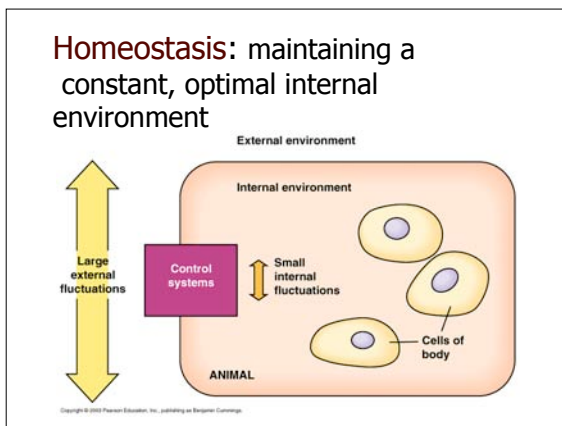
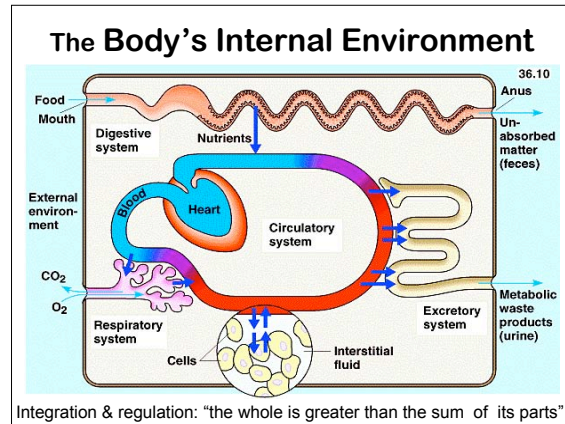
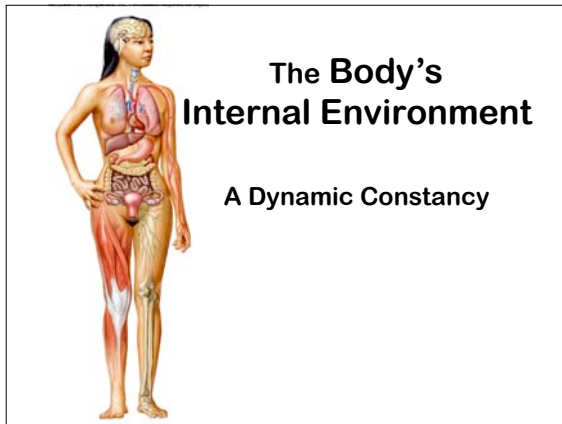


# Homeostasis & Thermoregulation



**Why is Homeostasis so important?**

Among other things...

- Proteins**
  - including the enzymes and other molecular machines that run everything,
- are very sensitive to deviations in conditions
  - Esp., temp & pH
  - protein shape  $\square \neq \square$  fx

(a) Optimal temperature for two enzymes

Enzyme activity vs pH

**Conformers & Regulators**

- Conformers: allow internal environment to conform to external
- Regulators: use control mechanisms to maintain constant internal environment despite external variations
- Note: an organism may be different for different variables
  - The same fish may be a thermoconformer and an osmoregulator

Body temperature (°C) vs Ambient (environmental) temperature (°C)

River otter (temperature regulator)

Largemouth bass (temperature conformer)

otter & bass from same stream

**Conformers vs. Homeostasis?**

- How can they be homeostatic and conforming?
- Live in a stable environment
  - At least with respect to the conformed variable
- and/or
- Be able to make new versions of proteins for each variation
  - Requires larger genome
  - Transition to new condition must be gradual enough to allow sufficient expression of new proteins

Body temperature (°C) vs Ambient (environmental) temperature (°C)

River otter (temperature regulator)

Largemouth bass (temperature conformer)

otter & bass from same stream

# Homeostasis & Thermoregulation

For Example:  
**Thermoregulation**

- **Poikilotherm (variable temp):** body temp ( $T_B$ ) varies with environment temp
- **Homeotherm (same temp):** maintains constant  $T_B$
- **Ectothermic:** most of body's thermal energy acquired from environment
- **Endothermic:** most of body's thermal energy derived from metabolism

otter & bass from same stream

Poikilotherms not necessarily "cold blooded"

## Environmental Heat Transfer

- Radiation: radiant energy absorbed/rereleased as thermal
- Conduction: direct transfer of thermal energy
- Convection: thermal energy absorbed by medium
- Heat of evaporation: evaporating water absorbs energy

## Metabolic Heat Production

- Energy cannot be created nor destroyed
- Energy can be transformed
- All energy transformations lose some energy as heat

## Metabolic Heat Production

Food energy +  $O_2$   $\xrightarrow{\text{Cell respiration}}$   $CO_2 + H_2O + \text{energy}$

ADP  $\xrightarrow{\text{Cell work}}$  ATP  $\rightarrow$  HEAT

**Standard metabolic rate (SMR)— in poikilotherms:**

- Minimum metabolism to produce sufficient ATP for running ion pumps (electrolyte gradients), heart & ventilation muscle activity, etc. (sleeping/fasting) at standard temp

**Basal metabolic rate (BMR)— in homeotherms:**

- SMR + energy demand to keep body warm

## Metabolic Heat Production

Food energy +  $O_2$   $\xrightarrow{\text{Cell respiration}}$   $CO_2 + H_2O + \text{energy}$

ADP  $\xrightarrow{\text{Cell work}}$  ATP  $\rightarrow$  HEAT

↑ cellular work (esp. muscle activity) □  
 ↑ demand for ATP □  
 ↑ metabolic rate □  
 Heat production

## Metabolic Heat Production

Food energy +  $O_2$   $\xrightarrow{\text{Cell respiration}}$   $CO_2 + H_2O + \text{energy}$

ADP  $\xrightarrow{\text{Cell work}}$  ATP  $\rightarrow$  HEAT

**Estimating metabolic rate:**

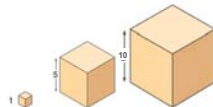
- Measure rate of
  - Net food energy consumption
  - Oxygen consumption
  - Carbon dioxide production
  - Heat production

# Homeostasis & Thermoregulation

Once again, ...

## Size Matters!

- **Heat exchange** with the environment is proportional to body **surface area** ( $x^2$ )
- **Heat generation** from metabolism is proportional with body **mass** (or volume =  $x^3$ )
- $\uparrow x \square \uparrow x^3$  increases faster than  $\uparrow x^2$ 
  - **Small organisms** have a **large sa/v** ratio
    - Ectothermy favored
  - **Large organisms** have a **small sa/v** ratio
    - Endothermy favored

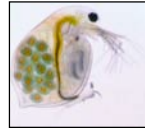


Total surface area (height x width x number of sides)	6	150	600
Total volume (height x width x length)	1	125	1000
Surface-to-volume ratio (surface area ÷ volume)	6	1.2	0.6

## Environment also matters!

Conduction & Convection in Aquatic vs. Terrestrial —

- Water absorbs heat energy 50–100x faster than does air!



- It's near impossible for a small aquatic organism to be endothermic
- It's near impossible for a large terrestrial organism to be ectothermic

## Size & Environment Matter!

Conduction & Convection in Aquatic vs. Terrestrial —

- Water absorbs heat energy 50–100x faster than does air!

Marine iguanas of the Galapagos

- Juveniles & adult females feed on exposed intertidal alga
- Only large males have sufficient body mass to generate enough heat to forage underwater



## Poikilotherms — toleration ≠ thriving

Even if can survive  $\square$  temps, do best in a small range

- $\uparrow \uparrow T_b \square \uparrow$  stress & mortality
- $\square \square T_b \square \square$  metabolic rate & activity
- Lizards —
  - $\square$  discrimination in T-maze tests
  - $\square$  behavior: warm lizards flee; cool lizards threaten



Western fence lizard

## Poikilotherms — Tolerating extreme cold

How can your proteins work below freezing?

- Make unsaturated fats in membranes to remain fluid
- Concentrate antifreeze alcohols (esp. glycerol) in tissues to lower freezing point
- Synthesize ice-binding proteins to prevent ice crystals from growing



Ice fish under the polar ice cap

## Poikilotherms — Tolerating extreme cold

How can your proteins work below freezing?

- **Give up! — Go dormant**
- Largest land animals in Antarctica are tiny mites & springtails — freeze quickly most of year; thaw quickly to scavenge seal castings in brief warm season
- Frogs and others:
  - ice on skin  $\square$  adrenalin rush
  - $\square$  liver glycogen released as glucose
  - $\square$  cells concentrate glucose to lower freezing point
  - 67% of body freezes solid, but cells remain fluid down to  $-5^\circ\text{C}$ .
  - Regains activity within hours of thawing



A frozen arctic wood toad

### Homeotherms

- Behavioral homeothermy
- Physiological homeothermy
- Anatomical homeothermy
- Part-time homeothermy
- (combinations of any/all of the above)

### Behavioral Homeothermy

- Live in a stable environment  
or
- Move with the constant conditions



### Behavioral Homeothermy

- Seek shade/wet to cool off
  - Kangaroos lick their legs.
  - Camels pee on them
- Orient body to minimize radiation



burrowing



bathing

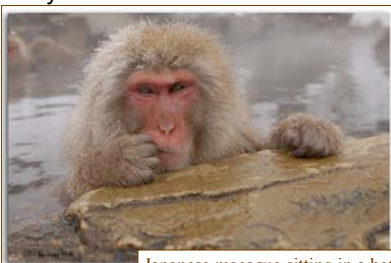
### Behavioral Homeothermy

- Seek sun/dry to warm up (basking)
- Orient body to maximize radiation



### Behavioral Homeothermy

- Seek sun/dry to warm up (basking)
- Or maybe some wet heat!



Japanese macaque sitting in a hot spring

### Behavioral Homeothermy

- Seek/conservate body heat

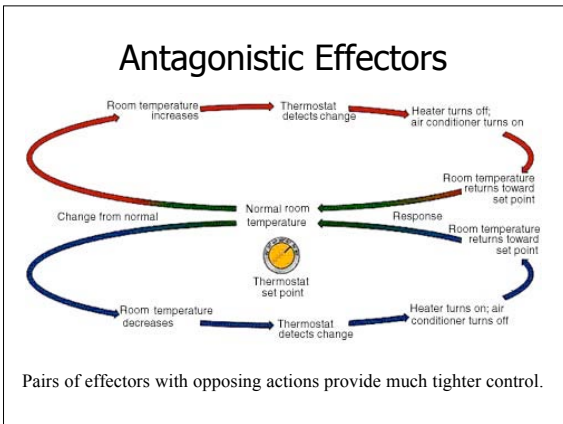
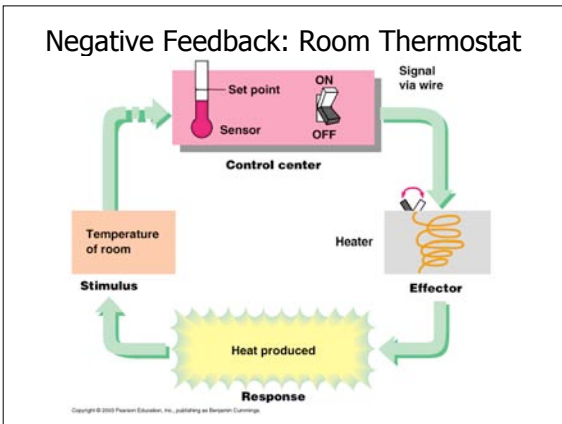
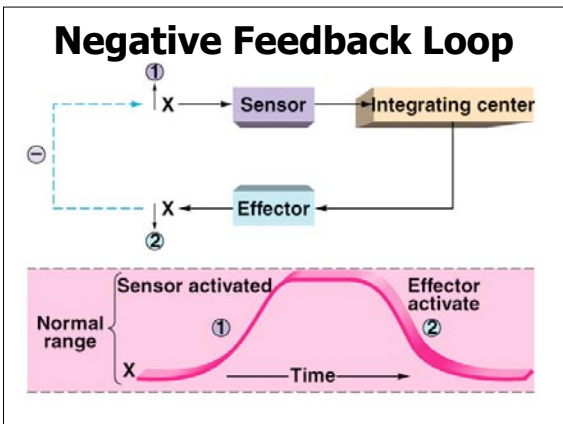
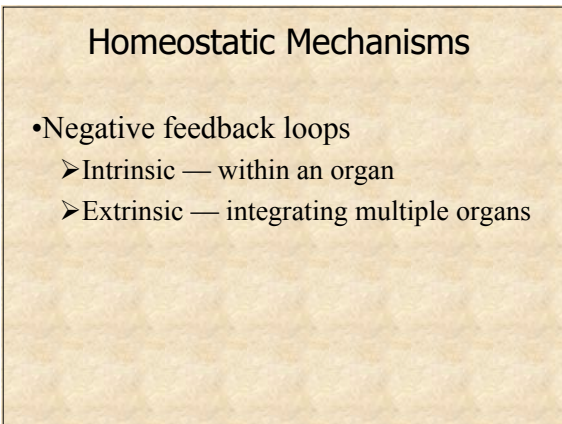
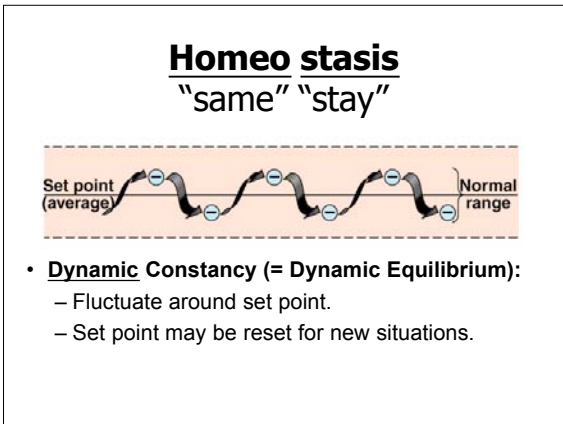
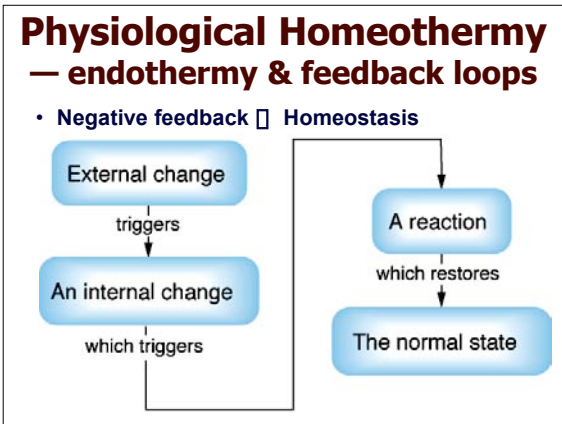


huddling



Sleep curled up

# Homeostasis & Thermoregulation

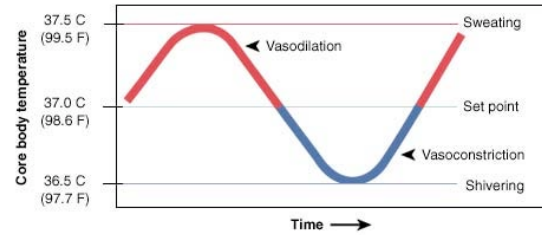


# Homeostasis & Thermoregulation

## Endothermic Effector Sets

- Heat producer:** metabolic heat,
    - esp. from **muscle**
  - Heat exchanger:** integument system
  - Heat convection** between producer & exchanger: **circulatory system**
- \* In addition to these effectors, need nervous & endocrine systems to integrate & coordinate actions

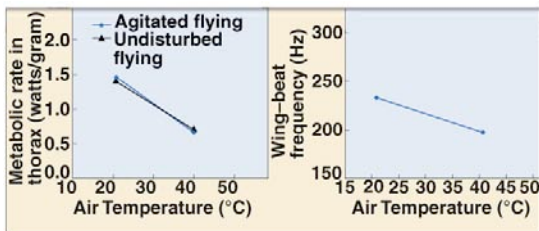
## Endothermic Effector Sets



Redundant effectors allow stronger responses to stronger deviations.

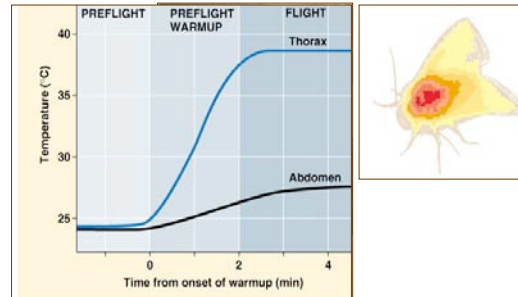
## Heat Production — muscle activity

- Some insects may fly inefficiently, just to generate enough heat to keep warm



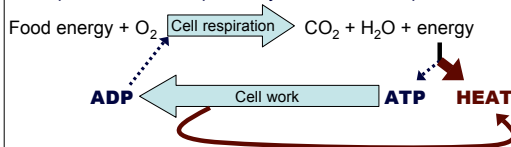
## Heat Production — muscle activity

- Shivering:** "ineffective" muscle contractions

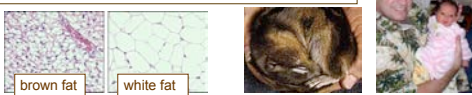


## Heat Production — another effector?

- Non-shivering thermogenesis:** uncoupling ATP production so respiration yields more heat per unit fuel

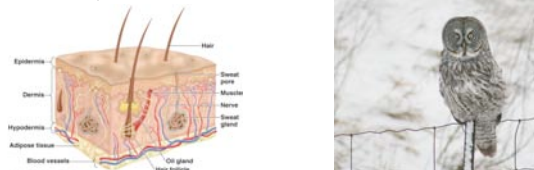


Esp. in brown fat of newborn & hibernating mammals



## Heat Exchange — integument


- Skin:**
  - **Epidermis:** Pigments reduce/enhance radiant absorption
  - **Dermis:** produce hair or feathers □ trap air space
    - convection, conduction, & evaporation
    - Pigments further reduce/enhance radiant absorption
  - **Hypodermis:**
    - Blood vessels regulate convective loss of metabolic heat
    - Adipose tissue insulates from conductive transfer



# Homeostasis & Thermoregulation


## Heat Exchange — integument

- Increase insulation by increasing fat layer — blubber



## Heat Exchange — integument

- Sea otters — problem: small; no blubber; live in cold water
- Increase insulation by increasing hair density
- Increase heat production by increased metabolic rate



### Hair Density of 3 Mammals

Animal	Hairs per Square cm
Human	~100,000
Rat	~100,000
Sea Otter	~160,000

Insulation


### Average Daily Schedule for Sea Otter

Activity	Percentage
Eating	~25%
Sleeping	~25%
Grooming	~50%

Metabolism Must eat 25% of body weight in food per day!  
Like a 150 pound person having to eat 125 hamburgers per day!!!

## Heat Exchange — integument

- Polar bears — large, thick fat layer & fur
- Black skin absorbs radiant energy — fur acts as light guide to direct sunlight to skin while appearing white
- High calorie diet to support increased metabolic rate



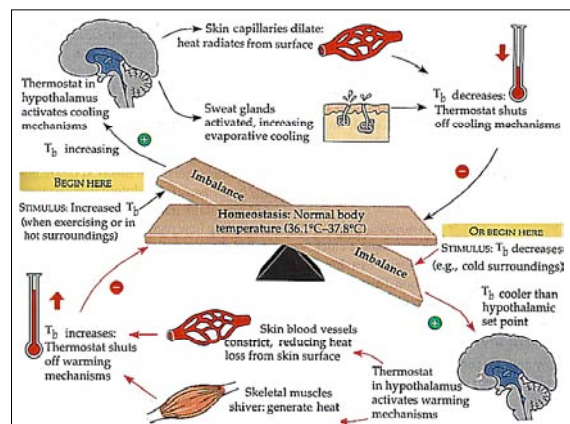
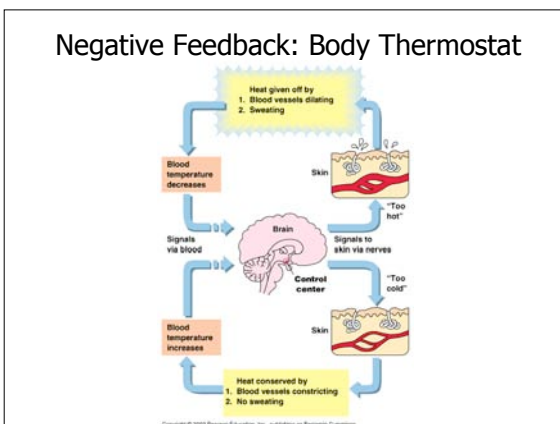
## Heat Exchange — integument

- Evaporative cooling: evaporating water absorbs much heat energy
- Wet epidermis cools much faster 540 calories/g water evaporated
- IF you can afford the water loss!




sweating

panting



# Homeostasis & Thermoregulation

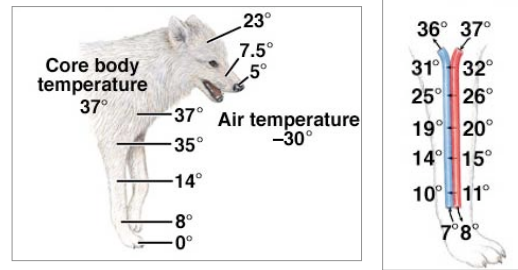
## Blood flow & heat transfer

- **Radiators:** Increase cooling by vasodilation to long, thin appendages



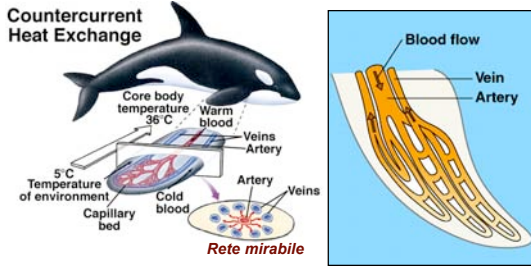
## Blood flow & heat transfer

- **Counter-current exchangers:** Decrease heat loss — reclaim it in returning blood flow
- Marine mammals, arctic homeotherms, sloths



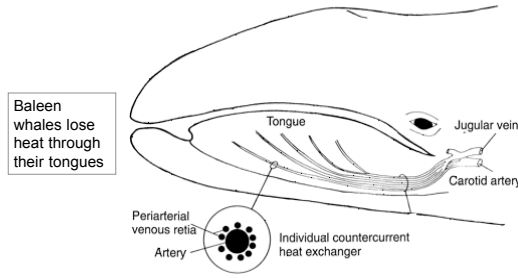
## Blood flow & heat transfer

- **Counter-current exchangers:** Decrease heat loss — reclaim it in returning blood flow
- Marine mammals, arctic homeotherms, sloths



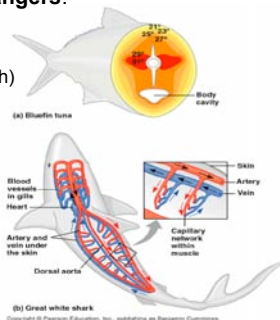
## Blood flow & heat transfer

- **Counter-current exchangers:** Decrease heat loss — reclaim it in returning blood flow
- Marine mammals, arctic homeotherms, sloths



## Blood flow & heat transfer

- **Counter-current exchangers:**
- Also in large-body, active, endothermic poikilotherms (lamnid sharks, tunas, billfish)
- $T_B$  not constant, but swimming muscles, brain & eyes may be 10–15° warmer than ambient ocean temp



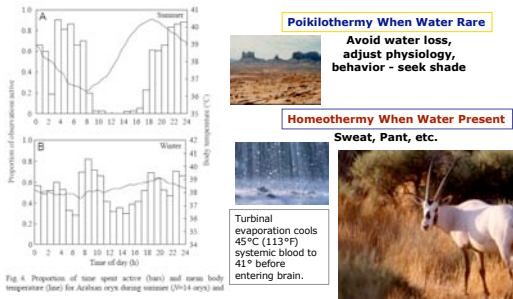
## Dynamic Constancy

- Fluctuate around set point.
- Set point may be reset for new situations.
- $T_B$  at times of low activity (sleep)
- $\uparrow T_B$  to fight infection (fever)

# Homeostasis & Thermoregulation

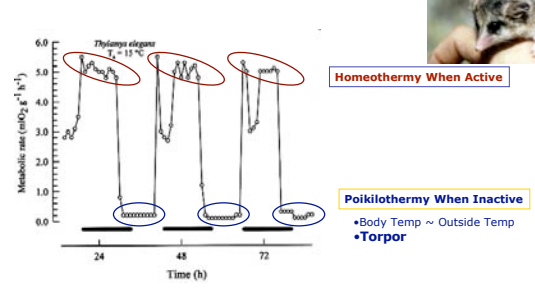
## Part-time Homeothermy

- Using physiological homeothermy *only under certain conditions*
- Arabian oryx — when water is available



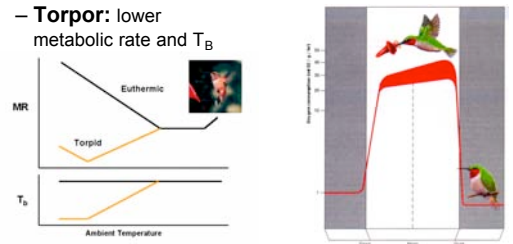
## Part-time Homeothermy

- Using physiological homeothermy *only under certain conditions*
- Mouse Opossum — when food intake is sufficient



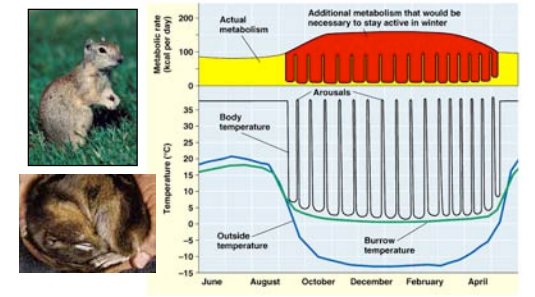
## Part-time Homeothermy

- Using physiological homeothermy *only under certain conditions*
- Hummingbird
  - Small body = high metabolism
  - Can't store enough energy overnight
  - Torpor:** lower metabolic rate and  $T_B$



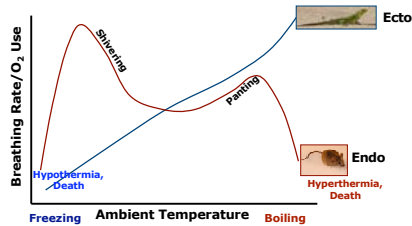
## Part-time Homeothermy

- Long-term torpor = **hibernation**
- Belding ground squirrels



## Endothermic-Homeotherms vs. Ectothermic-Poikilotherms

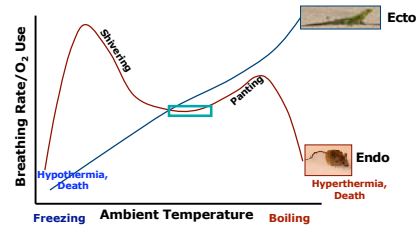
— relative advantages



General Rules:  
Endotherms use more  $O_2$ /metabolism as outside temp  $\uparrow$   
Ectotherms use less  $O_2$ /metabolism as outside temp  $\uparrow$

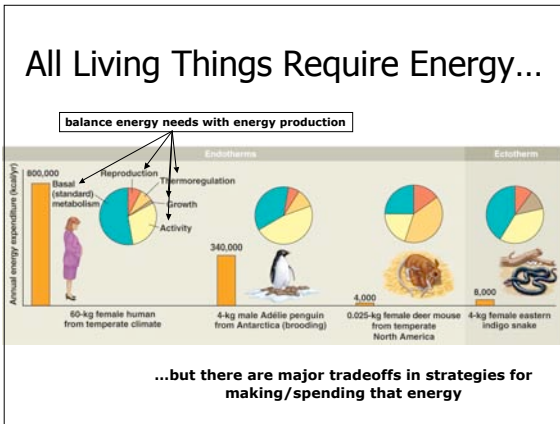
## Endothermic-Homeotherms vs. Ectothermic-Poikilotherms

— relative advantages



**Thermal Neutral Zone** — temperature range requiring the lowest metabolic rate in endotherms

# Homeostasis & Thermoregulation



### Endothermic-Homeotherms vs. Ectothermic-Poikilotherms

— relative advantages

	Endothermic-Homeotherms	Ectothermic-Poikilotherms
Advantages	Activity level independent of environmental temp	Low food energy demands
Disadvantages	High food energy demands	Activity level dependent on environmental temp
Selection	Favored in high nutrient environments	Favored in low nutrient environments



- ### Adjusting to a new environment
- **Aclimatization:** an *organism* gradually
    - metabolic rate, thickness of fat/fur/feathers; enzyme expression; etc.
    - **Aclimation:** adjusting to an artificial change
  - **Adaptation:** a *population* shifts its characters over many generations
    - **Bergmann's Rule:** species farther from the equator have larger body mass (cooler climate □ □sa/v ratio)
    - **Allen's Rule:** colder climates □ shorter appendages; warmer climates □ longer