“When it is seventy five below zero, a man must not fail in his first attempt to build a fire – that is, if his feet are wet.”

- Jack London, *To Build a Fire*
The Thermal Environment

• Fluctuations in temperature of the physical environment are a challenge for all animals

• Hot temperatures
  - denature proteins
  - accelerate chemical processes
  - affect properties of lipids
  - typical upper limit for most animals: 45° C

• Cold temperatures
  - disrupt life processes (slow chemical reactions)
  - ice crystals damage cell structures

• How do animals cope with this challenge?
Poikilothermy

- **Poikilotherms**: Internal body temperature ($T_b$) fluctuates with that of the ambient environment ($T_a$)

![Graph showing the relationship between $T_b$ and $T_a$](graph.jpg)

Advantages of Poikilothermy

- Reptiles and amphibians (also fish)
- Low energy expenditure
  - can live without food for long time
- Can be very small
  - heat loss not an issue

Oregon spotted frog ($Rana pretiosa$)
Costs of Poikilothermy

- Inability to exploit cold environs
- Impaired performance prior to warming up; reduced stamina
  - depleted energy stores recovered slowly

Homeothermy

- Homeotherms: maintain a constant internal body temperature ($T_b$)
Homeotherms

- Primarily **endothermic** birds and mammals
  - endotherms produce body heat internally (from metabolism)
  - known colloquially as “warm-blooded”
  - typical $T_b$ is 35-42° C

- Are all homeotherms also endothermic?
  - **no**
  - some are **ectothermic** (derive warmth from the ambient environment)
    - i.e., some homeotherms are actually species we would call “cold-blooded”!
  - ectotherms can maintain stable $T_b$ via behavioral regulation (described shortly)
Natural History Aside

- Are any animals other than birds and mammals endothermic?
  - yes
  - some fishes (tuna)
  - also, at least one reptile…
Leatherback turtle (*Dermochelys coriacea*)

- Can live in very cold waters at high latitudes, also found in warm waters near the equator
- Huge – up to 900 kg
- Deep divers – 1280 meters (4200 ft)
- Travel avg of 6000 km between nesting beaches and foraging grounds
- Produce heat internally (metabolically)
  - heat conserved because of large body size
  - allows for swift movement, even in cold water
    - up to 36 km/h (22 mph)
  - reduce activity to dissipate heat when in warm water
  - internal body temperature relatively stable despite extreme variation in external environment
    - ~ 25° C

Bostrom et al. (2010) *PLoS ONE*
Advantages of Homeothermy

- Can live and function optimally in a wide variety of environments
  - homeotherms found from deserts and the tropics to the arctic

- Greater stamina
  - depleted energy supplies recovered more rapidly

- Can respond rapidly to environmental stimuli
  - don’t need to warm up

Costs of Homeothermy

- Homeotherms use enzymes that are specialized for a narrow range of body temperature
  - over-cooling and over-heating can lead rapidly to reduced performance, death

- Great deal of energy required to maintain $T_b$ outside of thermo-neutral zone (TNZ)
  - homeotherms must eat lots of food
  - especially true for small homeotherms
    - high surface-to-volume ratio
    - rapidly lose heat to the ambient environment
  - energetic cost of homeothermy has led to two trends
Allen’s Rule

• Homeothermic species (and populations within polytypic species) living in cold climates tend to have smaller extremities (limbs, tails, ears)
  - e.g., the Genus *Lepus* (hares) in North America

Bergmann’s Rule

• Homeothermic species (and populations within polytypic species) living in cold climates tend to be larger
  - lots of small critters in the tropics
  - e.g., North American bears
Adaptations for Homeothermy

• Three kinds
  - Structural
  - Physiological
  - Behavioral

• Adaptations can either prevent
  - over-cooling (hypothermia), or
  - over-heating (hyperthermia)

Structural Adaptations for Avoiding Hypothermia

• Hypothermia – the condition of having a body temperature ($T_b$) below the normal range
  - impedes proper enzyme function, leads to impaired performance, death

• Fur
  - Guard hairs and underfur reduce heat loss by trapping a layer of air, which is then warmed

Musk ox (Ovibos moschatus)
Structural Adaptations for Avoiding Hypothermia

- **Feathers**
  - “fluffing” traps air, which is then warmed
  - oil matting leads to hypothermia
- **Blubber**
  - thick, insulative layer of adipose (fat) tissue found under skin
  - marine mammals (cetaceans, pinnipeds)

[Image of Weddell seal (Leptonychotes weddelli)]

Physiological Adaptations for Avoiding Hypothermia

- **Increase heat production**
  - activity (elevated metabolism)
  - shivering
- **Vasoconstriction**
  - narrowing of superficial blood vessels
  - diverts flow of heated blood to the body core
Physiological Adaptations for Avoiding Hypothermia

- **Countercurrent heat exchange**
  - alignment of blood vessels such that arterial blood from core warms up colder venous blood from extremities
  - heat diverted to the core; extremities (e.g., legs or flippers) stay cool, minimizing heat loss
    - weak temperature gradient at interface with ambient environment

- e.g., bare legs of many wading birds
- Why not just feathers?
Physiological Adaptations for Avoiding Hypothermia

- Countercurrent heat exchange
  - e.g., bare legs of many wading birds
  - Why not just feathers?
  - Expensive care for feathers (mud, matting, etc.)
  - Also good for heat dissipation (heat in venous blood stays in the legs)

Behavioral Adaptations for Avoiding Hypothermia

- Migration
  - avoid cold weather
  - elevational
    - e.g., deer
  - latitudinal (N-S)
    - birds, bats, whales

- Burrowing
  - in snow or ground
  - e.g., grouse (in snow)
Behavioral Adaptations for Avoiding Hypothermia

- Change posture
  - e.g., curl up
- Form tightly packed groups
  - e.g., quail, bison

Bison (Bison bison)

Behavioral Adaptations for Avoiding Hypothermia

- Hibernation
  - state of torpor characterized by depressed metabolism and temperature (reduced heating costs)
  - can last days to weeks
  - typically, basal metabolic rate is reduced to 2-4% of normal rates and $T_b$ is maintained within a few degrees above ambient temperatures
  - common in ground squirrels, bats
  - Interestingly, some species hibernate without dropping temperature
    - bears, hummingbirds (at night)
    - more to save energy
Structural Adaptations for Avoiding Hyperthermia

- Hyperthermia – the condition of having a body temperature ($T_b$) above the normal range
  - leads to organ failure, death if persistent

- **Small size**
  - Remember Bergmann’s rule

- **Thermal windows**
  - Birds: gular pouch, feet, legs, face
  - Mammals: face, feet, arm pits, belly
    - remember Allen’s rule
    - hairlessness in humans: signature of evolution as runners?

Physiological Adaptations for Avoiding Hyperthermia

- **Evaporative cooling**
  - Mammals: sweating, panting
  - Birds: no sweat glands, so evaporation via lungs, air sacs, gular pouch
    - accomplished by panting, gular fluttering

*Gular pouch of the male frigate bird (Fregata magnificens)*
Inflated to attract females
Physiological Adaptations for Avoiding Hyperthermia

- **Vasodilation**
  - expansion of peripheral blood vessels to dissipate heat

- **Countercurrent heat exchange**

- **Heat storage**
  - effective for large mammals, birds
  - body volume absorbs heat during day, lost passively at night
  - e.g., camels

Behavioral Adaptations for Avoiding Hyperthermia

- **Reduce activity**
  - Lower metabolism, minimize heat production

- **Increase water intake**

- **Seek cooler activity times and space, heat dissipating opportunities**
  - become crepuscular, nocturnal
  - shade, vegetation to reduce heat gain
  - shift activity space toward water
  - shift activity space underground (become fossorial)
Another Natural History Aside

- Behavioral homeothermy in an ectotherm…

Behavioral Homeothermy in an Ectothermic Lizard

- Lacertid lizard (*Podarcis hispanica atrata*)
- Columbretes Archipelago, Mediterranean Sea (province of Spain)
- Maintain relatively stable $T_b$ by selecting for narrow range of ambient thermal conditions
  - Using sunny microsites
  - Adopting basking posture

![Graph](image1.png)

**Fig. 1.** Distributions of body temperature ($T_b$) in a population of *Podarcis hispanica atrata* and available operative temperature ($T_e$) during early autumn. The shaded area identifies the selected temperature range ($T_{sel}$).

Bauwens et al. (1996) Ecology