Thermal Strategies: Chapter 9

1. Two main types
   A. Tolerance
   B. Regulation
2. Both strategies have costs and benefits
3. Do not use “warm-blooded” and “cold-blooded” to describe strategies.

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**Terminology**

1. **Thermal Strategies**
   A. Endothermy
   B. Homeothermy
   C. Heterothermy
   D. Poikilothermy or Ectothermy
2. **Temperature**
   A. Average kinetic energy of a system
   B. Most important aspect of the physical environment for life
3. **Heat**
   A. Temperature depends on the amount of heat contained per unit mass tissue
Overview of Thermal Physiology

1. Thermal energy
   A. influences chemical interactions
2. Thermal strategy
   A. responses that regulate body temperature
3. Ambient temperature
4. Surviving thermal extremes and change
5. Spatial and temporal variation

Physics of heat transfer

1. Heat loss = Heat gain
2. Figure 9.3 An animal exchanges heat with its environment
   A. Conduction
   B. Convection
   C. Evaporation
   D. Radiation

1. Conduction
   A. transfer of heat between 2 bodies in direct contact
2. Convection
   A. transfer of heat to an external fluid that is moving
   B. Conduction rate is increased by convection
3. Evaporation
   A. Water molecules absorb thermal energy
4. Radiation
   A. Emission of electromagnetic radiation
   B. Basking
   C. Animals lose thermal energy when they emit radiant heat
1. Physiological Regulation
   A. Redirect blood flow for increased heat gain-heat loss
   B. Figure 9.5 An antelope jackrabbit

2. Behavioral Thermoregulation
   A. Reposition body relative to heat sources
   B. Figure 9.8 Behavioral thermoregulation documented by comparison of real lizards with inanimate lizard models

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**Effects of Body Temperature Change**

1. Temperature affects the rate of chemical reactions
   A. Affects chemical reactions needed to maintain homeostasis
   B. Too low
      a. metabolism not fast enough to maintain homeostasis
   C. Too high
      a. reactions in metabolic pathways uncouple, enzymes denature, etc.

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**Effects of Temperature Change**

1. Metabolic reactions and metabolic rates vary with temperature.
2. Temperature increases accelerate most physiological processes.
3. A temperature increase of 10 °C typically increases the rate of O$_2$ consumption 2-3-fold.
$Q_{10}$

1. $= \text{increase in physiological rate when } T_{\text{body}} \text{ increases 10 } \degree C$
2. $= \frac{\text{Velocity}_{\text{reaction}}(T + 10\degree)}{\text{V}_{\text{reaction}}(T)}$

A. If the metabolic rate doubles with increase of 10°C, $Q_{10} = 2$.
B. If metabolic rate triples, $Q_{10} = 3$.

Typical $Q_{10}$ values for biological rates (metabolic rate, etc) range from 2 to 3 (doubling or tripling of rate)

1. Figure 9.10 The relation between metabolic rate and body temperature in tiger moth caterpillars (family Arctiidae), plotted in two ways

Figure 9.11 Acclimation of the metabolism–temperature relation to a change in chronic temperature in a poikilotherm
Temperature acclimation

1. Cells may increase the production of certain enzymes to compensate for the lowered activity of enzymes
2. Cells may produce variants of enzymes that have the same function but different temperature optima (Different homologs/isozymes selected to function at the temperature the animal lives at)

Figure 9.18 The affinity of the enzyme lactate dehydrogenase for substrate as a function of temperature

Strategies for Surviving Freezing Temperatures

1. Deleterious effects of ice crystal formation
   A. Ice crystal formation
   B. Supercooling

2. Freeze-avoidance
   A.

3. Freeze-tolerance
   A.
Freeze Avoidance

1. Solutes in general depress the freezing point of a liquid (Supercooling)
2. Antifreeze macromolecules
   A. Freezing point depression
   B. Figure 9.22 Barnacles encased in ice during low tide along a northern seacoast
   C. Figure 9.24 Seasonal changes in antifreeze protection in winter flounder (*Pleuronectes americanus*)

Freeze Tolerance

1. Cryoprotectants
   A. Substances that help animals avoid damage from freezing of body tissues
2. Many freeze tolerant organisms have ice-nucleating agents
   A. Figure 9.23 The process of extracellular freezing in a tissue
   B. Wood frog, *Rana sylvatica* figure 9.28

Figure 9.26 The relation between resting metabolic rate and ambient temperature in mammals and birds
Thermal Zones

1. Mammals and Birds modify conductance, etc. in the Thermal Neutral Zone to alter heat loss.
2. Upper critical temperature
3. Lower critical temperature
4. Below the TNZ
   A. metabolic heat production
   B. metabolic rate increases linearly with decreasing temperature

Figure 9.27 A model of the relation between metabolic rate and ambient temperature in and below the thermoneutral zone

1. Conductance (C) is inversely proportional to insulation (I)
2. $M = \frac{1}{I} (T_b - T_a)$
3. In TNZ, balance between I and Tb-Ta
4. Below LCT, animal needs to generate heat to match heat loss, increase MR
TEMPERATURES ABOVE THERMONEUTRALITY

1. Keeping Cool:
   A. Evaporation
   B. Sweating – humans, camels, antelope, cattle.
   C. Panting – carnivores, sheep, goats.
   D. Saliva spreading by licking
      a. many marsupials & some rodents.
   E. Gular Flutter in birds
      a. vibration of upper throat & floor of mouth.

Maintaining a Constant Body Temperature

1. Endothermy requires high metabolic rate
2. Two components
   A. Mechanisms to retain heat
      a. Modulating Insulation
         • Pilosection
         • Postural Responses
         • Vasomotor Response
            o Altering blood flow to the body surface
   B. Ability to produce heat (thermogenesis)

Thermogenesis

1. Heat is a by-product of metabolic processes
   A. Energy metabolism
   B. Digestion
   C. Muscle activity
2. Shivering Thermogenesis
3. Nonshivering Thermogenesis
   A. Brown Adipose Tissue (BAT)
   B. Figure 9.29 The deposits of brown adipose tissue in newborn rabbits
1. Figure 9.31  A thermal map of an opossum showing regional heterothermy in the pinna of the ear (black). The surface of the ear was close to ambient (10°C)

2. Figure 9.32  Heat loss across appendages is sometimes modulated in ways that aid thermoregulation
Controlling brain temperature

1. Figure 9.35
Structures hypothesized to be responsible for cooling the brain in artiodactyls.

Figure 9.39: Mammalian physiological specialization to different climates

Temporal heterotherms

1. Undergo prolonged changes in body temperature
   A. Hibernation
   B. Aestivation
   C. Daily Torpor
Figure 9.40 Changes in body temperature during hibernation

Figure 9.41 Changes in metabolic rate during daily torpor

Fig. 9.42 Torpor saves energy; Energy savings depend on temperature

Energy increases linearly as ambient temperature decreases for an active animal that maintains a constant body temperature.
Fish that are Regional Heterotherms

1. Retain heat in specific regions of the body

2. Cross section of a tuna showing nature of blood supply to red swimming muscles

Heat Production in Insects Prior to Flight

1. Three mechanisms
   A. Carbohydrate metabolism within flight muscles
   B. Antagonistic flight muscles contract simultaneously
   C. Wing movement

Some insects are part-time endotherms

1. During cool temperatures (0-10°C) some bees and moths can warm their tissues
2. At 37°C they are able to fly.
3. A counter current heat exchanger retains heat in the thorax and abdomen.