The elephant can regulate heat loss through its ears by exposing or not exposing the back of the ear, and dilating or constricting blood vessels.

Finally, some small mammals stay underground and relax their Tb during stressful hot periods.

Like hibernation, but called estivation.

Kangaroo mice hibernate in winter, estivate in summer!

Study questions for physiological ecology lectures:

1. Be able to describe some ways that mammals use behavior to cope with cold ambient temperatures (including thermal advantages of nests and burrows, huddling).

2. How does hair function as an insulator?

3. Describe 2 main types of vascular arrangements that mammals use to help with thermoregulation. (hint: shunts and counter-current systems)

4. How does brown adipose tissue (BAT) differ from ordinary white adipose tissue? (think structure, function, and placement within body) How does it generate heat?

5. Contrast the physiological changes in marmots and bears during hibernation. Consider changes in body temperature, heart and breathing rates, and active suppression of BMR. Why might some people claim that bears don’t really hibernate? How does hibernation differ from torpor?

6. What enables a deep-diving marine mammal to stay under water for so long? Describe both anatomical features and physiological responses during diving.

7. Water conducts heat about 25X faster than air. Describe some ways that marine mammals reduce or regulate loss of body heat to the marine environment.

8. What is the main mechanism used by terrestrial mammals to get rid of excess heat? Why is this method a problem for mammals in hot deserts, especially small mammals?

9. Describe how a camel, or a kangaroo rat, copes with the stressful environment of a hot, dry desert.

10. Graphically compare the pattern of daily fluctuations in body temperature in a large desert mammal (like a camel) and a small, diurnal desert mammal (like an antelope ground squirrel). Explain what is going on in each pattern (ground squirrel vs camel).

11. Describe how the counter-current exchange system in a kangaroo rat's nasal passages help it to conserve water, and how the counter-current exchange system in the flow of blood to the brain of a gazelle help keep it's brain from over-heating.

12. What is a thermal window, and give a mammalian example. How does an elephant use its ears to thermoregulate?