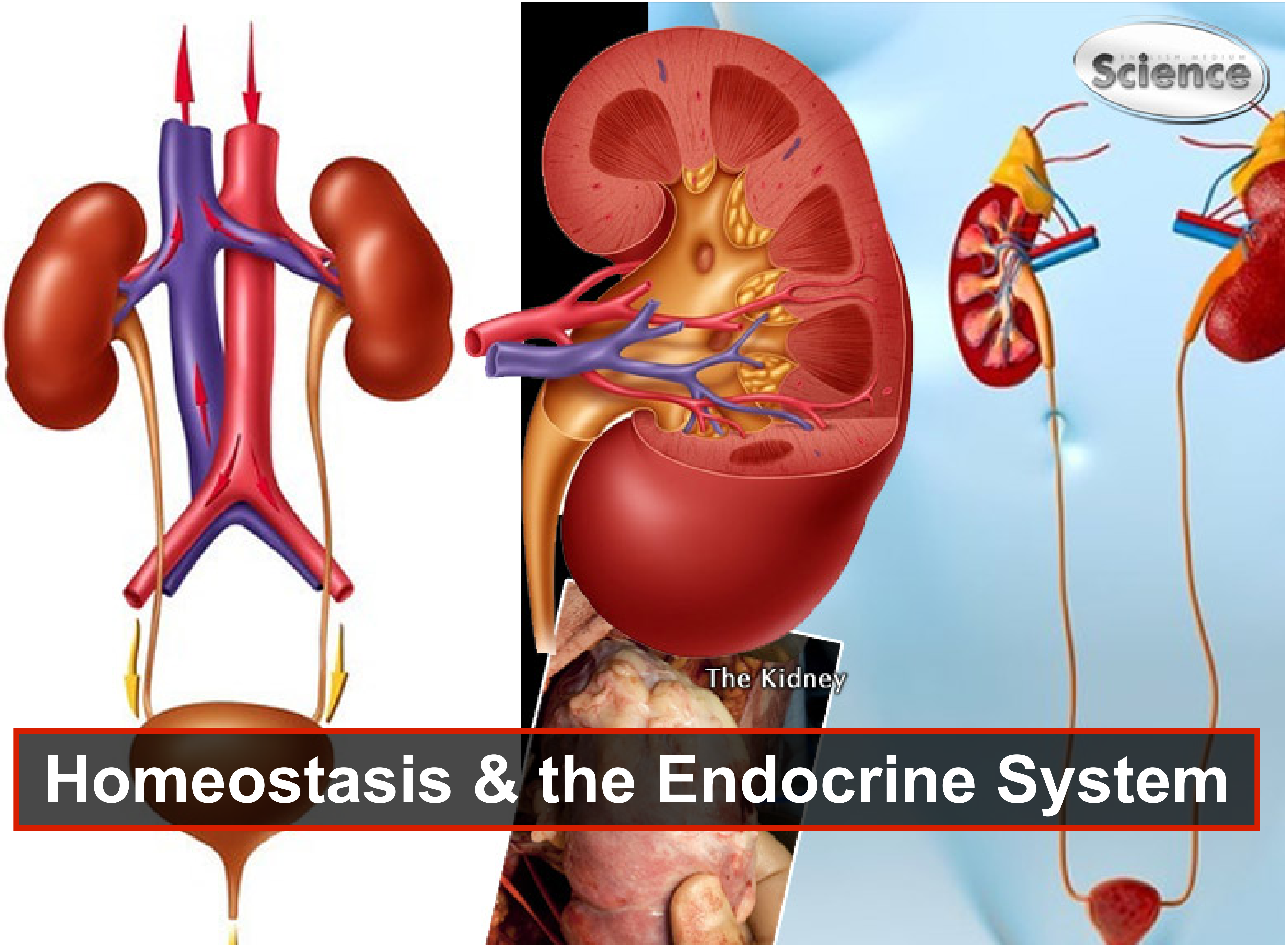
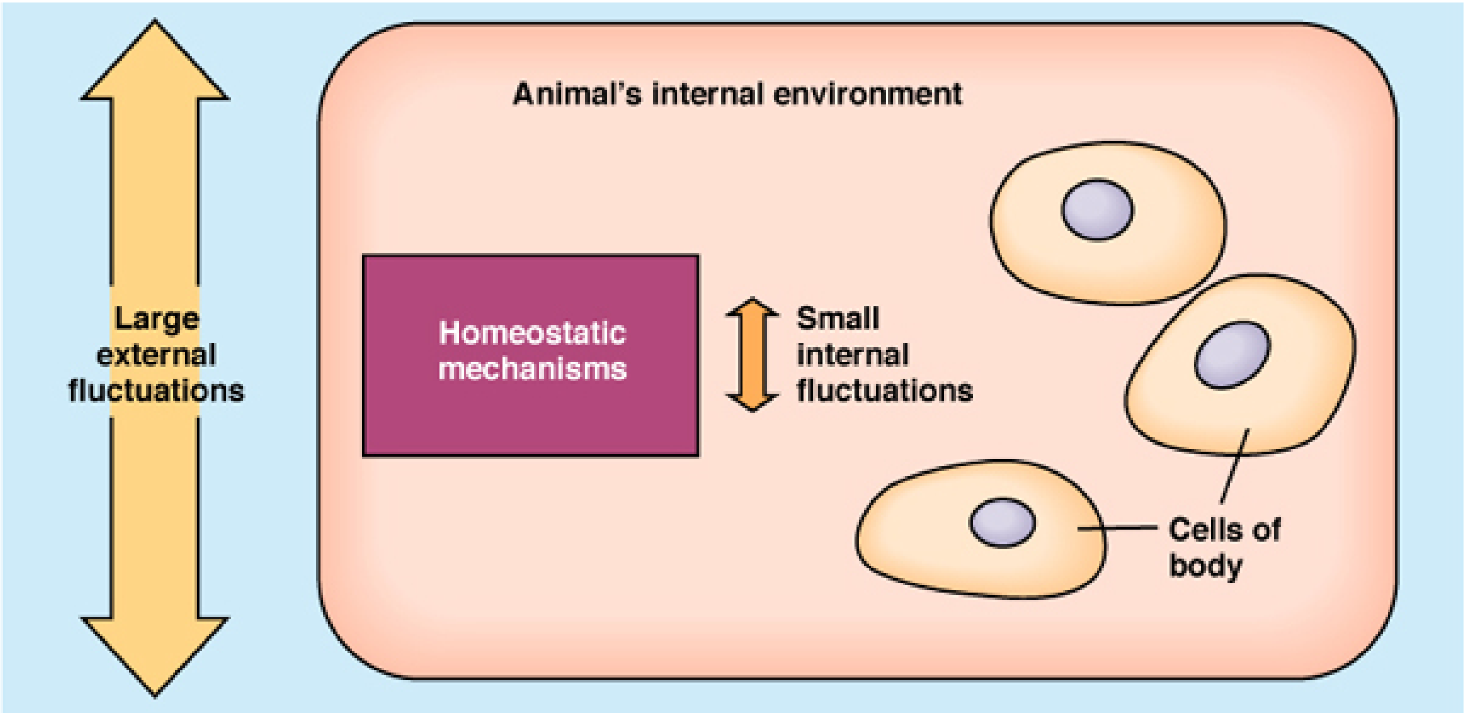


Homeostasis & the Endocrine System

Homeostasis

- **Processes animals use to regulate their internal 'cellular' environment**
  - **The maintenance of a steady state internal constancy in face of a changing external environment**
    - pH of blood 7.4 +/- 0.1
    - body temp 37° C +/- 1° C
    - blood sugar 70 mg/dl to 110 mg/dl ***(mg/dl means milligrams of glucose in 100 mL of blood)***

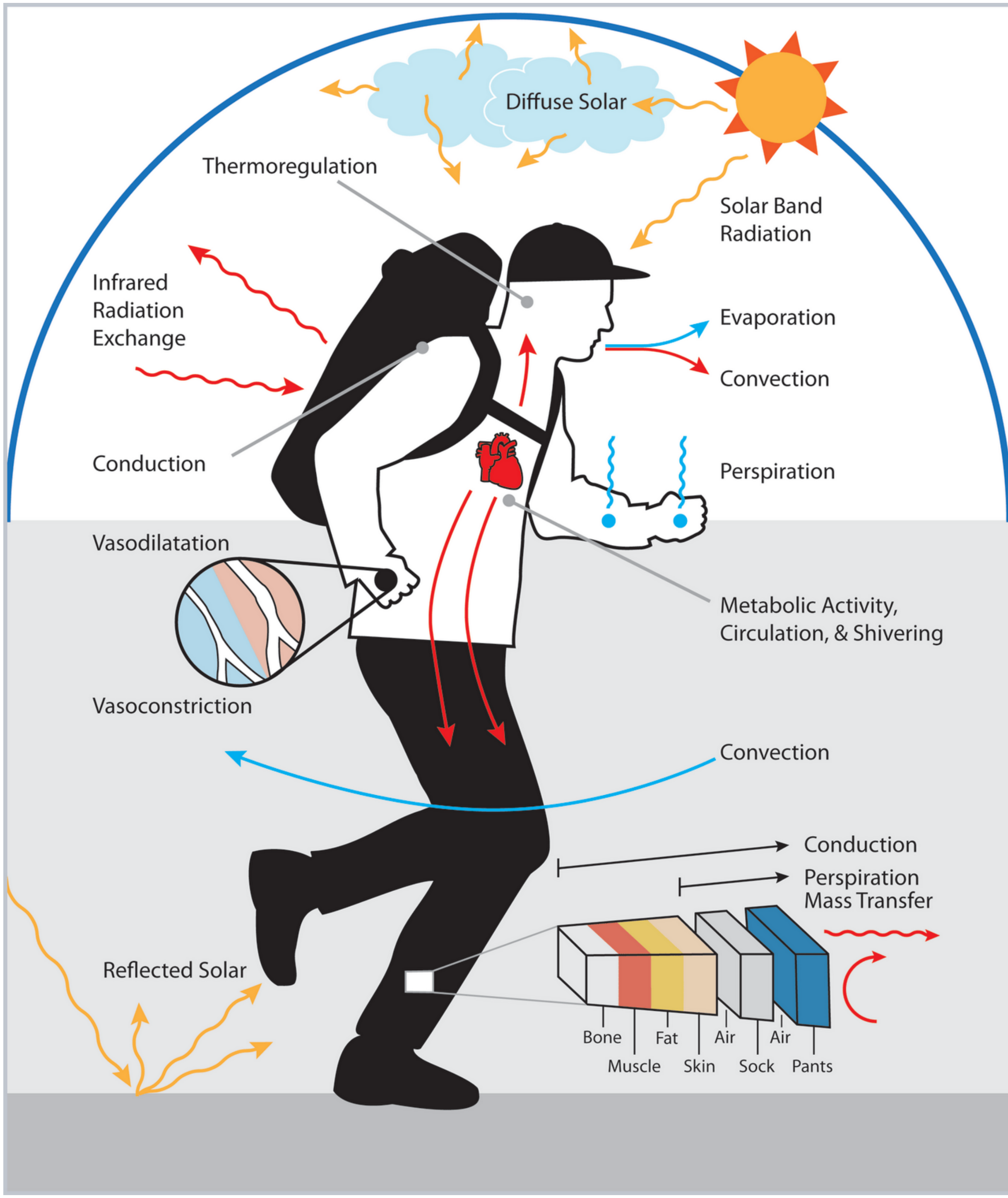


Homeostatic Regulation

- **Homeostasis involves the regulation of numerous variables.**

1. Temperature
2. Ph of blood
3. Calcium levels
4. Blood glucose levels
5. Water balance (osmoregulation)
6. Waste disposal

- Just to name a few…



Homeostasis:

Let's take a closer look at <u>Thermo-regulation</u>

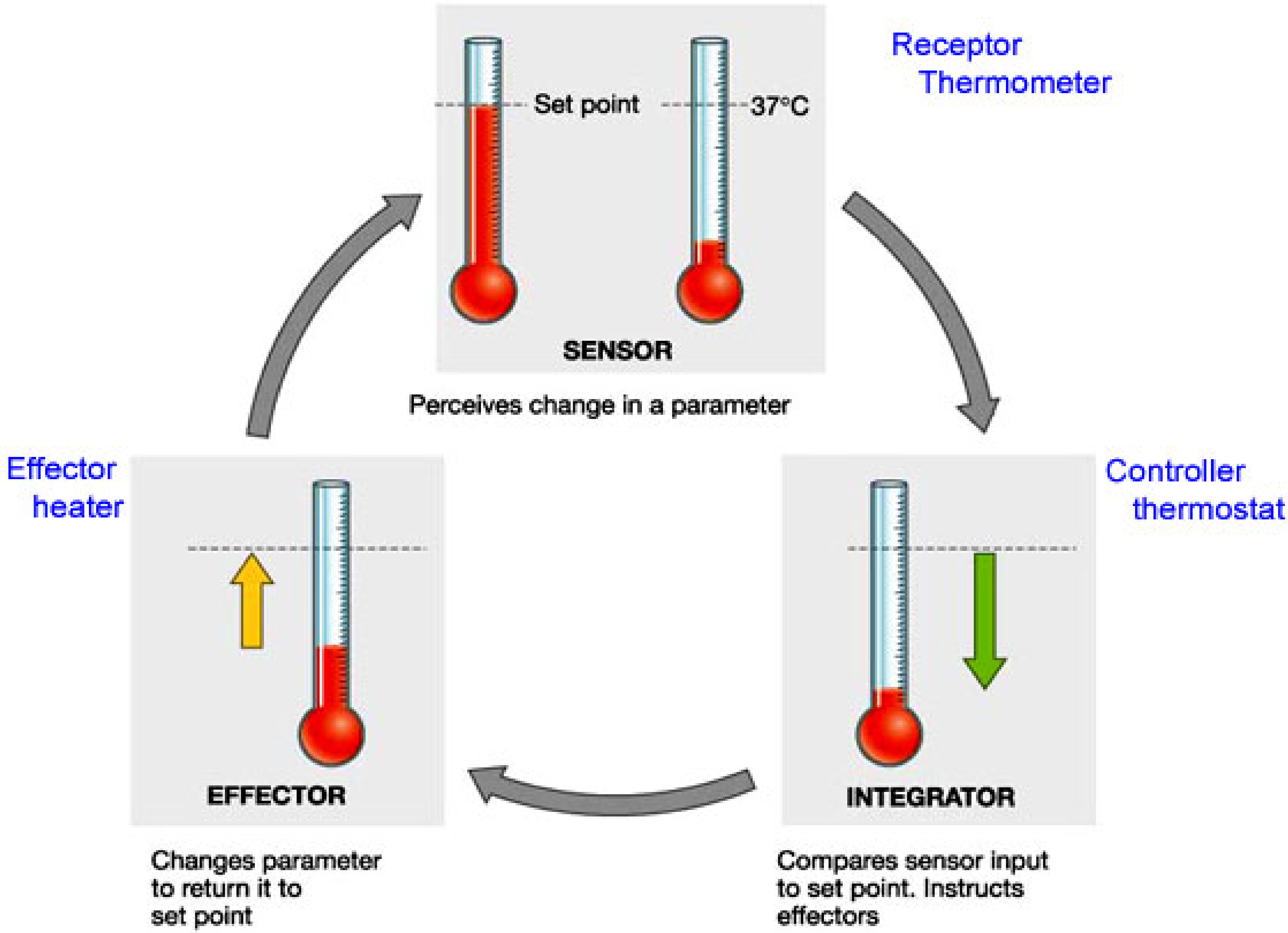
Thermoregulation

- **Thermoregulation**
  - **Process by which animals maintain an internal temperature within tolerable range**
    - **Critical because biochemical, physiological processes, and membrane fluidity are very sensitive to change in body temperature**

- **Homeostatic Regulator like a heating system mechanism has 3 parts...**

1. **receptor ....** **detects a change...** **thermometer**
2. **controller ...** **processes info...** **thermostat responds**
3. **effector .....** **produces a response...** **heater**

Taking a look at how Thermostats Work



AP

Thermoregulation

- Ectotherms
  - Organisms gain most of their heat from external sources
    - Reptiles, fish, invertebrates, amphibians

- Endotherms
  - Warmed mostly by heat generated by metabolism *(cellular respiration followed by the use of a decoupler protein to release energy as heat instead of only ATP synthase to build ATP in the mitochondria)*
    - Birds, mammals

- BOTH make use of behavioral mechanisms to regulate temperate either solely - like in ectotherms - or in conjunction with altering the body's metabolism - like in endotherms.
  - Hypothalamus: Brain region that regulates body temperature by linking nervous & endocrine (hormone) systems in homeostatic thermoregulation.

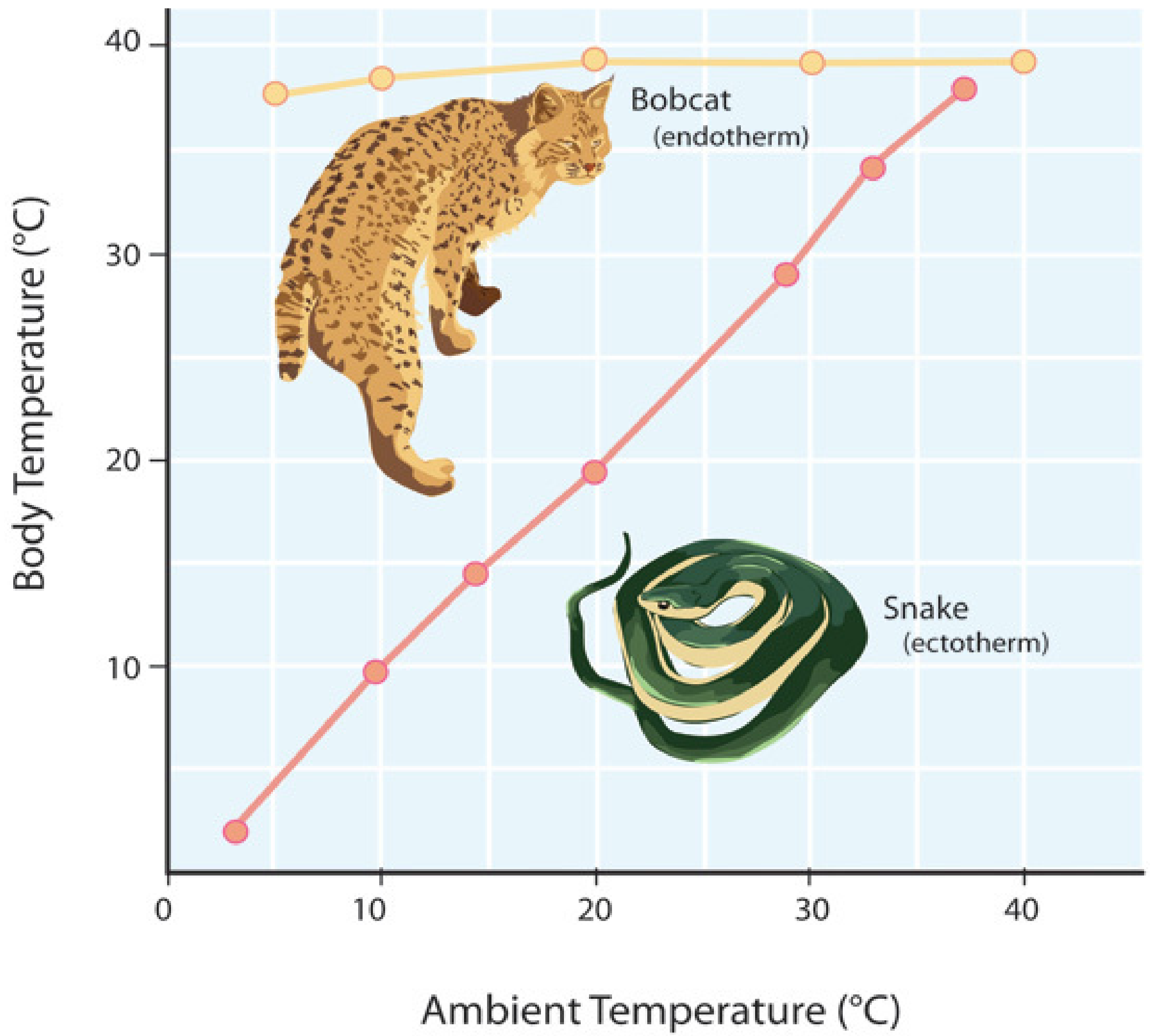
Body Temp. fluctuations in Endo- vs. Ectotherms as Ambient Temperature Changes

Endotherms maintain the same body temperature when the external environment is cold or hot.

> **Adaptive Benefit:** Enzymes kept at optimal temperature no matter external temperature so cells are ready to react at optimal speeds to stimuli 24 hours a day.

Ectotherms' body temperature will fluctuate according to the external environmental temperature, being hot when it is hot outside and cold when it is cold outside.

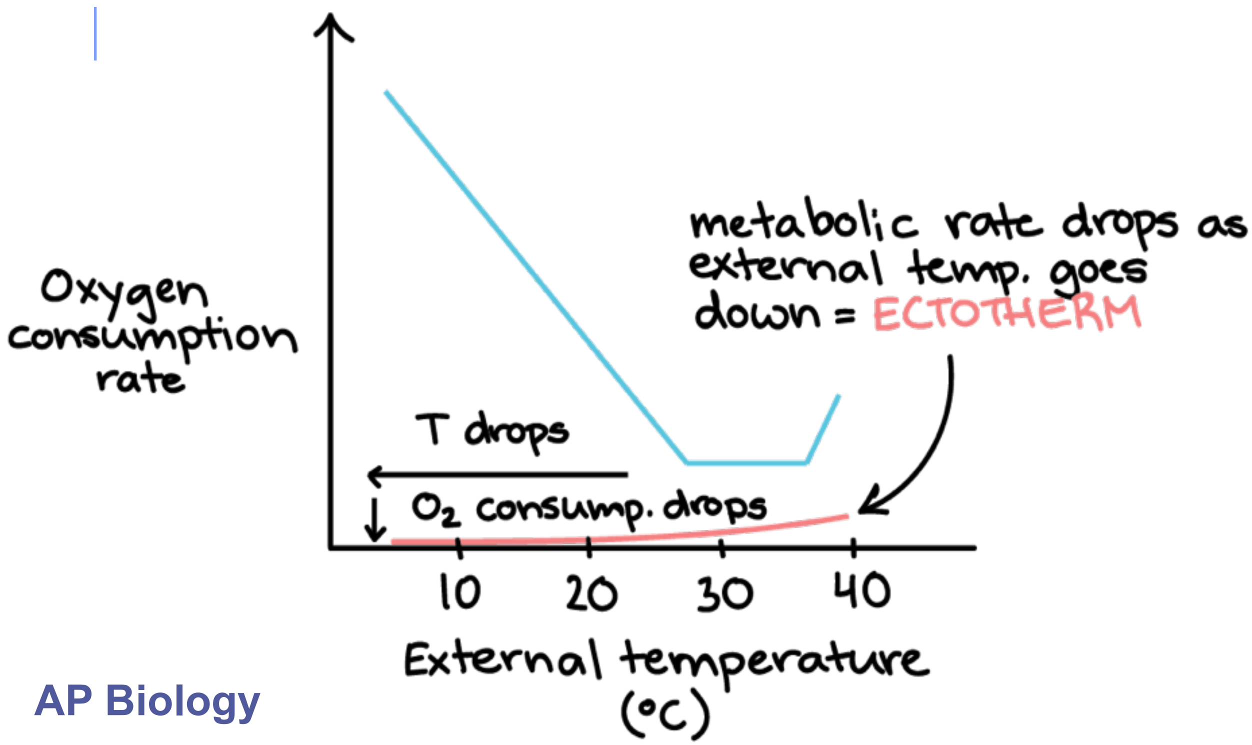
> **Adaptive Benefit:** Energy from organic molecules catabolized in Cellular Respiration used to make ATP and not also used as a source of heat to warm body with so fewer calories (food) needs to be consumed to survive per day.



Effects of Ambient Temperature on Metabolic Rate

(Environmental Temperature's effect on Cellular Respiration Rate)

- Metabolism (Cellular Respiration) involves many chemical reactions.
- As environmental temperature drops, organisms loose thermal energy to the environmental (Heat transfers from area of higher temperature to lower temperature)



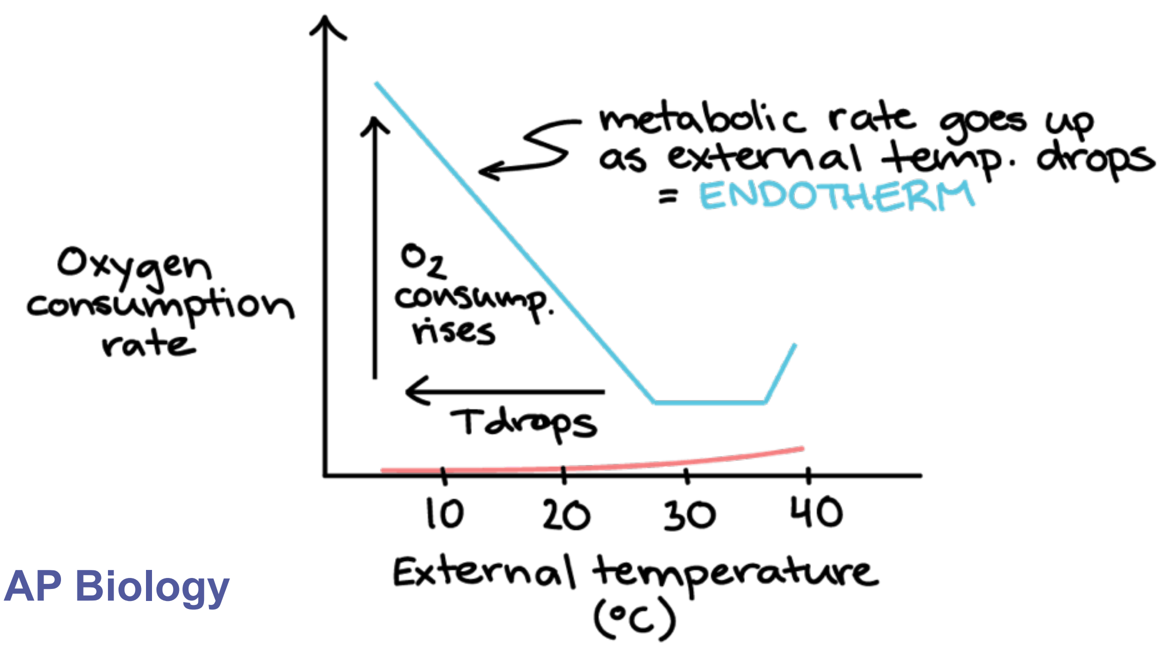
When body temperature drops, the reactants/ substrates and their enzymes collide less frequently and with less forces. Chemistry (including cellular respiration that breaks down high-energy molecules, consumes O_2, and produces CO_2) occurs more slowly.

When body temperature rises, the reactants/ substrates and their enzymes collide more frequently and with more forces. Chemistry (including cellular respiration that breaks down high energy molecules, consumes O_2, and produces CO_2) occurs more rapidly.

Effects of Ambient Temperature on Metabolic Rate

(Environmental Temperature's effect on Cellular Respiration Rate)

- Metabolism (Cellular Respiration) involves many <u>chemical reactions</u>.
- Endotherms use cellular respiration to make ATP <u>AND</u> to generate heat to maintain their body temperature as thermal energy is lost as heat
  - As environmental temperature drops, endothermic organisms loose thermal energy to the environmental as a faster rate *(Heat transfers from area of higher temp. to lower temp.)*



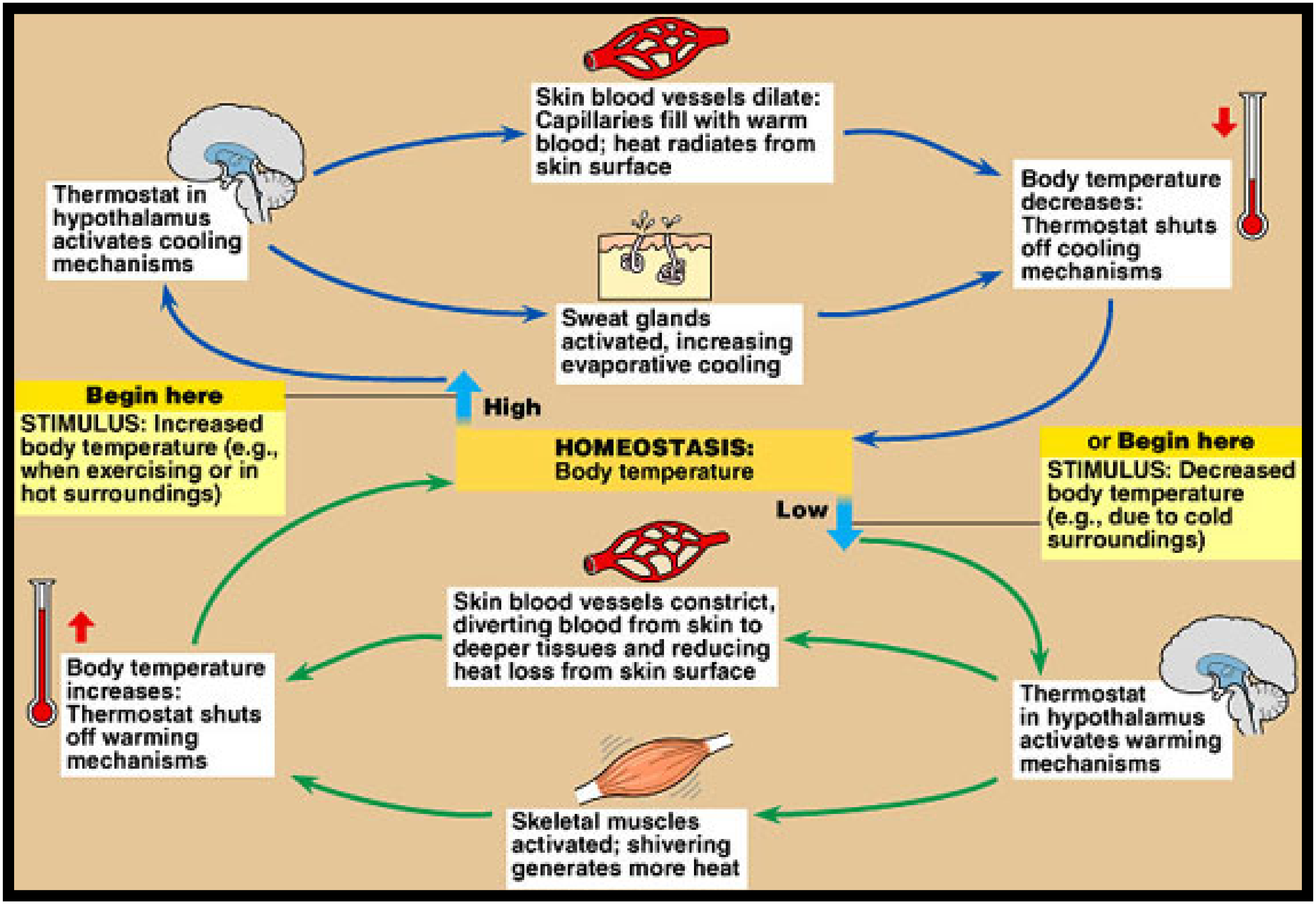
When ambient temperature drops, heat is lost at a faster rate. Therefore, cellular respiration must increase in rate so that more thermal energy can be released from high-energy molecules with the help of decoupler proteins in the mitochondrial inner membrane in order to provide the cells with the thermal energy needed to maintain a constant internal body temperature and make up for the thermal energy lost as heat to the colder environment.

Endotherm increases break down of high-energy molecules, consumption of O_2, and production of CO_2 when temperatures drop further below stable body stable temperature.

Thermoregulation

- To achieve homeostasis, a variable like body temperature is maintained at a particular value or <u>**set point**</u>.
- Fluctuations in the variable above or below the set point serve as the <u>**stimulus**</u>.
- A receptor, or <u>**sensor,**</u> detects the stimulus and triggers physiological activity or <u>**response**</u> that helps return the variable to the set point.
- In animals, homeostasis relies largely on <u>negative feedback</u>
  - Animals will engage in Responses that reduce the stimulus
    - Ex: If you exercise, your temperature rises triggering sweating. Evaporation of water from your skin cools your body, returning your body temperature to its set point.

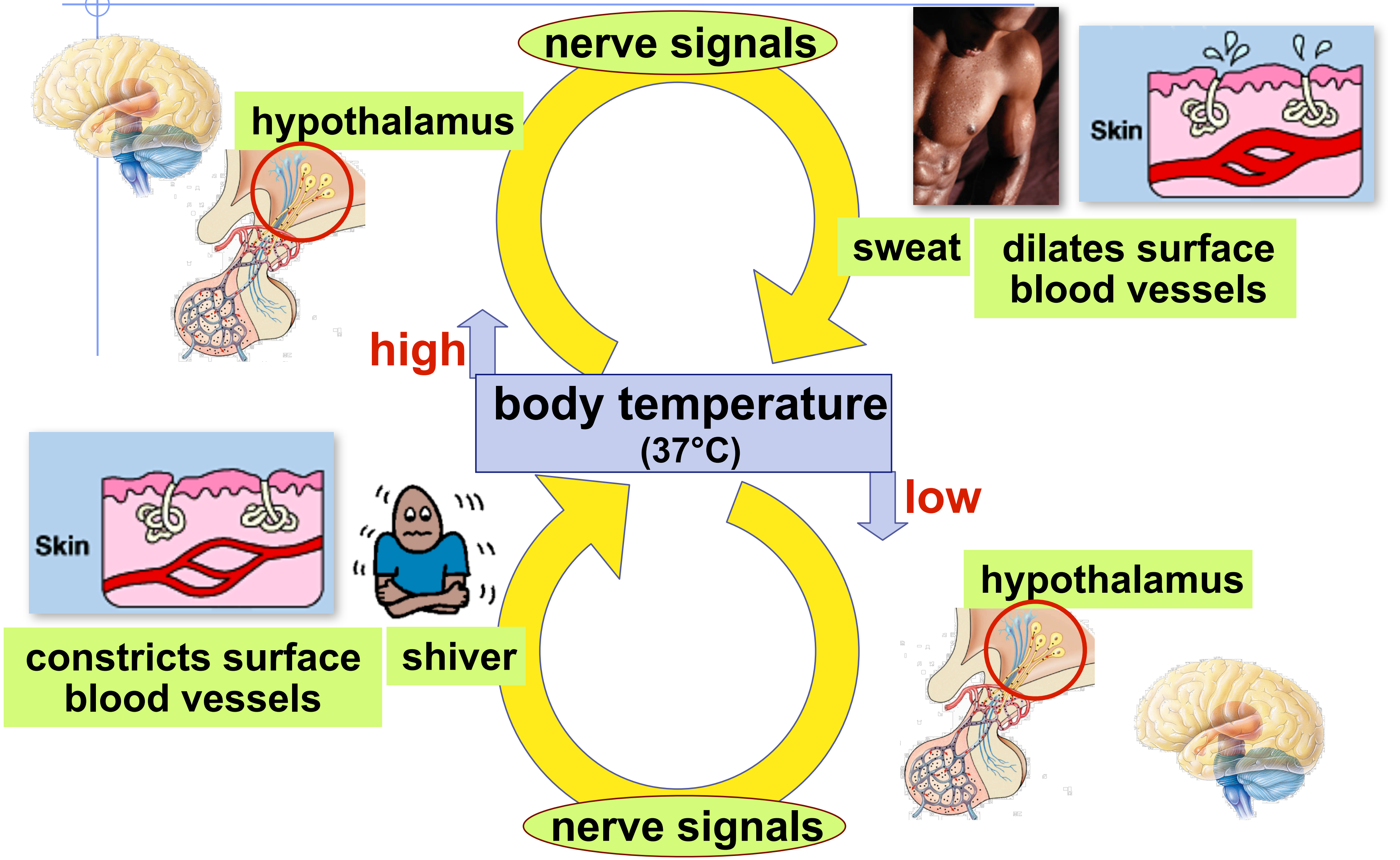
Hypothalamus acts as the thermostat in the body



Nervous System Control

Feedback

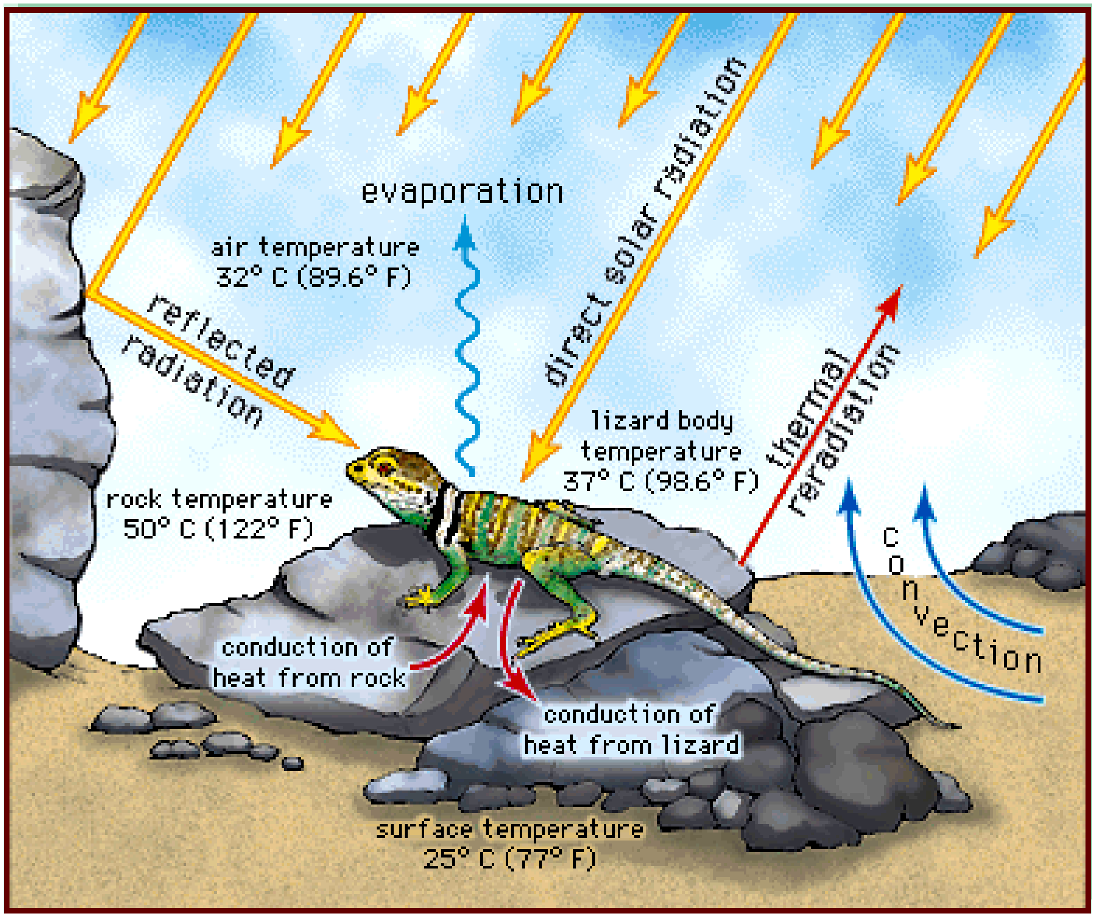
Controlling Body Temperature



Thermoregulation

- Heat transfers from warmer body to cooler body.
- Organisms exchange heat by 4 physical processes:

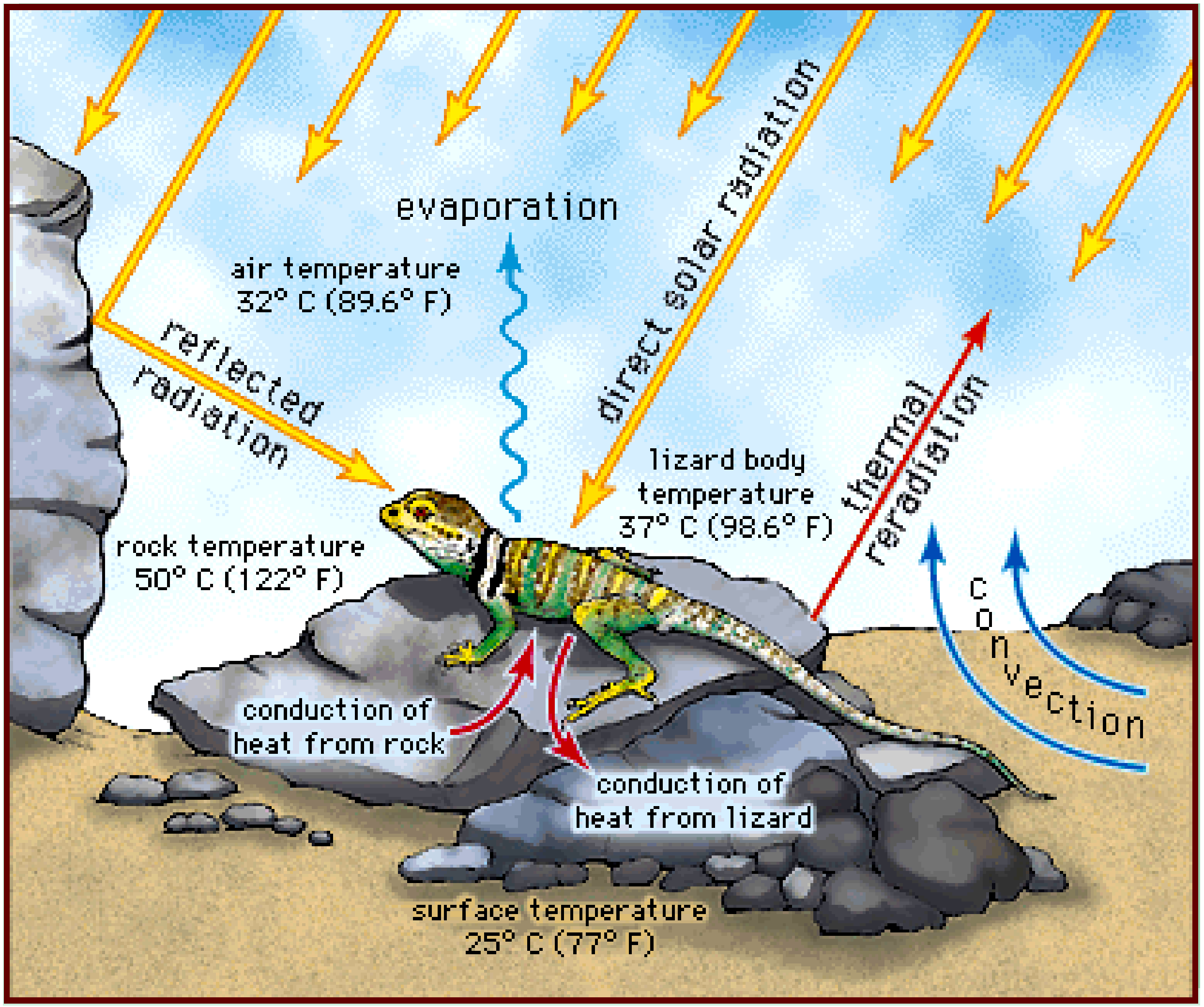
1. Conduction
2. Convection
3. Radiation
4. Evaporation



They can even use these methods to intentionally warm up or cool down.

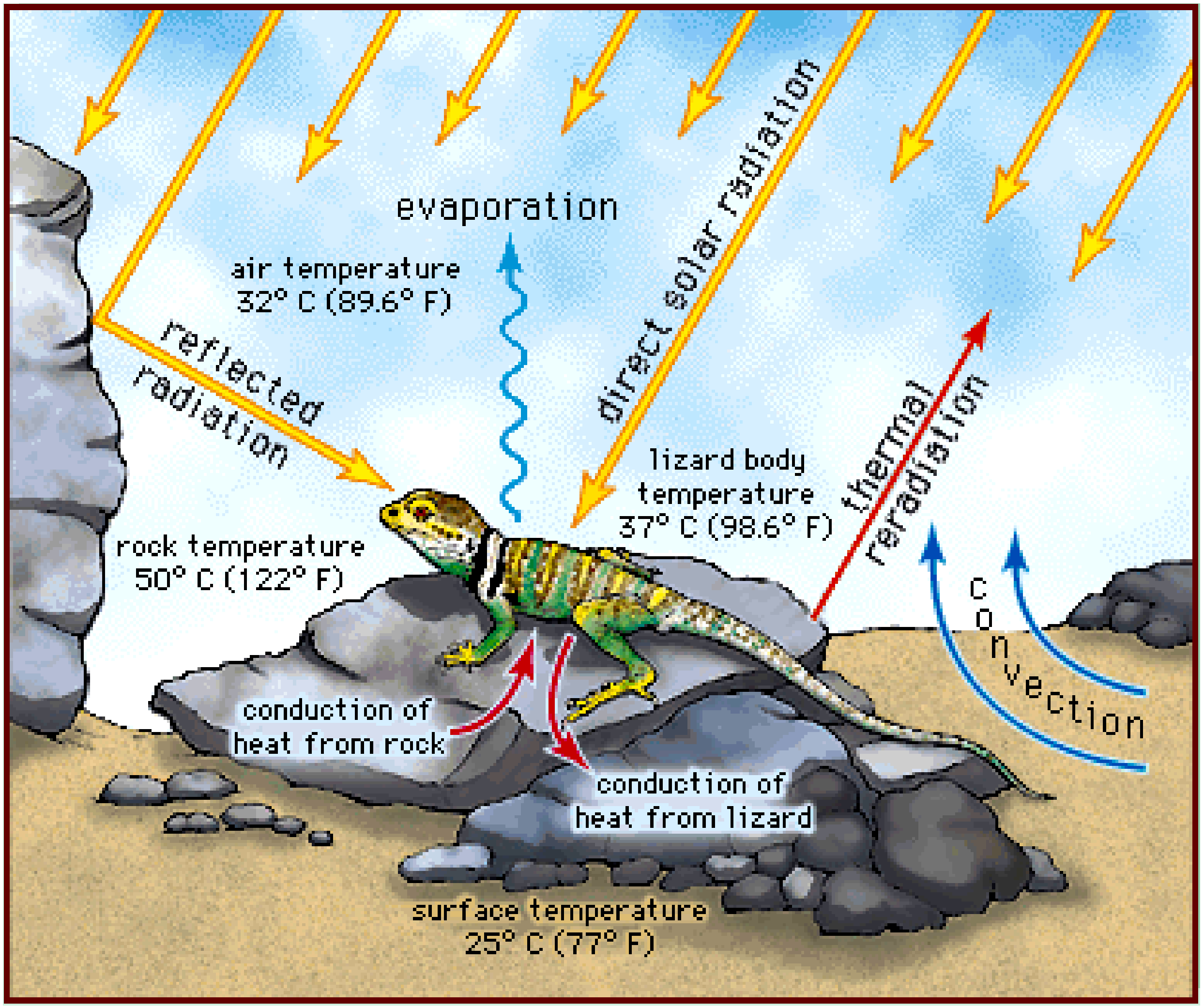
Heat Transfer

- **Conduction**
  - Direct transfer of thermal motion (heat) between molecules of objects in direct contact
- **Convection**
  - Transfer of heat by the movement of air or liquid past a surface



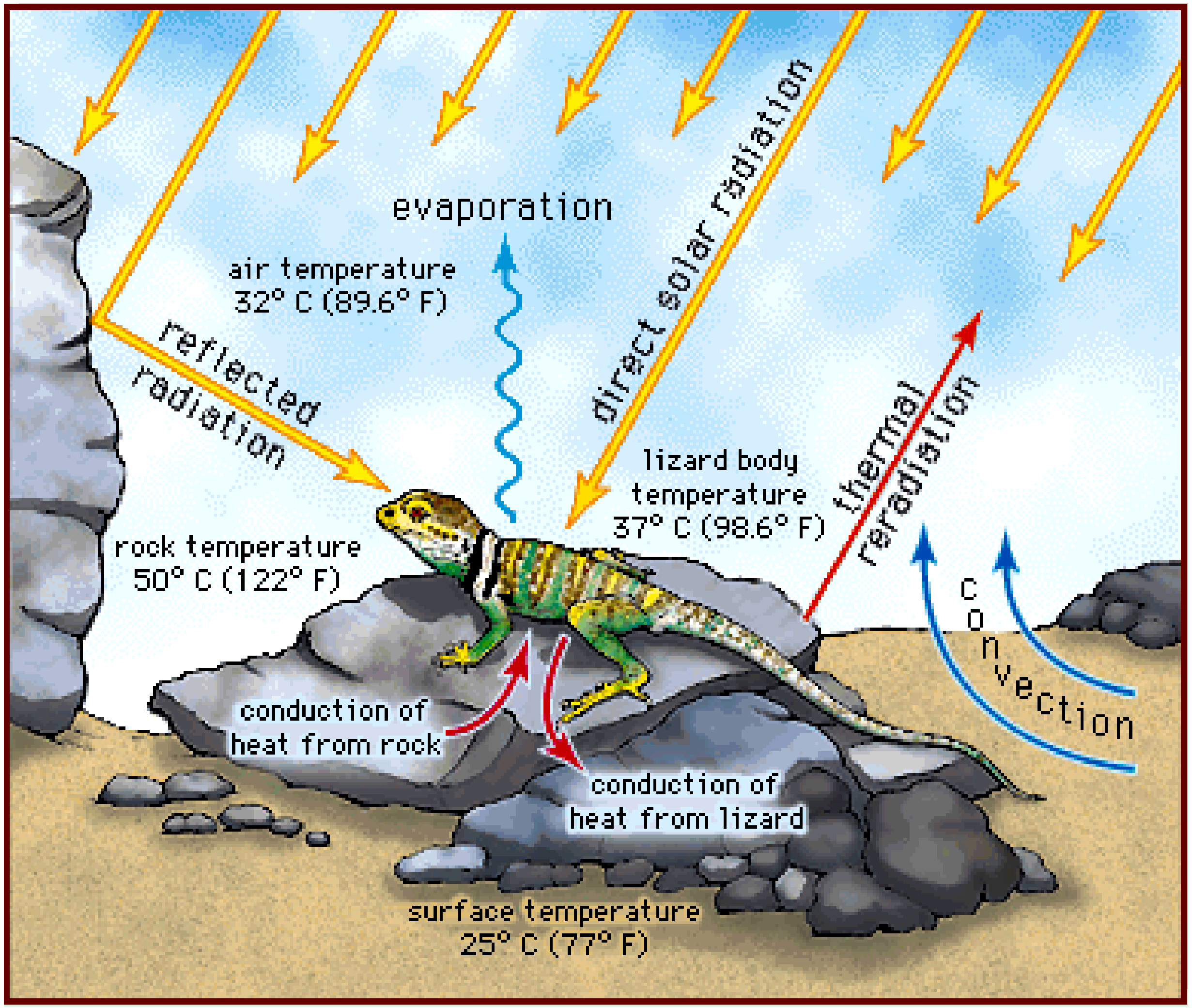
Heat Transfer

- Evaporation
  - Removal of heat from the surface of a liquid that is losing some its molecules as gas
    - Strong cooling effect



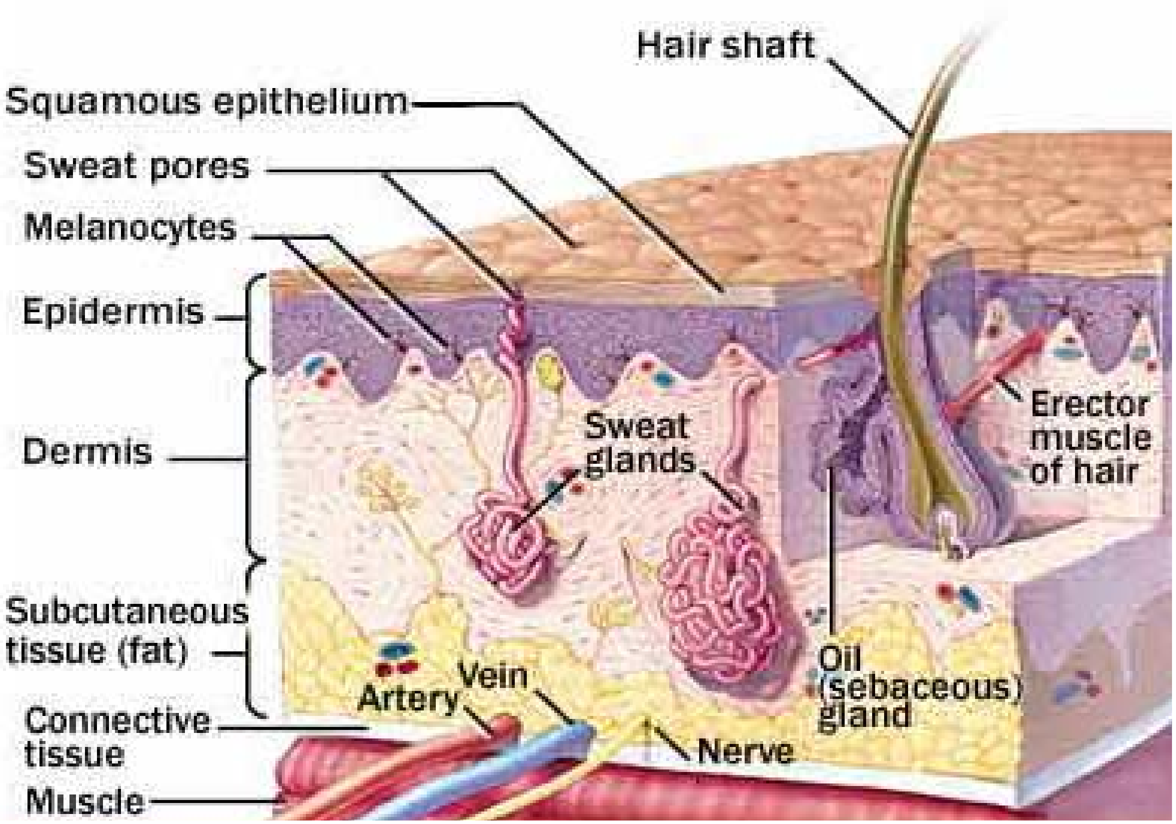
Heat Transfer

- Radiation
  - Emission of electro-magnetic waves by all objects warmer than absolute zero
    - No direct contact needed for heat transfer



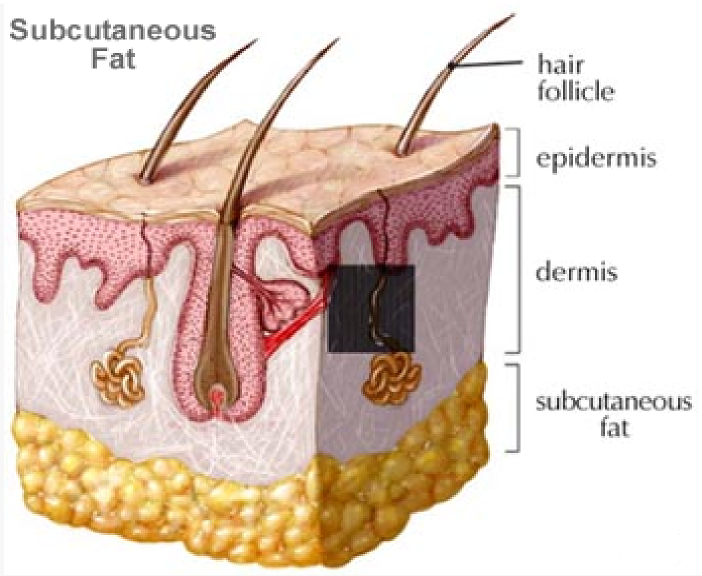
Thermoregulation

- Thermoregulation requires an organism to control the amount of heat exchanged with its environment.
- Adaptations that provide **INSULATION**
  - Integumentary system
    - outer covering of skin, hair, nails, claws or hooves
  - Skin consists of epidermis (dead cells) and dermis.
  - The inner layer contains hair follicles & feathers which trap air when raised in response to cold

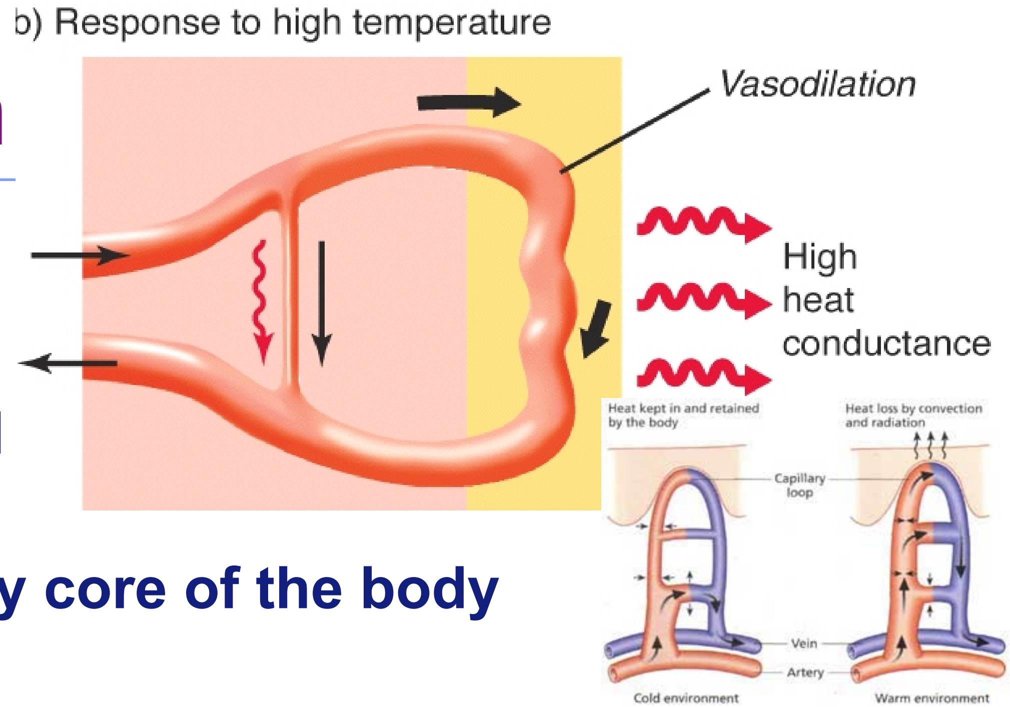


Thermoregulation

- **Insulation:** Reduces the flow of heat between animals and their environments
  - Layers of fat under the skin provide insulation
    - Since heat transfer increases 50-100 fold in water, marine mammals have a very thick layer on insulating fat called blubber
  - Hair and feathers trap air when raised in response to cold
  - Some animals like ducks secrete oily substances that coat their skin and feathers that repel water



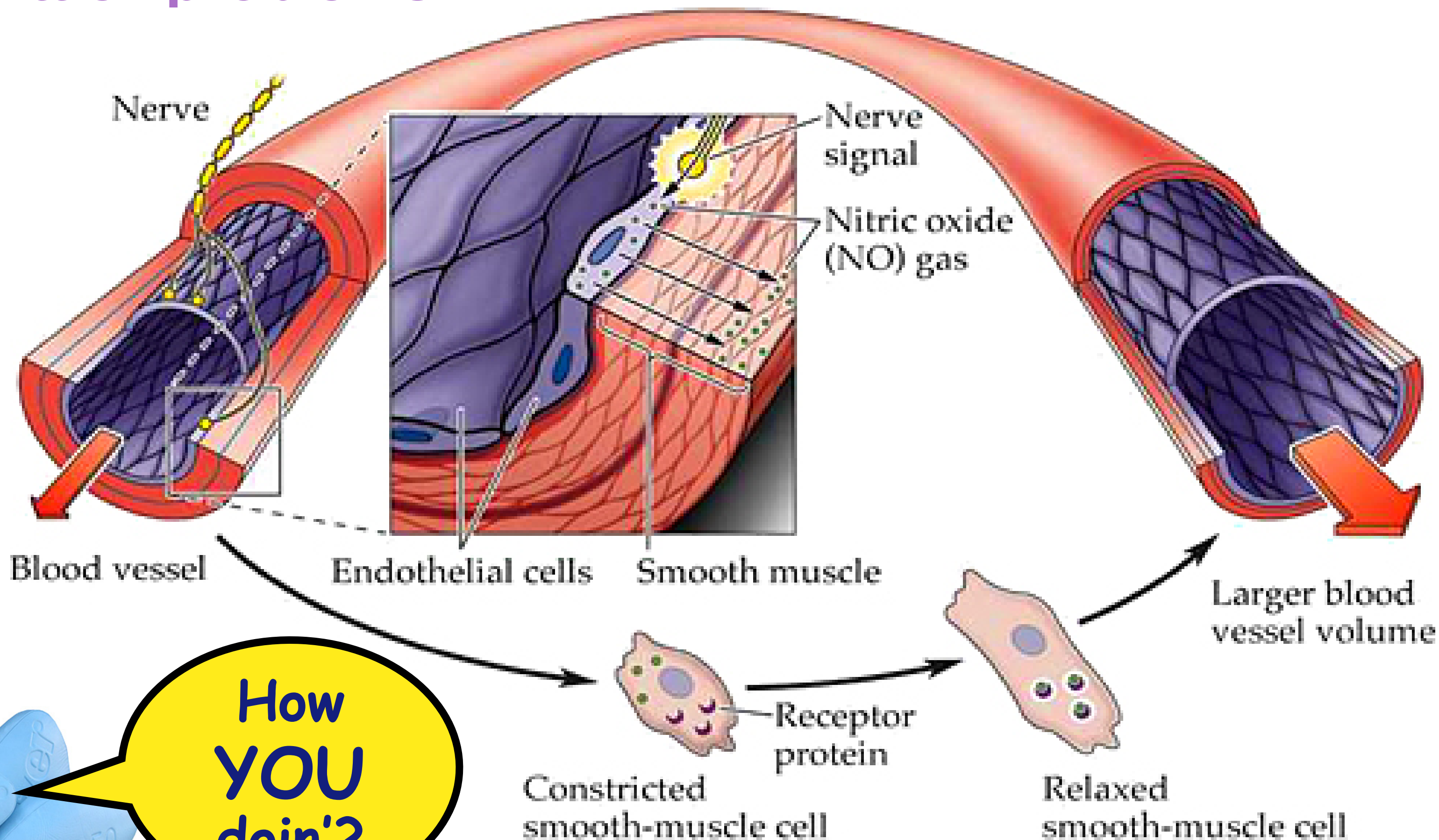
Thermoregulation



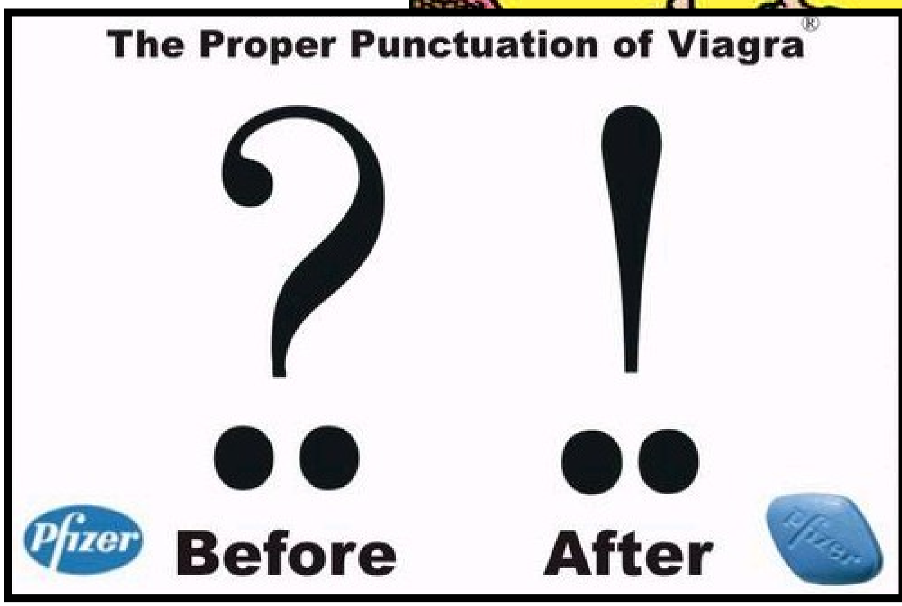
- **Circulatory Adaptations for thermoregulation**
  - **Regulate extent of blood flow near body surface**
  - **Trap heat within the body core of the body**
    - Vasodilation
      - **Increase in the diameter of superficial blood vessels**
      - **Warms skin as more blood flows to boy surface**
      - **Transfer of body heat to environment by radiation, conduction, and convection**
    - Vasoconstriction
      - **Decreasing the diameter of superficial blood vessels**
      - **Reduction in blood flow and therefore heat transfer**
    - Adaptation of both ectotherms and endotherms

Thermoregulation

- Humans apply this concept to solve all sorts of "little" problems



Dirty Science ???

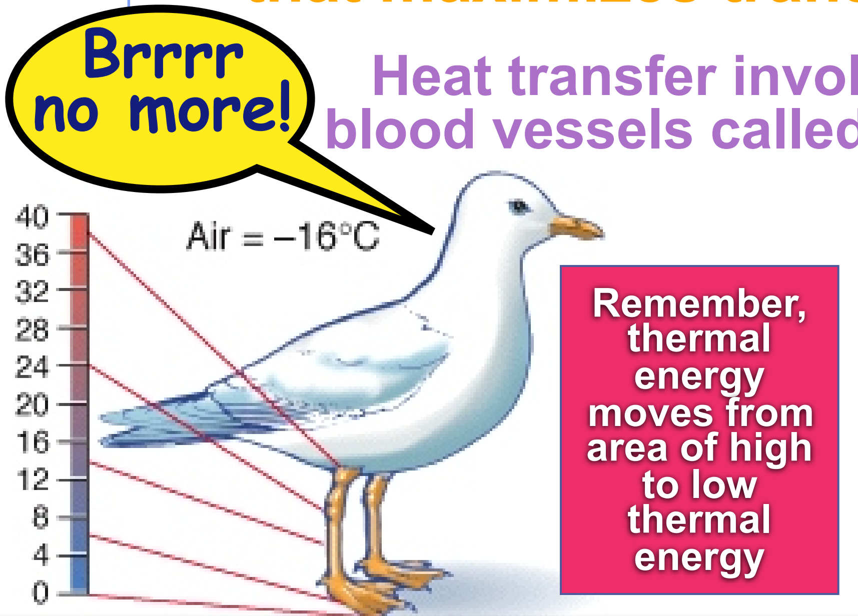


Thermoregulation by Countercurrent Exchange

Key Adaptation that minimizes thermal energy loss (heat loss) from the body core of sea gull.

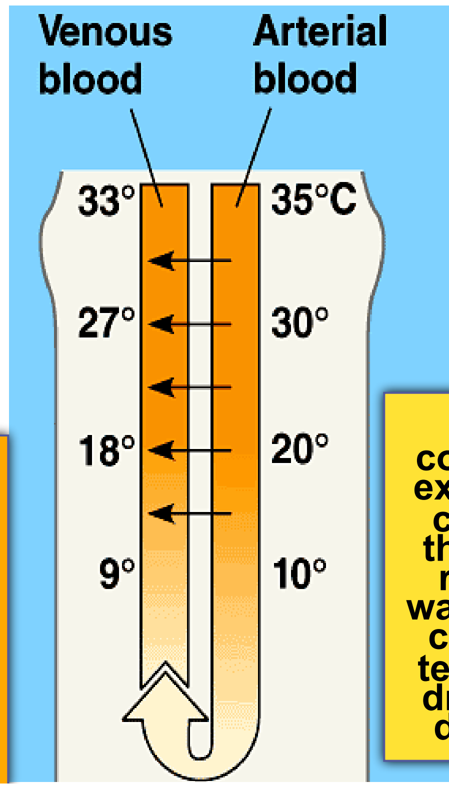
- ## Countercurrent exchange
  - Flow of nearby adjacent fluids in <u>OPPOSITE</u> directions that maximizes transfer rates of heat or solutes

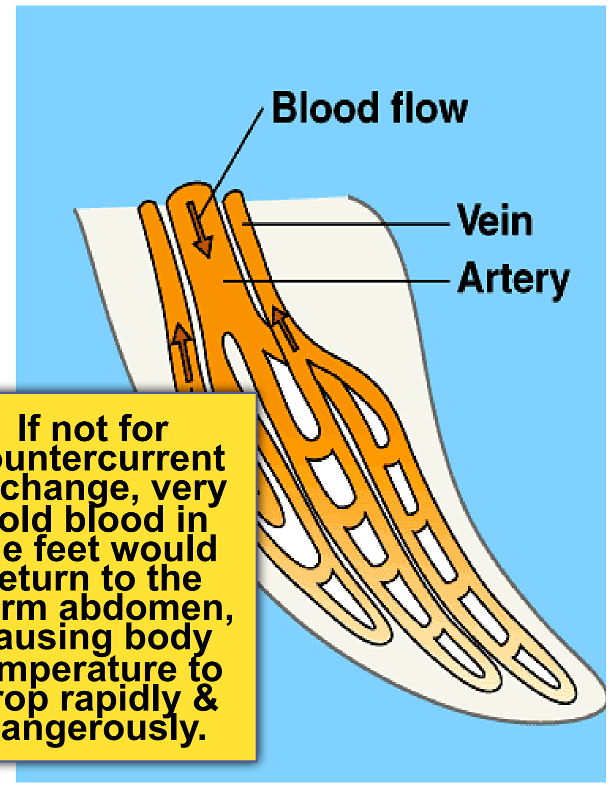
Heat transfer involves <u>close, antiparallel</u> arrangements of blood vessels called countercurrent heat exchangers



Remember, thermal energy moves from area of high to low thermal energy

As warm blood passes into leg arteries, it transfers heat to the close by colder blood returning from the extremities in veins *(instead of only to the cold air)*, **warming up the cooled blood before it enters the abdominal cavity again.**





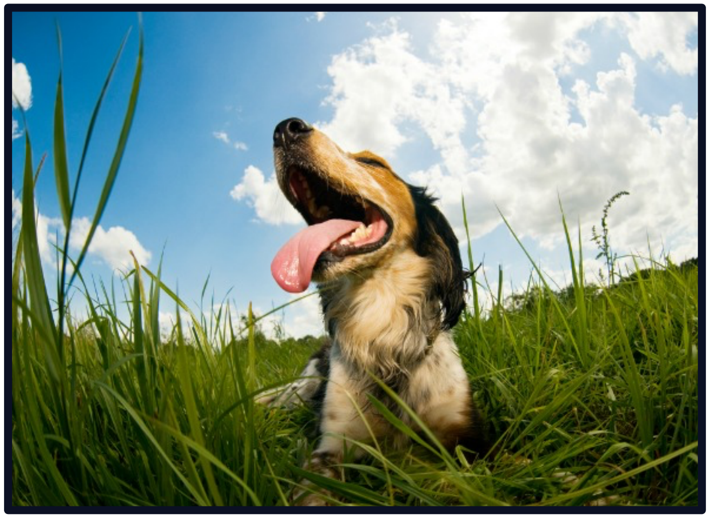
If not for countercurrent exchange, very cold blood in the feet would return to the warm abdomen, causing body temperature to drop rapidly & dangerously.

Thermoregulation

- Evaporative Cooling
  - Water absorbs heat when it evaporates
    - Recall: Thermal energy transfers from an area high in thermal energy to one lower in thermal energy
    - Recall: Because of water's high Specific Heat, water can absorb a lot of thermal energy before changing from liquid into gas.
      - The thermal energy absorbed breaks liquid water's hydrogen bonds and causes water molecules to start to collide with more force and move with greater speed
  - Heat absorbed by water secreted onto the surface of the body (sweat or saliva) is obtained from body
    - As heat leaves the body, the body temperature is lowered

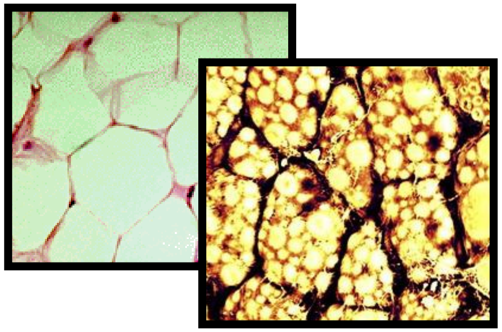
Thermoregulation

- Evaporative Cooling
  - Animals exhibit behavior that improves cooling effects too:
    - Panting in birds and mammals
    - Sweating or bathing
      - Sweat glands in mammals controlled by nervous system



Thermoregulation

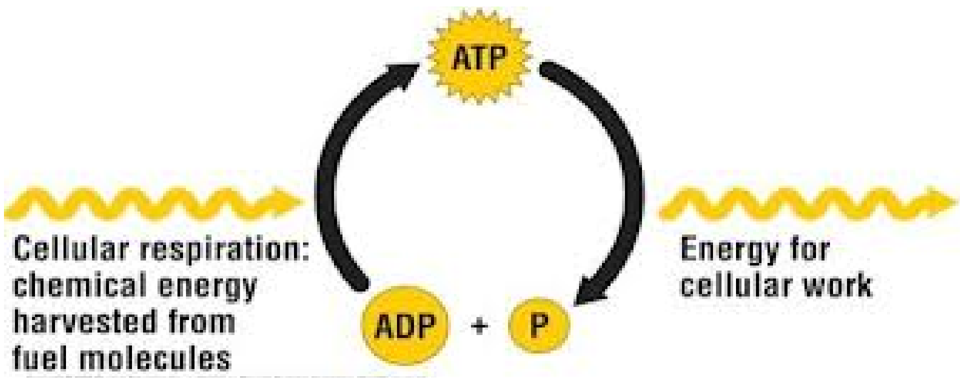
- Behavioral adaptation for thermoregulation
  - Behavior responses are used by ectoderms and endoderms
    - Hibernation
    - Migration
    - Moving to cooler areas
    - Postures that maximize or minimize heat absorption
    - Huddling
- Endoderms must really counter heat loss to maintain high body temperature
  - Shivering Response
  - Non-shivering Response *(in newborns that can't yet shiver to generate heat)*



    - Hormones increase mitochondrial burning of fuel to make heat instead of ATP
    - <u>Brown Fat</u> = located in neck and between shoulders and is specialized for rapid heat production
      - Unlike white fat, have multiple fat vacuoles & increased mitochondria

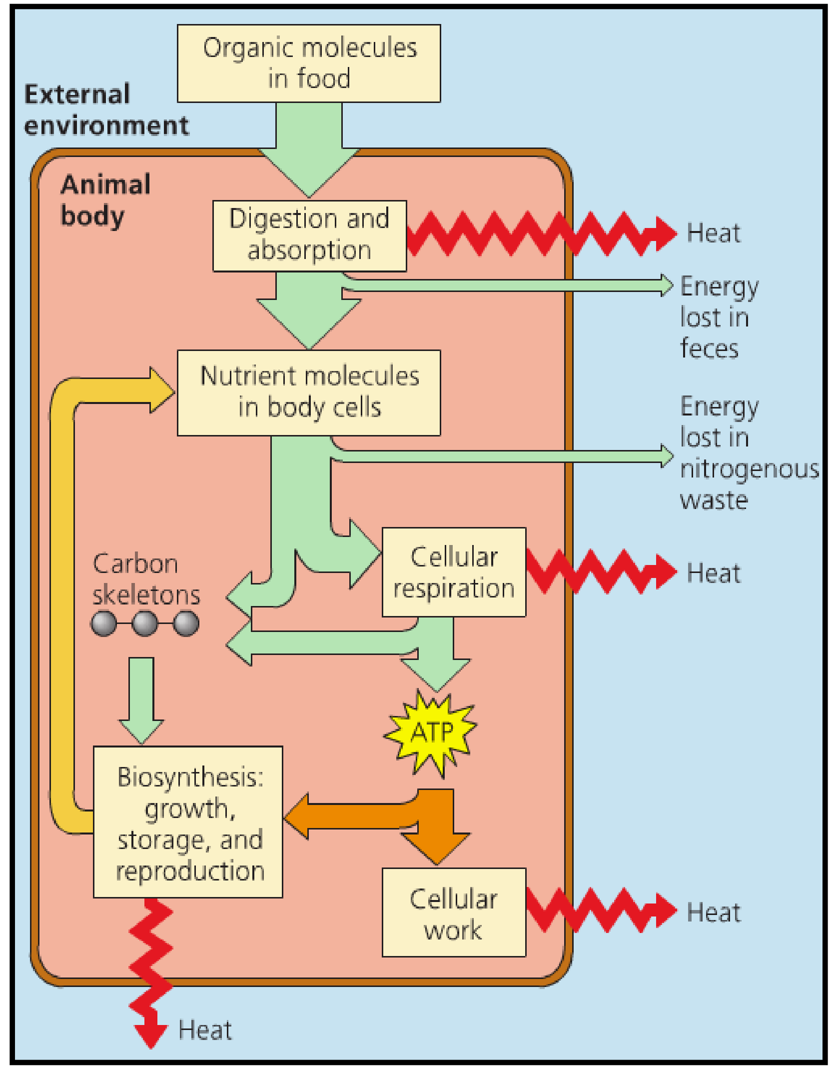
Energy requirements are related to animal size

- **Animals require chemical energy for growth, repair, activity, and reproduction**
  - **The transformation and flow of energy in an animal determines nutritional needs**
    - **This flow of energy is related to:**
      1. **Animal size**
      2. **Activity level**
      3. **Environment**



Energy requirements are related to animal size

- Autotrophs use light energy to build energy rich organic molecules
- Heterotrophs use chemical energy harvested from the food they eat
- ATP is produces by cellular respiration and/or fermentation
  - The energy in ATP is used to power cellular work and for biosynthesis for growth and repair, gamete production, synthesis of storage materials like fat.
    - Producing ATP produces HEAT
      - Heat is energy lost to the environment



Metabolic Rate

- **Metabolic Rate** = The amount of energy an animal uses in a unit of time
  - The sum of all the energy-requiring biochemical reactions over a given time interval
    - Energy is measured in calories or joules

- **How is Metabolic Rate measured?**

1. Metabolic rate can be determine by **monitoring rate of heat loss**
   - **calorimeter** = a closed insulated chamber equipped with a device that records animal heat loss
2. Metabolic rate can also be determined from the **amount of oxygen consumed or carbon dioxide produced**

Energy Costs of Endo- vs. Ectothermy

- **Basal Metabolic Rate (BMR)** = The minimum metabolic rate of a nongrowing **endotherm** that is at rest, has an empty stomach, and is not experiencing stress

- **Standard Metabolic Rate (SMR)** = The metabolic rate of a fasting, nonstressed **ectotherm** at rest at a particular temperature *(since temperature changes body temperature and metabolic rate in ectotherms)*

- **BMR for Humans**
  - 1,600-1,800 kcal/day for male - 1,300-1,500 kcal per day for female
- **SMR for Alligator**
  - 60 kcal per day at 20C (68F).
    - **Ectotherms have a much LOWER energetic requirement** *(need less food)*

Size and Metabolic Rate

- **Larger animals have more body cells and require more chemical energy to maintain all these cells**
  - **YET, overall metabolic rate and body mass is constant over a wide range of sizes and forms**

    - **Still the energy it takes to maintain each gram of body weight is <u>inversely</u> related to body size**

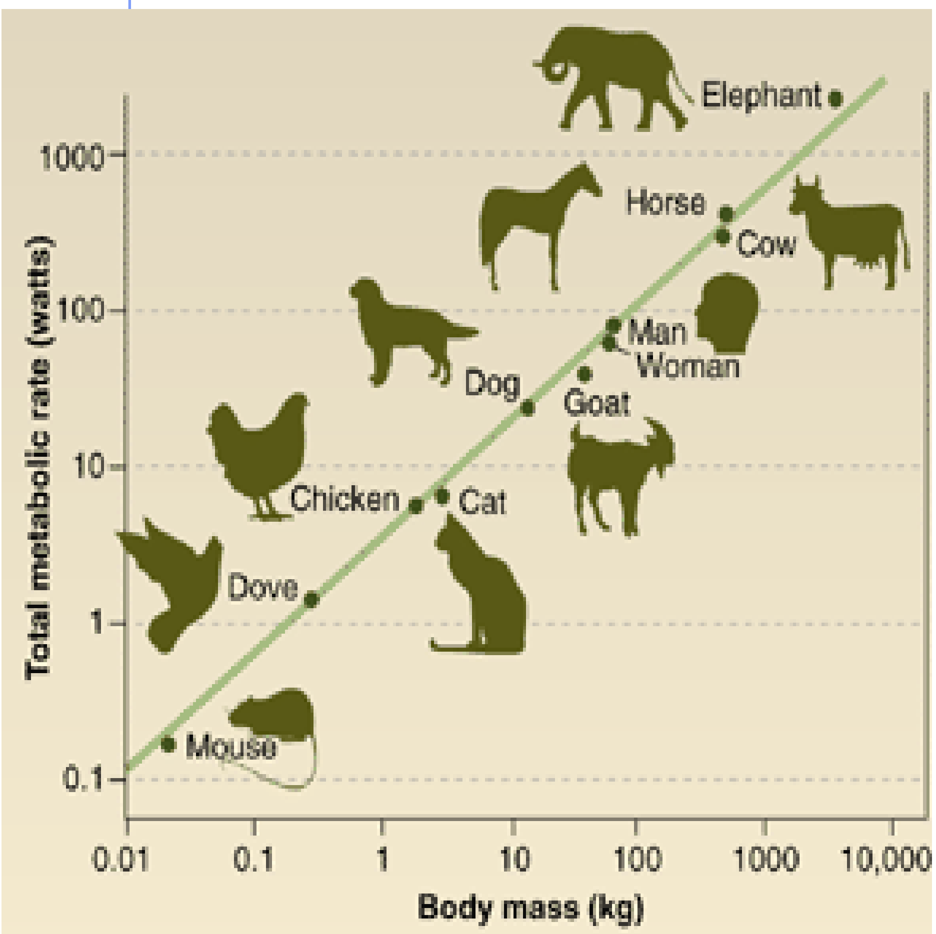
Each gram of a mouse requires 20x as many calories as a gram of an elephant, even though the elephant uses far more calories that the mouse as a whole.

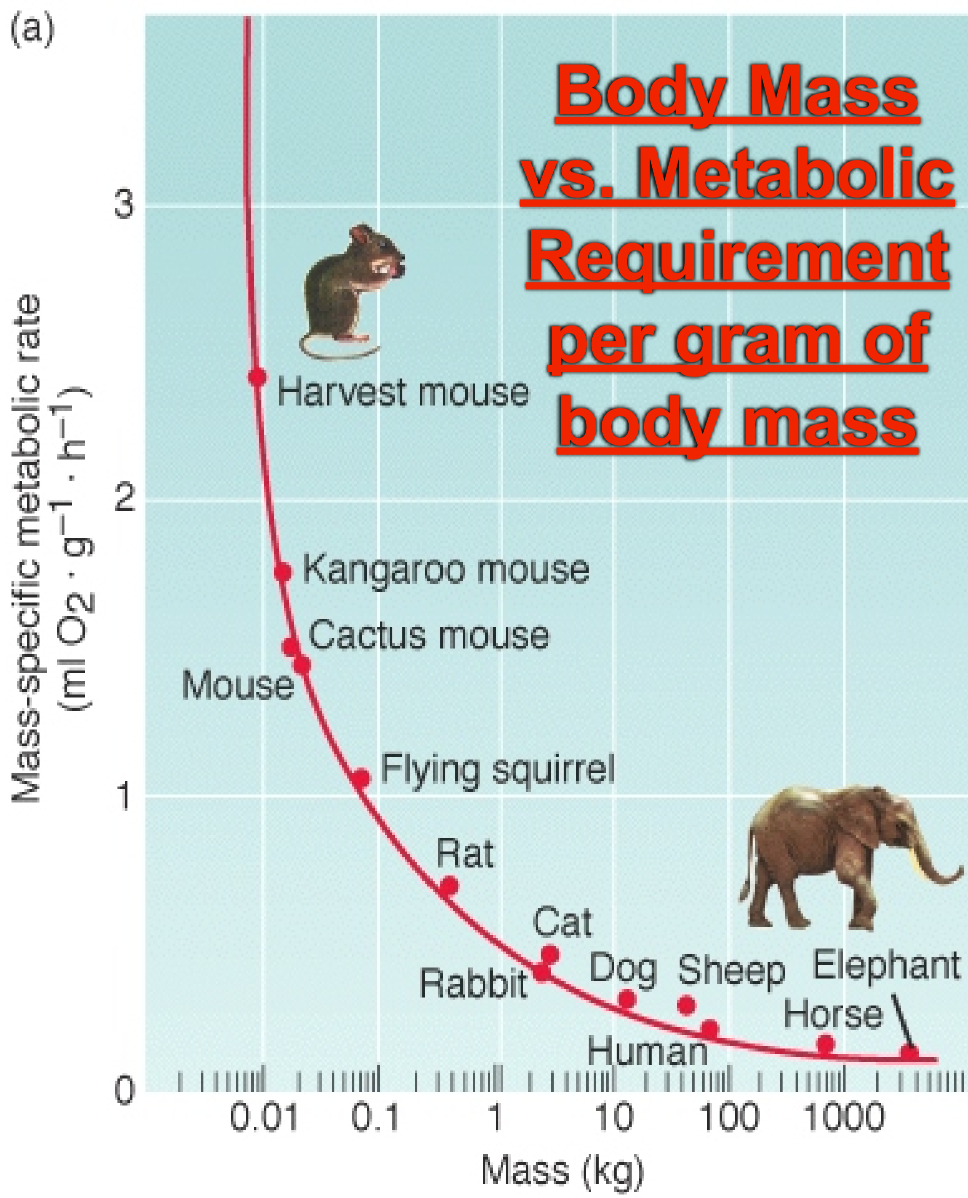
- **Hypothesis:**
  - **Smaller endotherms have greater energy costs trying to maintain stable body temperature**

    - **The <u>greater surface-to-volume ratio</u> of the whole body causes faster loss of heat in small animals vs large animals with smaller SA/V body ratio**
      - **Therefore, smaller animals have higher breathing rates, relative blood volume, heart rate, and must eat more per unit of body mass**

Note the difference in size vs Metabolic Rates

Total Body Mass vs Metabolic Rate





Activity and Metabolic Rate

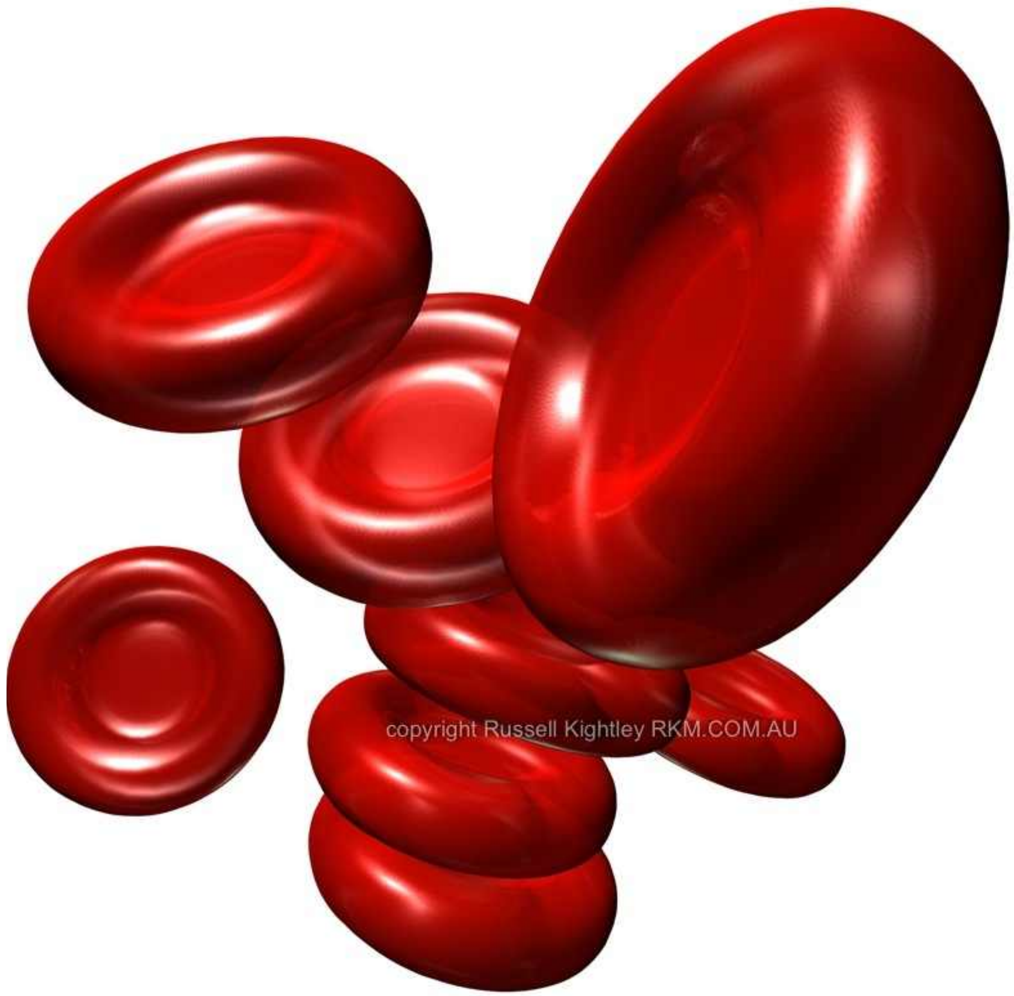
- Animals have **behavioral and physiological adaptations** to maintain temperature homeostasis
  - Animals may still though encounter conditions that challenge their ability to balance their heat, energy and materials budgets
- **Torpor** = a physiological state in which activity is low and metabolism decreases.
  - Enables an endothermic animal to save energy

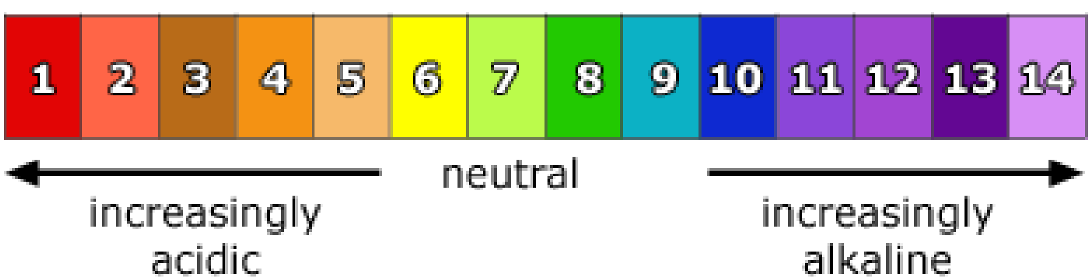
- **Hibernation** = long term torpor that is an adaptation to winter cold and food scarcity
  - During hibernation body temperature is significantly (to 1 - 2C from 37C) in endotherm bodies
- **Estivation** = summer torpor enables animals to survive long periods of high temperatures and scarce water supplies by slowing down metabolism and thus heat production

AP

Homeostasis:

Let's take a closer look at **Blood pH**





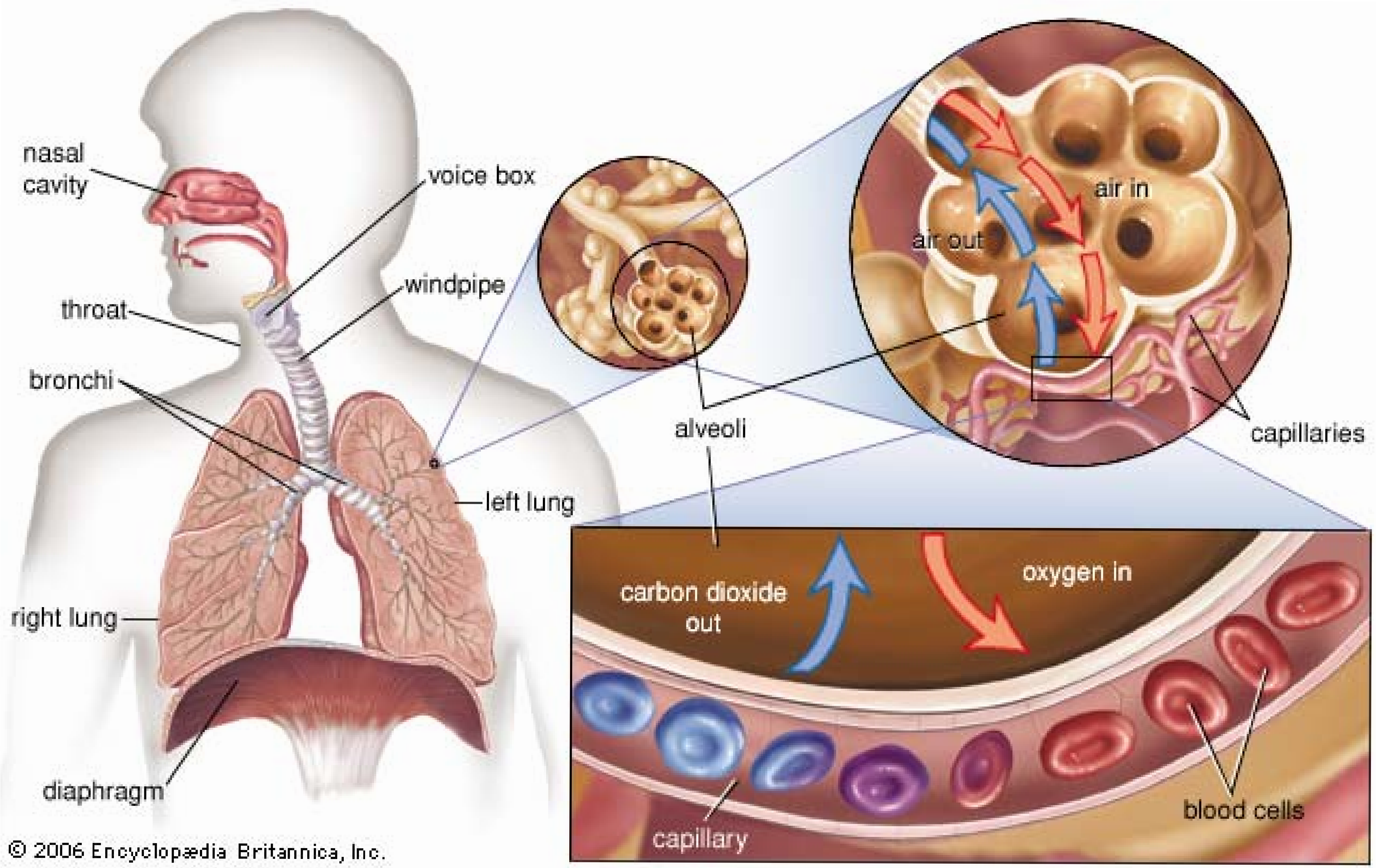
pH regulation in blood

- Human blood has an optimal pH
  - pH 7.4 ± 0.1
    - A shift of 0.4 pH unit = Death
- Blood contains various buffering systems

1. **Hemoglobin** when not binding O_2 does bind some CO_2 and also some H^+ if needed
2. **Carbonic Acid-Bicarbonate Buffer**
   - The enzyme carbonic anhydrase found in red blood cells catalyzes the conversion of CO_2 + H_2O into carbonic acid, H_2CO_3
     - Carbonic acid dissociates for form H^+ and bicarbonate HCO_3^- ions.
       - The entire process is readily reversible

$$CO_2 + H_2O \;\; \text{<--->} \;\; H_2CO_3 \;\; \text{<--->} \;\; H^+ + HCO_3^-$$

Alveoli are the locations of CO_2 vs O_2 gas exchange between blood and the lung air space



Carbonic Acid-Bicarbonate Buffer in Blood

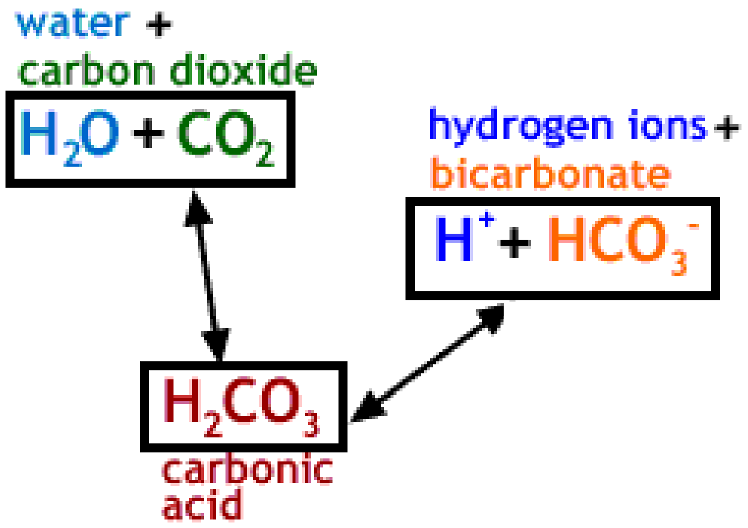
- **What happens as you exercise?**
  - Muscles use up more O_2 as they convert the energy in the bonds of glucose into mechanical energy.
  - CO_2 is produced as a waste product which increases H^+ concentration.
    - Unless something is done, the pH in your blood would DROP!
- **If the pH of the body gets too low (below 7.4), a condition known as acidosis results.**
  - Protein-mediated reactions in the body are pH dependent and very sensitive to changes in pH
  - Blood pH must be be kept at 7.4
    - If the pH drops below 6.8 or rises above 7.8, death may occur.

Carbonic Acid-Bicarbonate Buffer in Blood

- Fortunately, we have buffers in the blood to protect against large changes in pH.
  - The bicarbonate buffering system maintains acid-base homeostasis in animals, keeping blood plasma pH constant.

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

- Any disturbance of the system will be compensated by a shift in the chemical equilibrium according to Le Chatelier's principle.



Carbonic Acid-Bicarbonate Buffer in Blood

- When blood accumulates excess CO_2 during exercise, and if the blood had no buffer, the forward reactions would be favored, which would result in more H+ ions forming: carbon dioxide reacts with water to form carbonic acid, which decomposes into bicarbonate and H+ ions.

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows HCO_3^- + H^+$$

  - However, because we already have bicarbonate ion in our blood, some of these extra H+ ions associate with the extra bicarbonate ion already present in the blood and body fluids, which favors the second chemical reaction occurring in reverse. This results in the reforming of some carbonic acid, decreasing the concentration of H+ again, resulting in a smaller net increase in acidity than otherwise would happen.

- Of course, you are also breathing to exhale the excess CO_2.
  - Exhaling excess CO_2 also causes both reverse reactions to be favored, which would further remove any additional accumulated H+