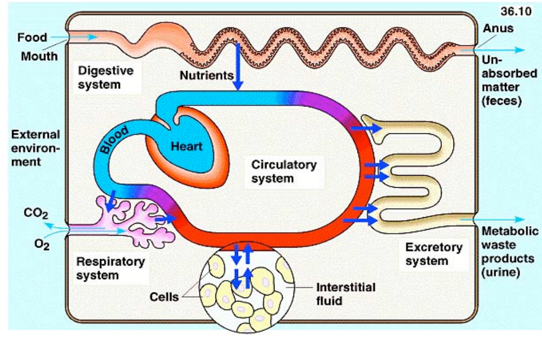
The Body's Internal Environment

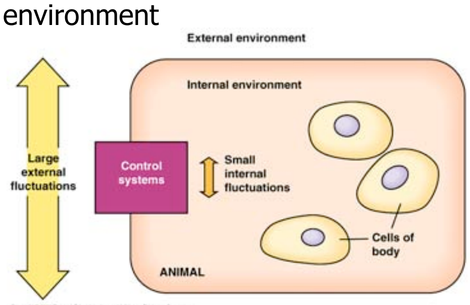
A Dynamic Constancy

The Body's Internal Environment



Integration & regulation: "the whole is greater than the sum of its parts"

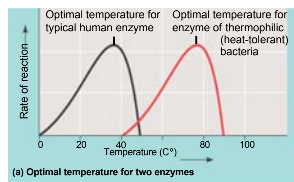
Homeostasis: maintaining a constant, optimal internal environment

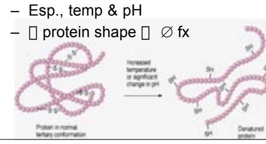


Why is Homeostasis so important?

Among other things…

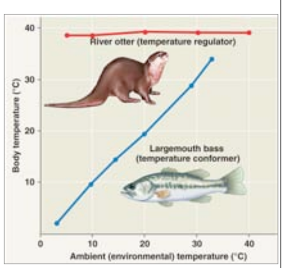
- **Proteins**
  - including the enzymes and other molecular machines that run everything,
- are very sensitive to deviations in conditions
  - Esp., temp & pH
  - □ protein shape □ ∅ fx





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



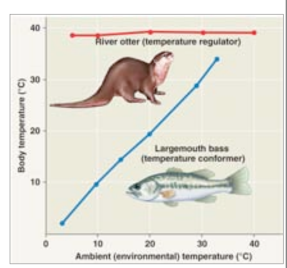
otter & bass from same stream

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

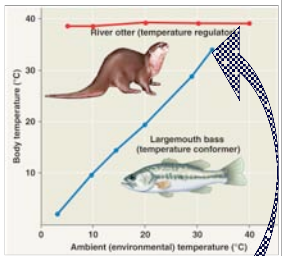


otter & bass from same stream

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

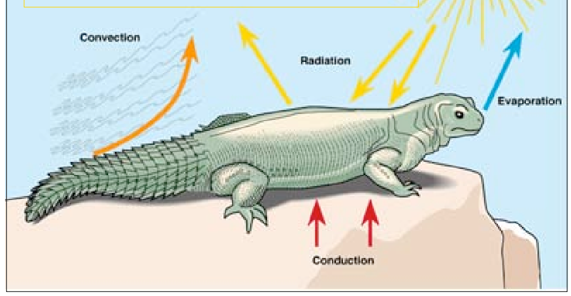


otter & bass from same stream

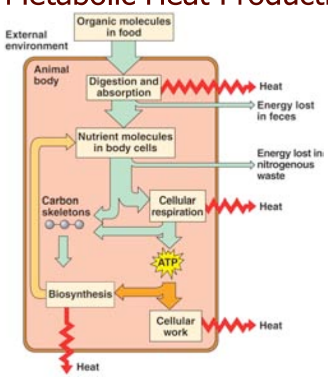
Poikilotherms not necessarily "cold blooded"

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

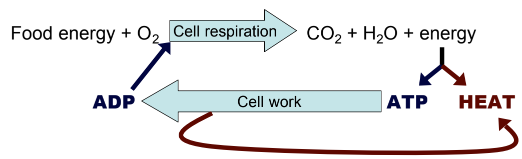


Metabolic Heat Production



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

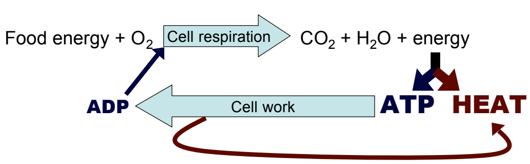
Metabolic Heat Production



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

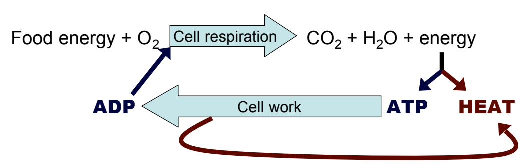
Basal metabolic rate (BMR)— in homeotherms:
- SMR + energy demand to keep body warm

Metabolic Heat Production



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

Metabolic Heat Production

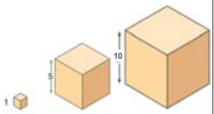


Estimating metabolic rate:
- Measure rate of
  - Net food energy consumption
  - Oxygen consumption
  - Carbon dioxide production
  - Heat production

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)
- ↑x □ ↑x^3 increases faster than ↑x^2
  - **Small organisms** have a **large sa/v** ratio
    - **Ectothermy** favored
  - **Large organisms** have a **small sa/v** ratio
    - **Endothermy** favored

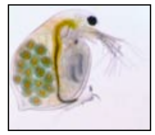


Total surface area (height × width × number of sides	6	150	600
Total volume (height × width × length	1	125	1000
Surface-to-volume ratio (surface area ÷ volume)	6	1.2	0.6

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 □ temps, do best in a small range

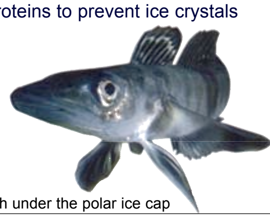
- ↑↑T_B□ ↑stress & mortality
- □□T_B□ □metabolic rate & activity
- Lizards —
  - □ discrimination in T-maze tests
  - □ behavior: warm lizards flee; cool lizards threaten

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

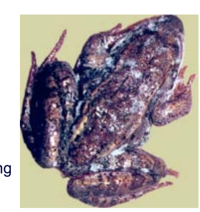


Ice fish under the polar ice cap

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□ adrenalin rush
    □ liver glycogen released as glucose
    □ cells concentrate glucose to lower freezing point
  - 67% of body freezes solid, but cells remain fluid down to –5°C.
  - Regains activity within hours of thawing



A frozen arctic wood toad

Homeotherms

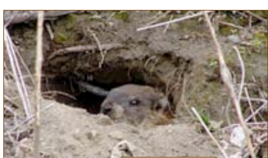
- **Behavioral homeothermy**
- **Physiological homeothermy**
- **Anatomical homeothermy**
- **Part-time homeothermy**
- **(combinations of any/all of the above)**

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

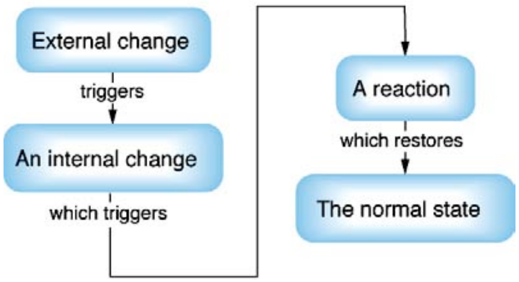
- Seek/conserve body heat

huddling

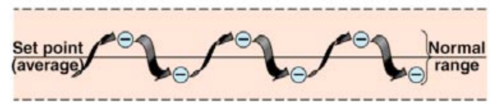
Sleep curled up

Physiological Homeothermy — endothermy & feedback loops

- **Negative feedback Homeostasis**



Homeo stasis
"same" "stay"

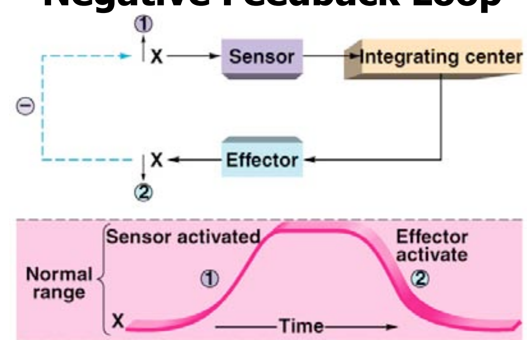


- **Dynamic Constancy (= Dynamic Equilibrium):**
  - Fluctuate around set point.
  - Set point may be reset for new situations.

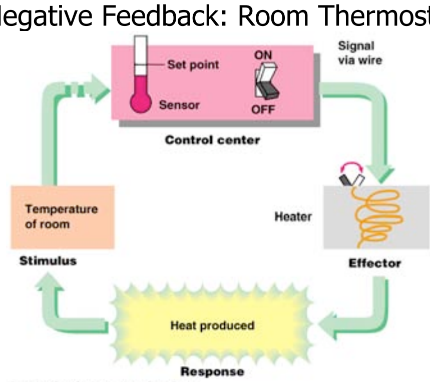
Homeostatic Mechanisms

- Negative feedback loops
  - Intrinsic — within an organ
  - Extrinsic — integrating multiple organs

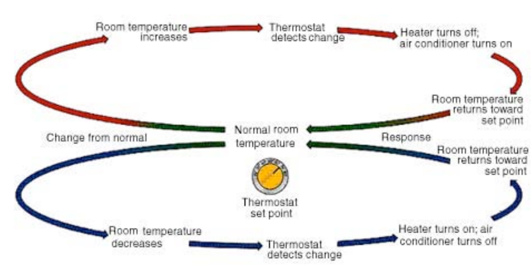
Negative Feedback Loop



Negative Feedback: Room Thermostat



Antagonistic Effectors



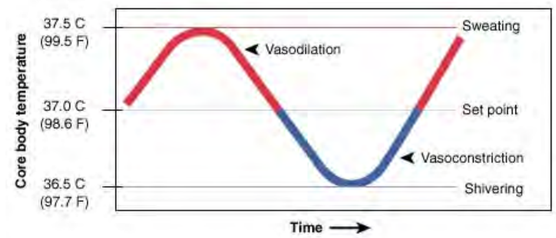
Pairs of effectors with opposing actions provide much tighter control.

Endothermic Effector Sets

1. **Heat producer**: metabolic heat,
   – esp. from **muscle**
2. **Heat exchanger**: **integument** system
3. **Heat convection** between producer & exchanger: **circulatory system**

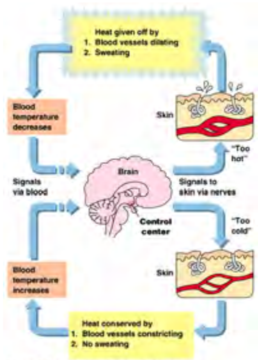
* In addition to these effectors, need nervous & endocrine systems to integrate & coordinate actions

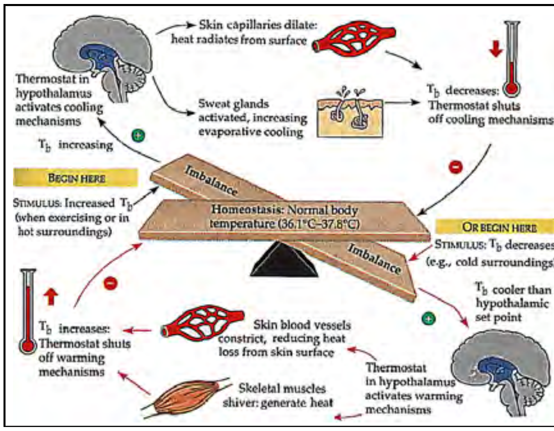
Endothermic Effector Sets



Redundant effectors allow stronger responses to stronger deviations.

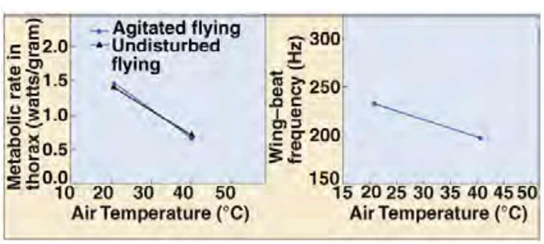
Negative Feedback: Body Thermostat





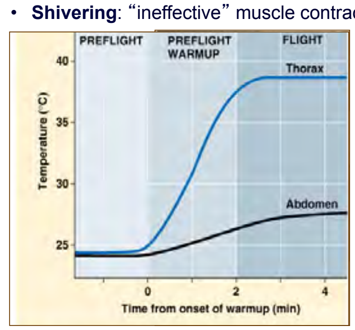
Heat Production — muscle activity

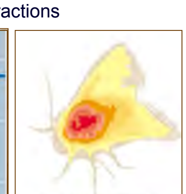
- Some insects may fly inefficiently, just to generate enough heat to keep warm



Heat Production — muscle activity

- **Shivering**: "ineffective" muscle contractions





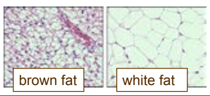
Heat Production — another effector?

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

Food energy + O_2 → (Cell respiration) → CO_2 + H_2O + energy

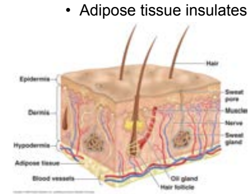
ADP ← (Cell work) ← ATP → **HEAT**

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

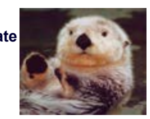


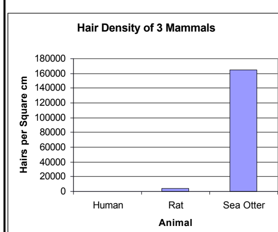
Heat Exchange — integument

- **Increase insulation by increasing fat layer — blubber**

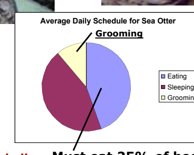
Heat Exchange — integument

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





Insulation



Metabolism **Must eat 25% of body weight in food per day!**

Like a 150 pound person having to eat *125 hamburgers* per day!!!

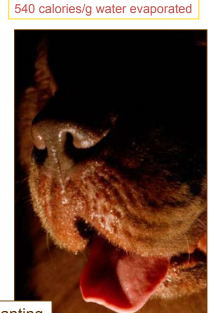
Heat Exchange — integument

- **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!**

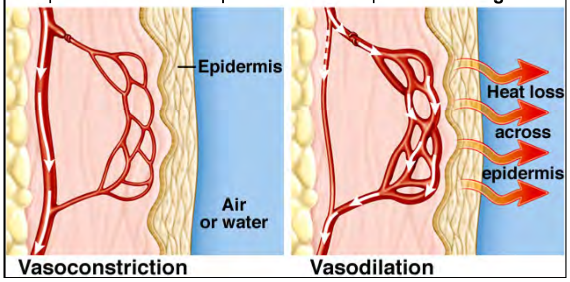
sweating



panting

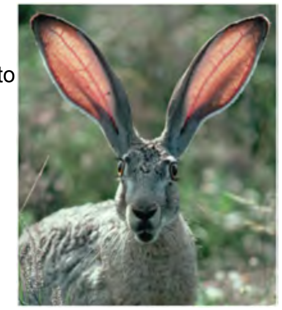
Blood flow & heat transfer
Regulation of Heat Loss

- ↑blood flow and/or ↑surface area → ↑ heat exchange



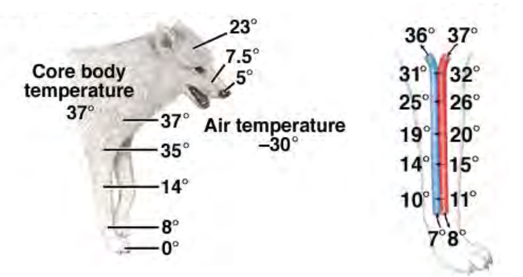
Blood flow & heat transfer

- **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



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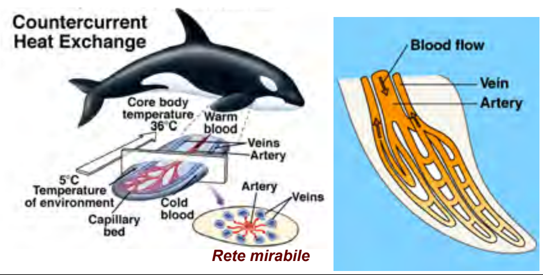

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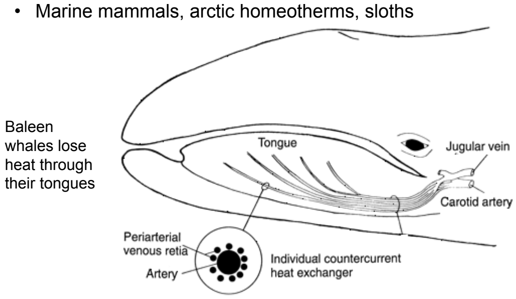
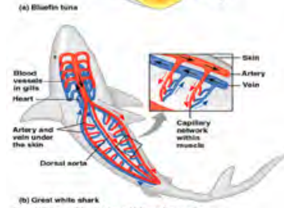


Blood flow & heat transfer

- **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

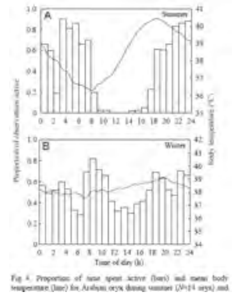
– Fluctuate around set point.

– **Set point may be reset for new situations.**

- **↓T_B at times of low activity (sleep)**
- **↑ T_B to fight infection (fever)**

Part-time Homeothermy

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



Poikilothermy When Water Rare

Avoid water loss, adjust physiology, behavior - seek shade

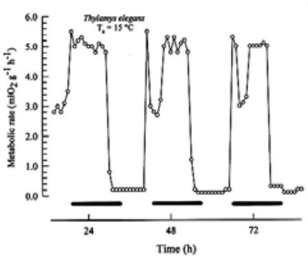
Homeothermy When Water Present

Sweat, Pant, etc.

Turbinal evaporation cools 45°C (113°F) systemic blood to 41° before entering brain.

Part-time Homeothermy

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



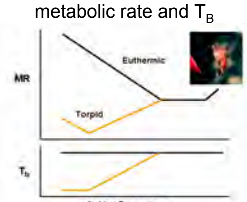
Homeothermy When Active

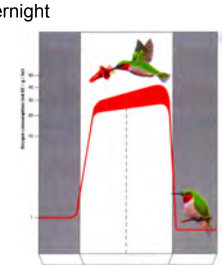
Poikilothermy When Inactive

•Body Temp ~ Outside Temp
•Torpor

Part-time Homeothermy

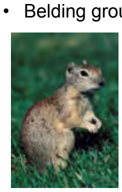
- Using physiological homeothermy *only under certain conditions*
- Hummingbird
  - Small body = high metabolism
  - Can't store enough energy overnight
  - **Torpor:** lower metabolic rate and T_B

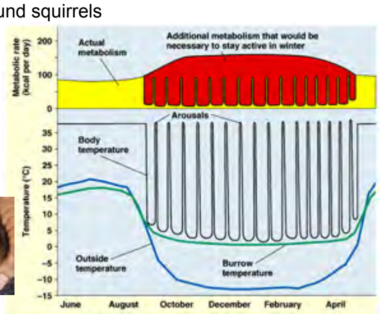




Part-time Homeothermy

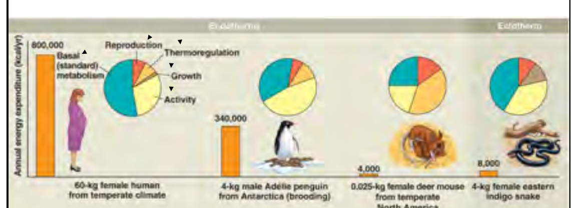
- Long-term torpor = **hibernation**
- Belding ground squirrels





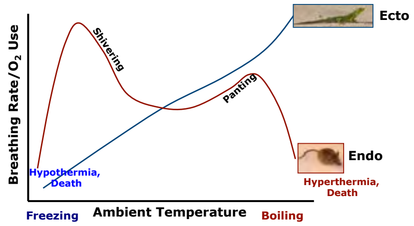
All Living Things Require Energy…

balance energy needs with energy production



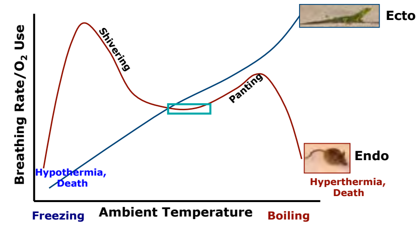
…but there are major tradeoffs in strategies for making/spending that energy

Endothermic-Homeotherms vs. Ectothermic-Poikilotherms — relative advantages

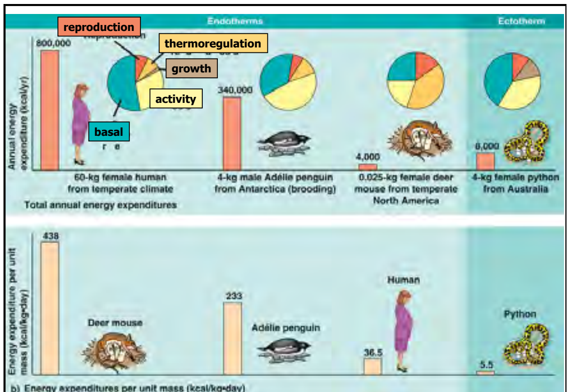


General Rules:
Endotherms use *more* O_2/metabolism as outside temp↓
Ectotherms use *less* O_2/metabolism as outside temp↓

Endothermic-Homeotherms vs. Ectothermic-Poikilotherms — relative advantages

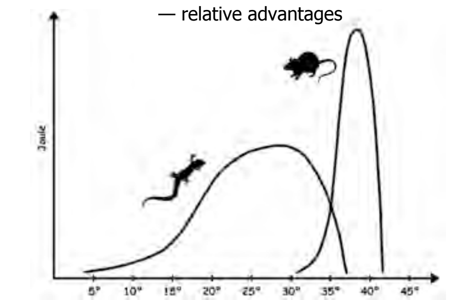


Thermal Neutral Zone — temperature range requiring the lowest metabolic rate in endotherms



Energy Budgets

Endothermic-Homeotherms vs. Ectothermic-Poikilotherms — relative advantages



Sustained energy output (Joule) of a poikilotherm (lizard) and a homeotherm (mouse) as a function of core body temperature. The hometherm has a much higher output, but can only function over a very narrow range of body temperatures.

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 Δ 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 father from the equator have larger body mass (cooler climate → ↓sa/v ratio)
  - **Allen's Rule**: colder climates → shorter appendages; warmer climates → longer