Life's Common Challenges

Thermoregulation

Life's Common Challenges

Introduction

- **THERMOREGULATION- is the process by which animals maintain an internal temperature within a tolerable range.**
    - **tolerable and optimum ranges do vary from species to species**
- **THERMOREGULATION- is critical to survival because most biochemical and physiological processes are sensitive to temperature.**
    - **proteins denature (change shape) and lose their function**
    - **enzymatic reactions slow down**
      (every 10 degree C sees a 2-3 fold decrease in reaction rate)
    - **membrane fluidity changes with temperature**
      (effects the rate of transport of materials in and out of cells)
    - **ice can form and puncture membranes**
    - **solubility of gases is effected by temperature**

Animals

Thermoregulation

Endothermy & Ectothermy

"source of heat"

- ***Endothermic*** organisms are warmed (from within) mostly by their metabolism
    - ex. birds, mammals
- ***Ectothermic*** organisms gain (from outside) most of their heat from external sources
    - ex. amphibians, lizards, snakes, fish

Note: These modes are not mutually exclusive!

Remember life's adaptations are all about "trade offs"

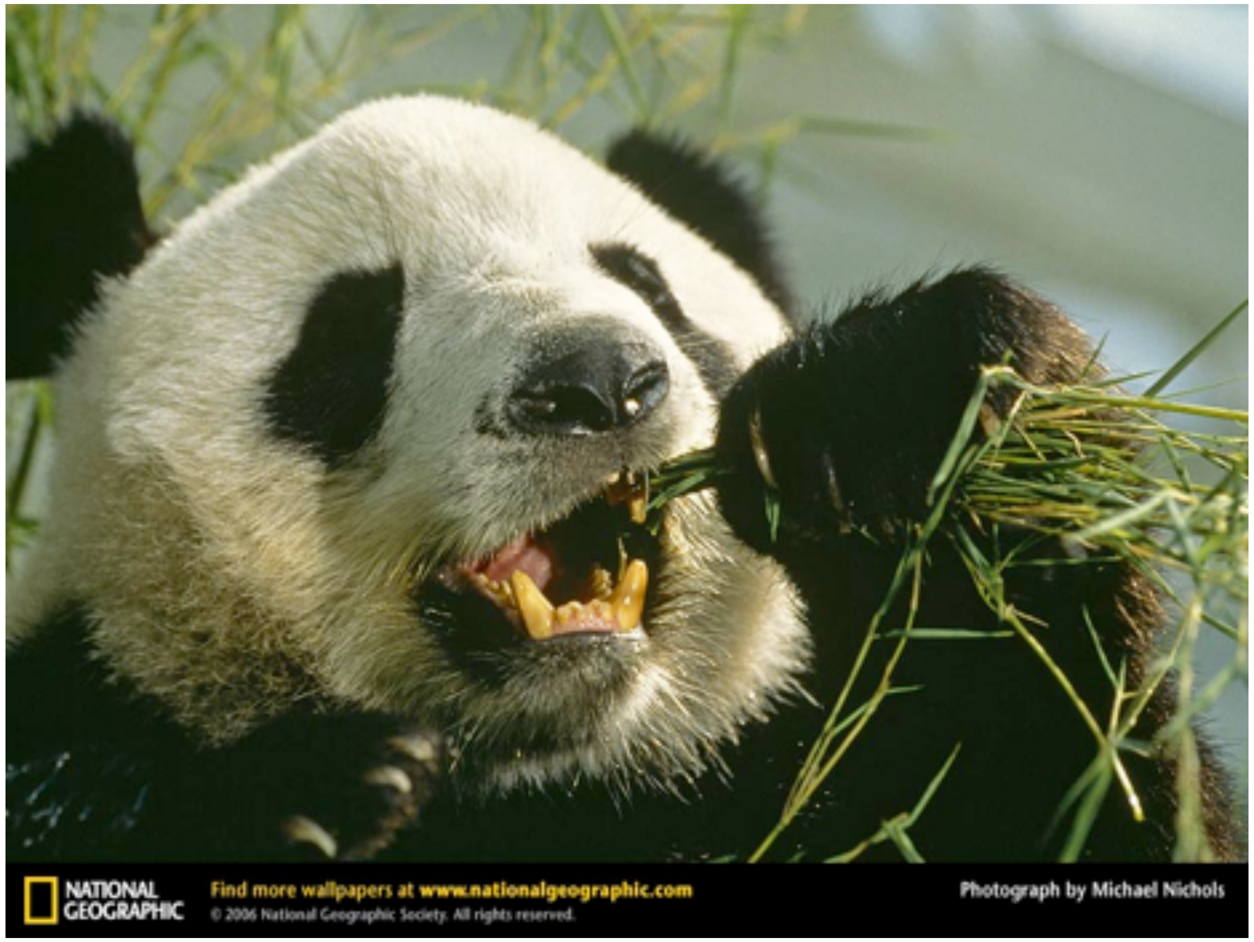
Endotherms...Pros!

- ***Endotherms*** can maintain stable body temps even with large fluctuations in environmental temps
- ***Endotherms*** function well in cold climates (not so for ectotherms)
- ***Endotherms*** function well in hot climates (they have cooling mechanisms)

Remember life's adaptations are all about "trade offs"

Endotherms...Cons!

- ***Endotherms*** do not tolerate large changes in their internal temps, inside temps are tightly regulated.
- ***Endotherms*** must consume large amounts of food to fuel their metabolisms



Remember life's adaptations are all about "trade offs"

Ectotherms...Pros!

- ***Ectotherms*** can tolerate a larger range of internal temps
- ***Endotherms*** do not require large amounts of food

Remember life's adaptations are all about "trade offs"

Ectotherms...Cons!

- ***Ectotherms*** do not tolerate sudden and or large fluctuations in environmental temperatures
- ***Ectotherms*** are rarely active in cold climates

In spite of this ectothermy is a successful strategy for thermoregulation supported by the abundance and diversity of ectothermic organisms

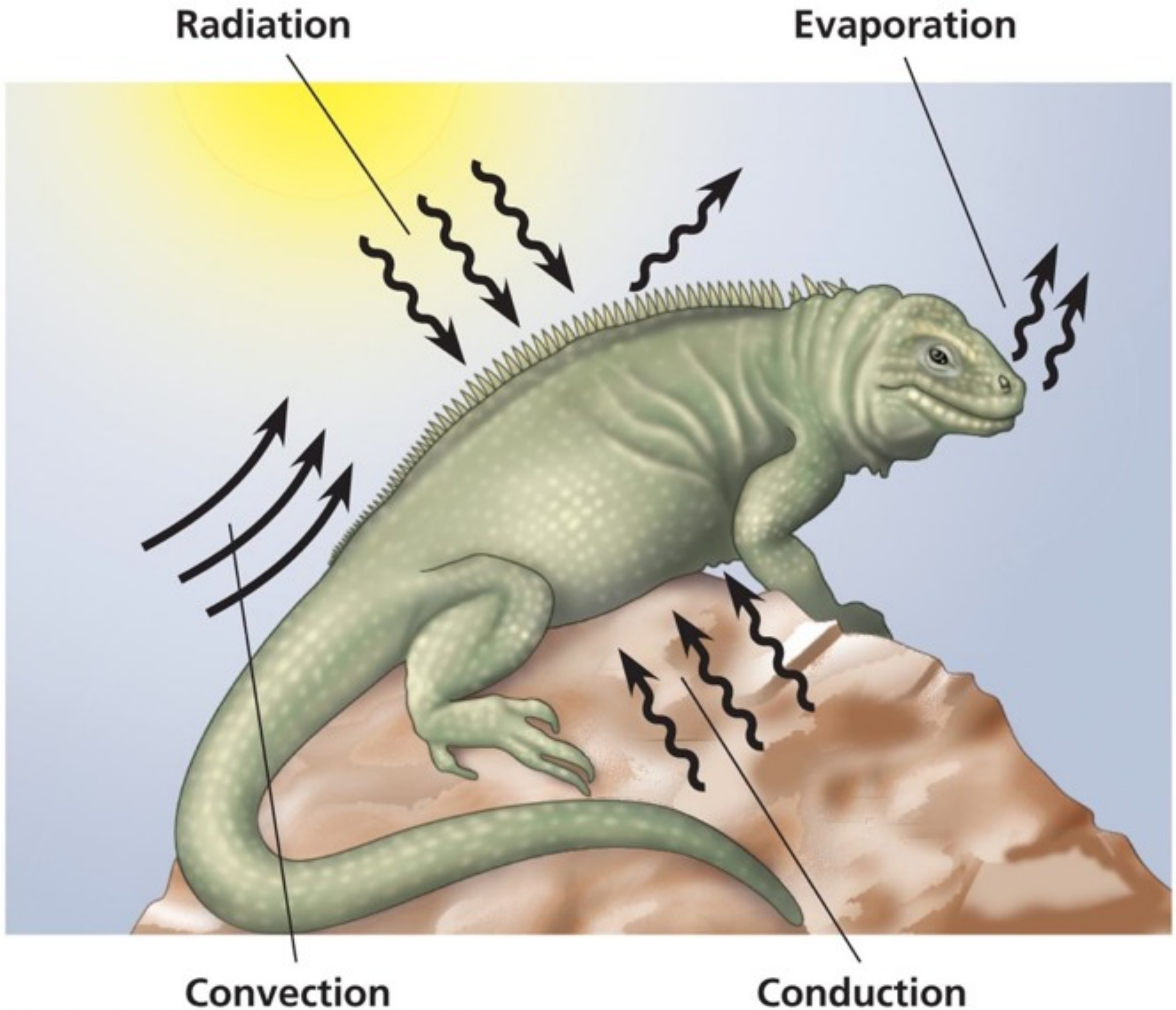
Balancing Heat Loss and Gain

- ***Thermoregulation*** depends on the organisms ability to control the exchange of heat with its environment
- The essence of ***Thermoregulation*** is balancing heat loss and heat gain!
- Any organism or object exchanges heat by one or more the following physical processes...
    - Radiation, Evaporation, Convection, Conduction

Note: Heat is always transferred from the object of higher temperature to the object of lower temperature.

Radiation is the emission of electromagnetic waves by all objects warmer than absolute zero

Evaporation is the removal of heat from the surface of a liquid that is losing some of its molecules as a gas.



Conduction is the direct transfer of thermal motion (heat) between molecules of objects in contact with one another.

Convection is the transfer of heat by the movement of air or liquid past a surface.

Insulation

- ***Insulation*** reduces flow of heat between organisms and their environment
  - major adaptation in birds and mammals
    - hair, feathers and adipose tissue (fat)
- Organisms can adjust their insulating layers accordingly
  - raising of fur or feathers, traps air creating a thicker layer
  - marine mammals have "blubber" (thick layer of fat)


Blubber is so effective that marine mammals can maintain internal body temps of 36-38C or 97-100F

Circulatory Adaptations

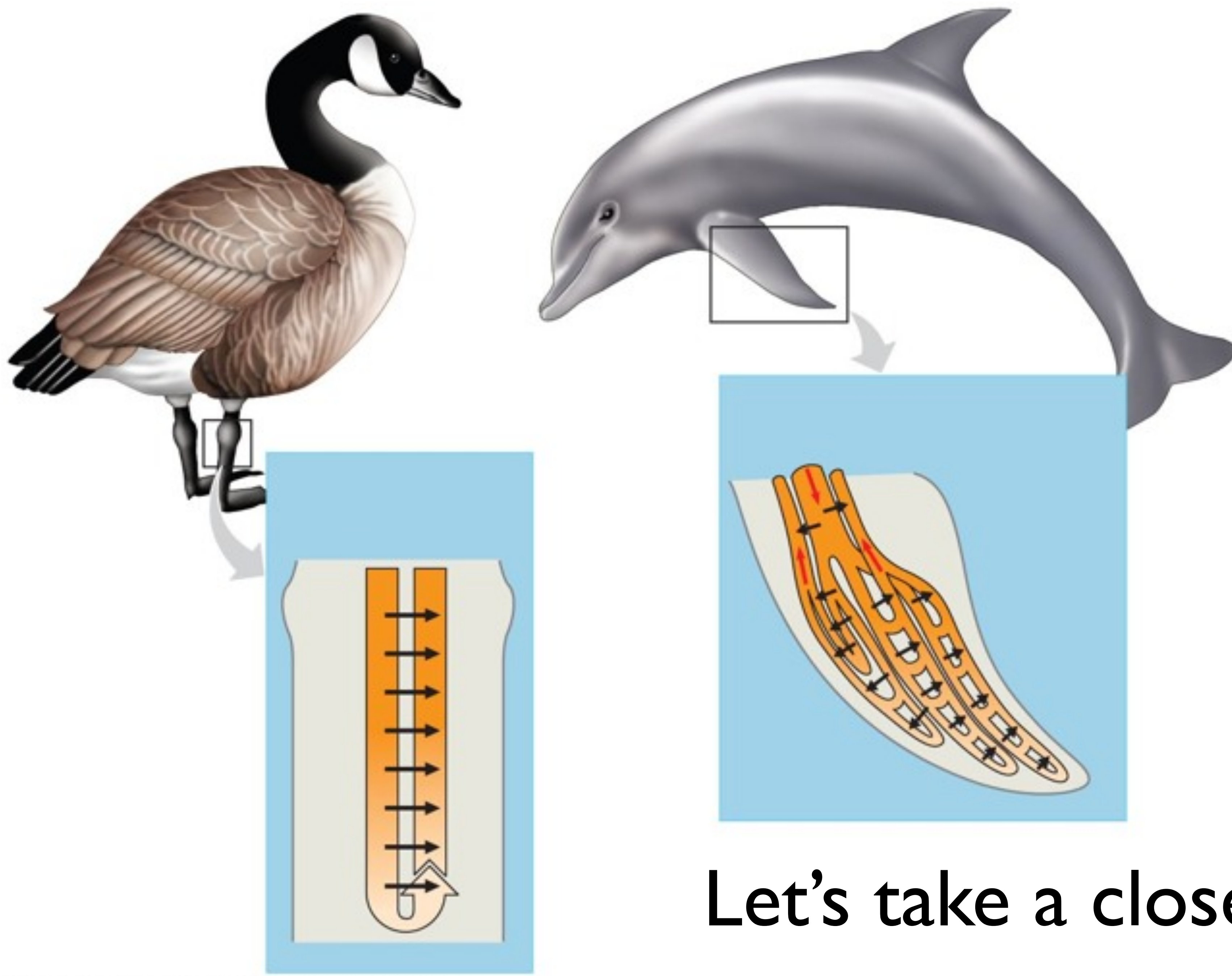
- One such adaptation involves the adjustment of vessel diameter.
    - Vasodilation opens vessels which consequently results in heat loss. Widening the vessels places blood closer to the skin (surface for heat exchange)
    - Vasoconstriction closes vessels which consequently lessens heat loss. Smaller vessels decrease blood flow and as a result heat exchange.

Present in both endotherms and ectotherms

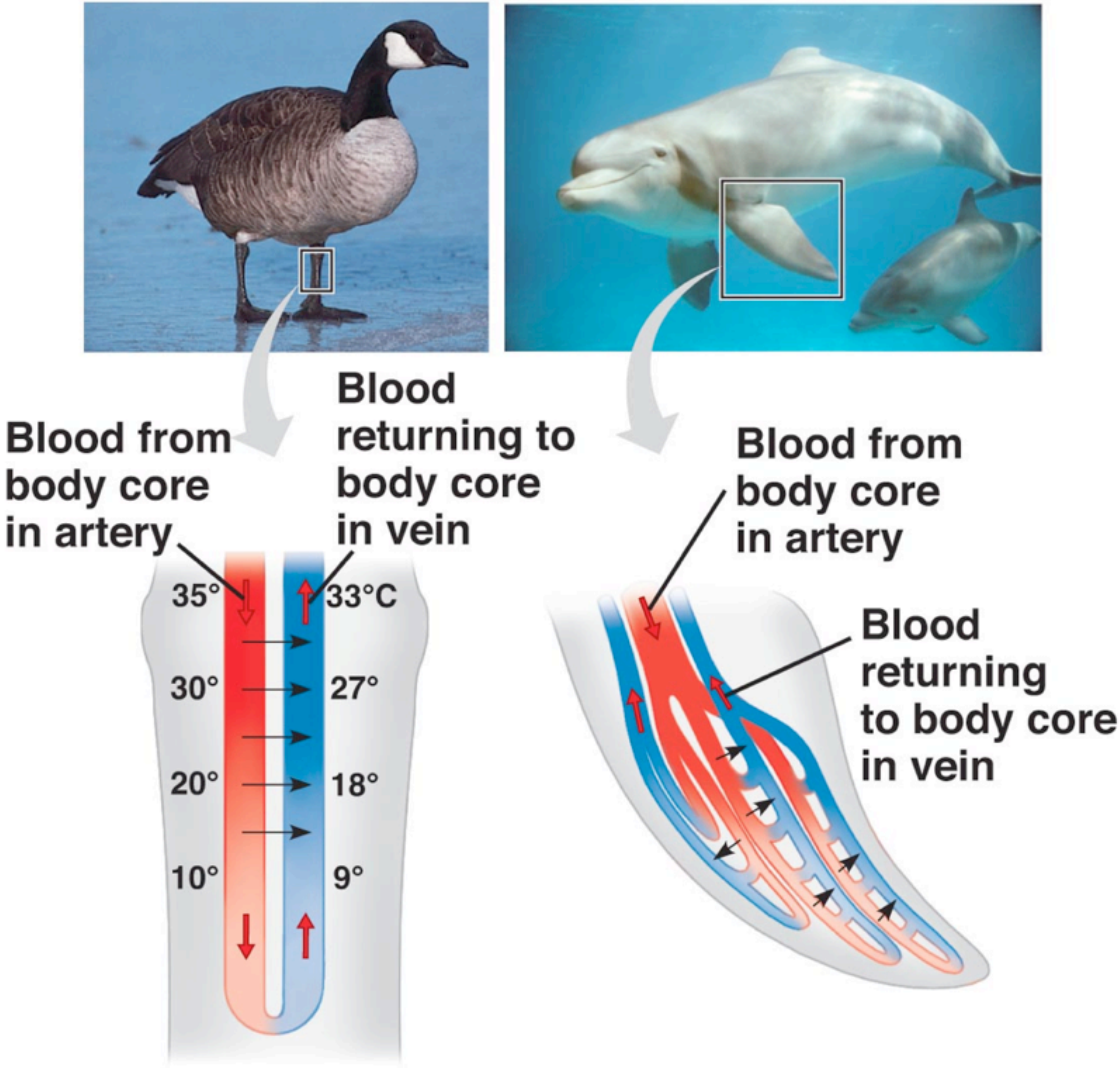
In which Iguana(s) is the blood vessels likely dilated? constricted? Why?

Circulatory Adaptations

- Another circulatory adaptation relies on a ***Countercurrent Exchange,*** the transfer of heat (or solutes) between fluids that are flowing in opposite directions



Let's take a closer look...



Blood from body core in artery
Blood returning to body core in vein
35°
33°C
30°
27°
20°
18°
10°
9°
Blood from body core in artery
Blood returning to body core in vein

Cooling by Evaporative Heat Loss

- Thermoregulation requires cooling as well as warming.
- Evaporation is the only way to keep body temperature from rising.
  - Terrestrial animals lose water (evaporation) through skin and respiratory surfaces.
    - remember water absorbs considerable amount of heat and much is carried away during evaporation
      - panting, sweating and bathing

Let's take a closer look...

Behavioral Responses

- Many organisms, both endotherms and ectotherms thermoregulate through behaviors.
  - These behaviors may be simple (moving into shade or sun) or complex (migration and hibernation).
  - Some behaviors involve postures that minimize or maximize surface area

“obelisk” posture minimizes sun exposure, thus reducing heat gain

Adjusting Metabolic Heat Production

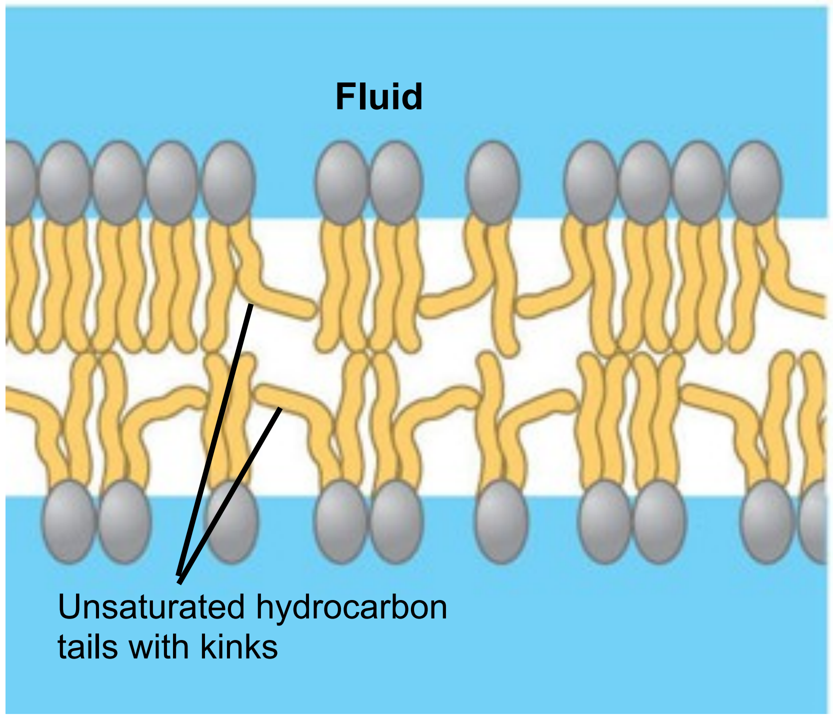
- Endotherms can vary heat production-***thermogenesis***-to match changing rates of heat loss.
  - ex. increase muscle activity through moving or shivering.
  - Check this out...chickadees can maintain a body temp of 40℃ (104 ℉) in temps as low as -40 ℃ (-40 ℉)
- Some mammals can generate heat at the cellular level through increase ATP production- *nonshivering thermogenesis*.

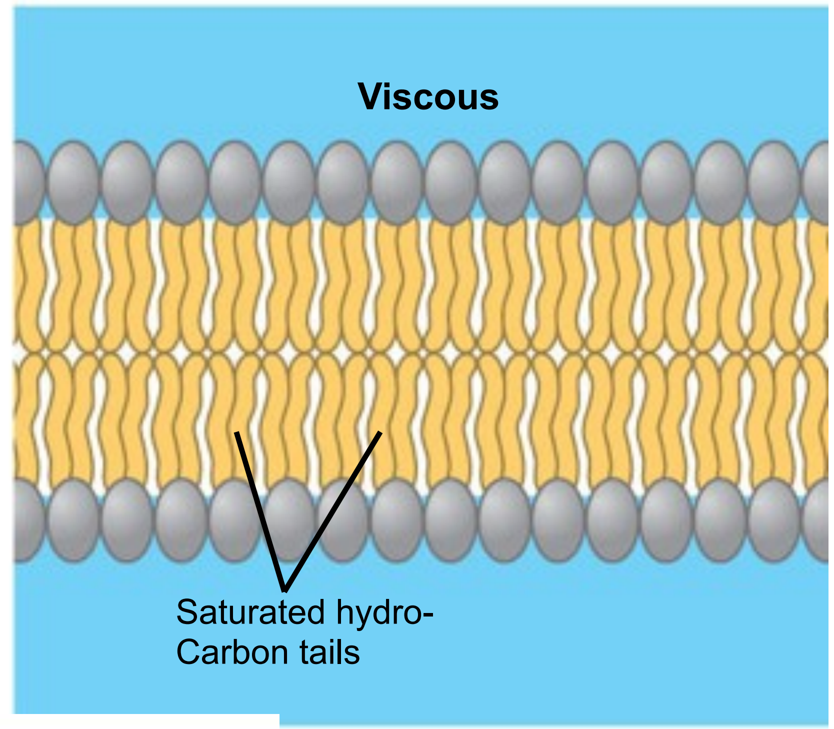
Acclimatization in Thermoregulation

- Organismal Level: Some animals adjust their insulating layers seasonally.
    - ex. growing a thicker coat during the winter months and shedding the excess during the summer months.
- Cellular Level: Some cells alter their proportions of saturated and unsaturated lipids that make up their membrane.
    - ex. winter wheat
- Cellular Level: Some cells can produce "antifreeze compounds" that prevent ice formation in their cells.
    - ex. certain fish can survive in water as cold as -2 ℃ (28 °F)

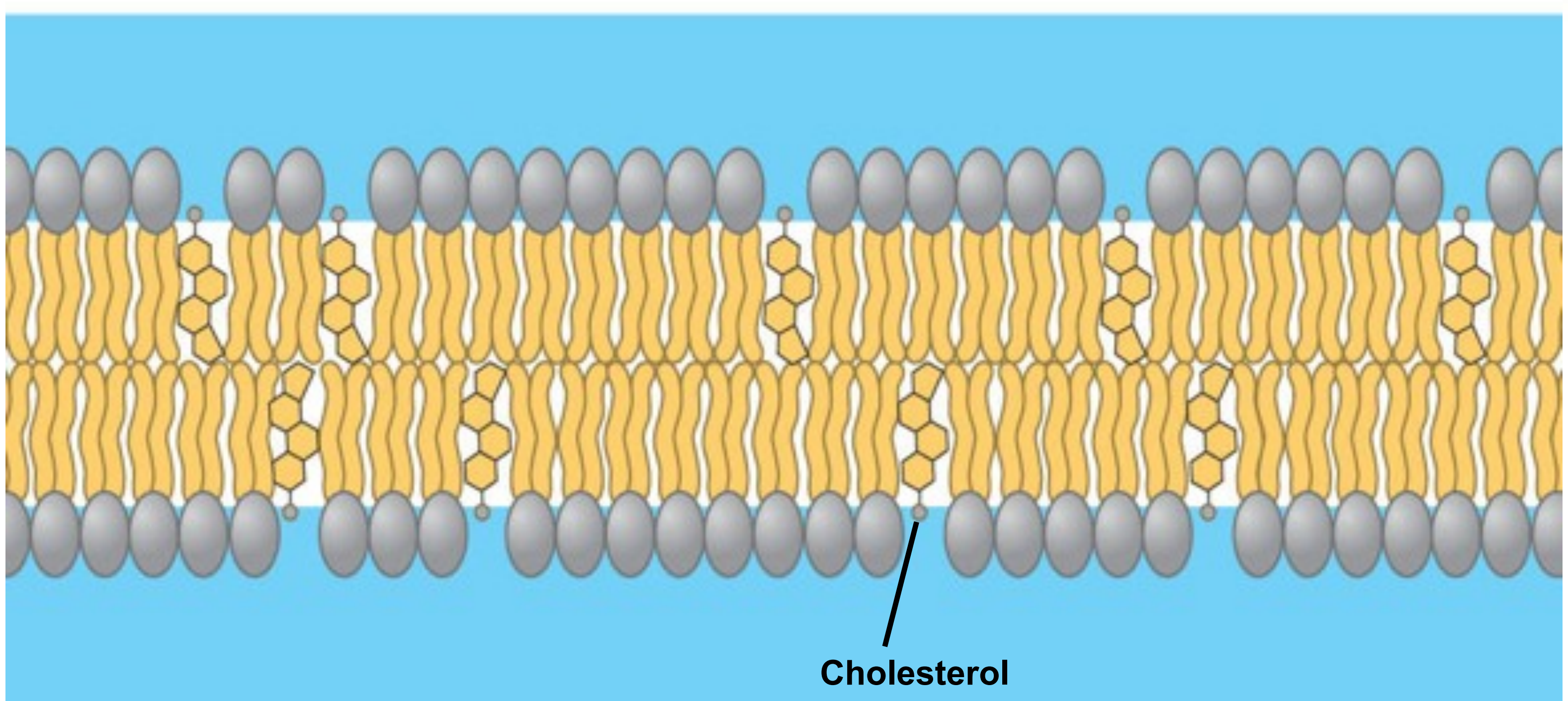
How would the proportions of lipids in the membrane of winter wheat change during winter? During summer?

Winter





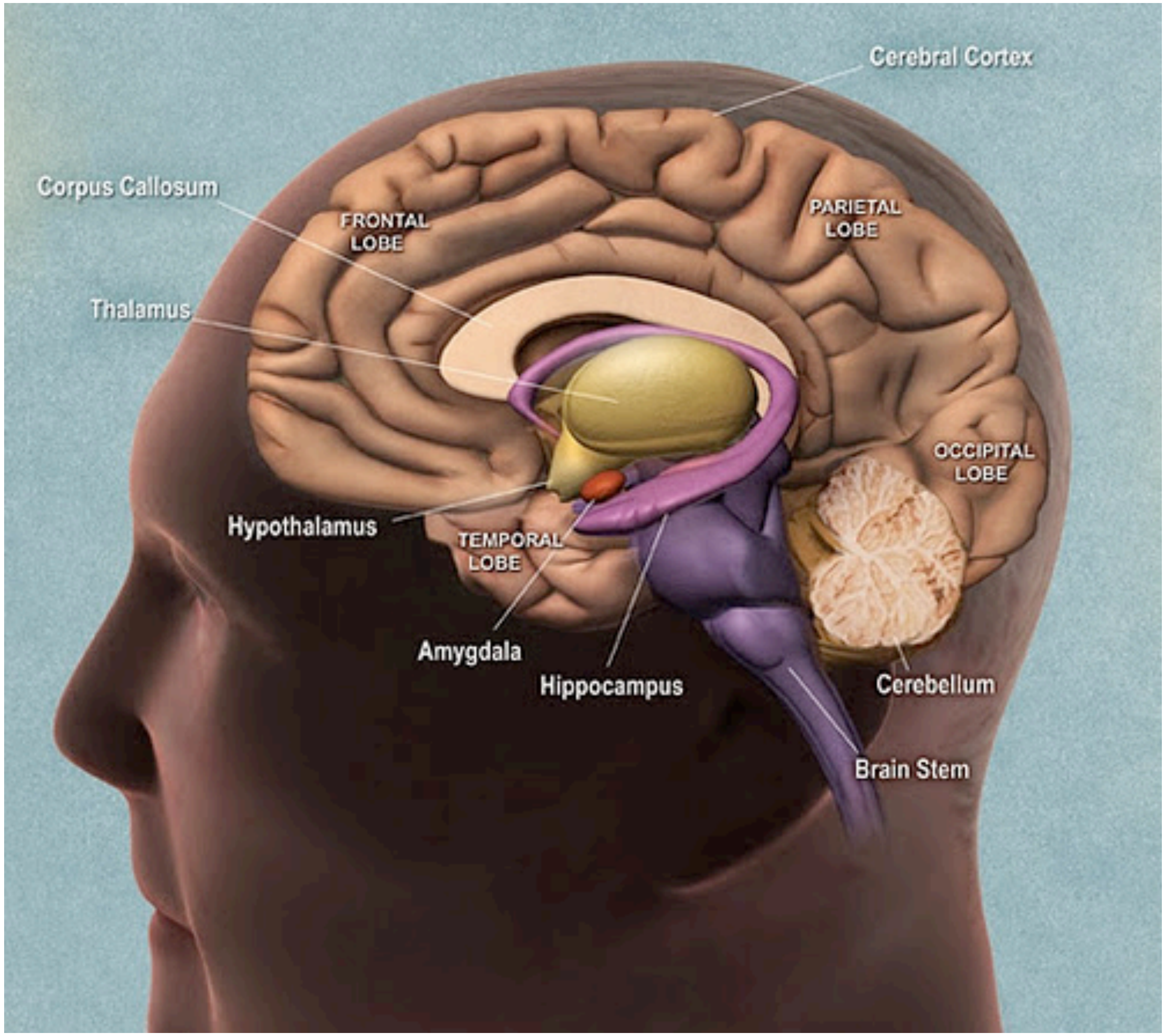
Summer

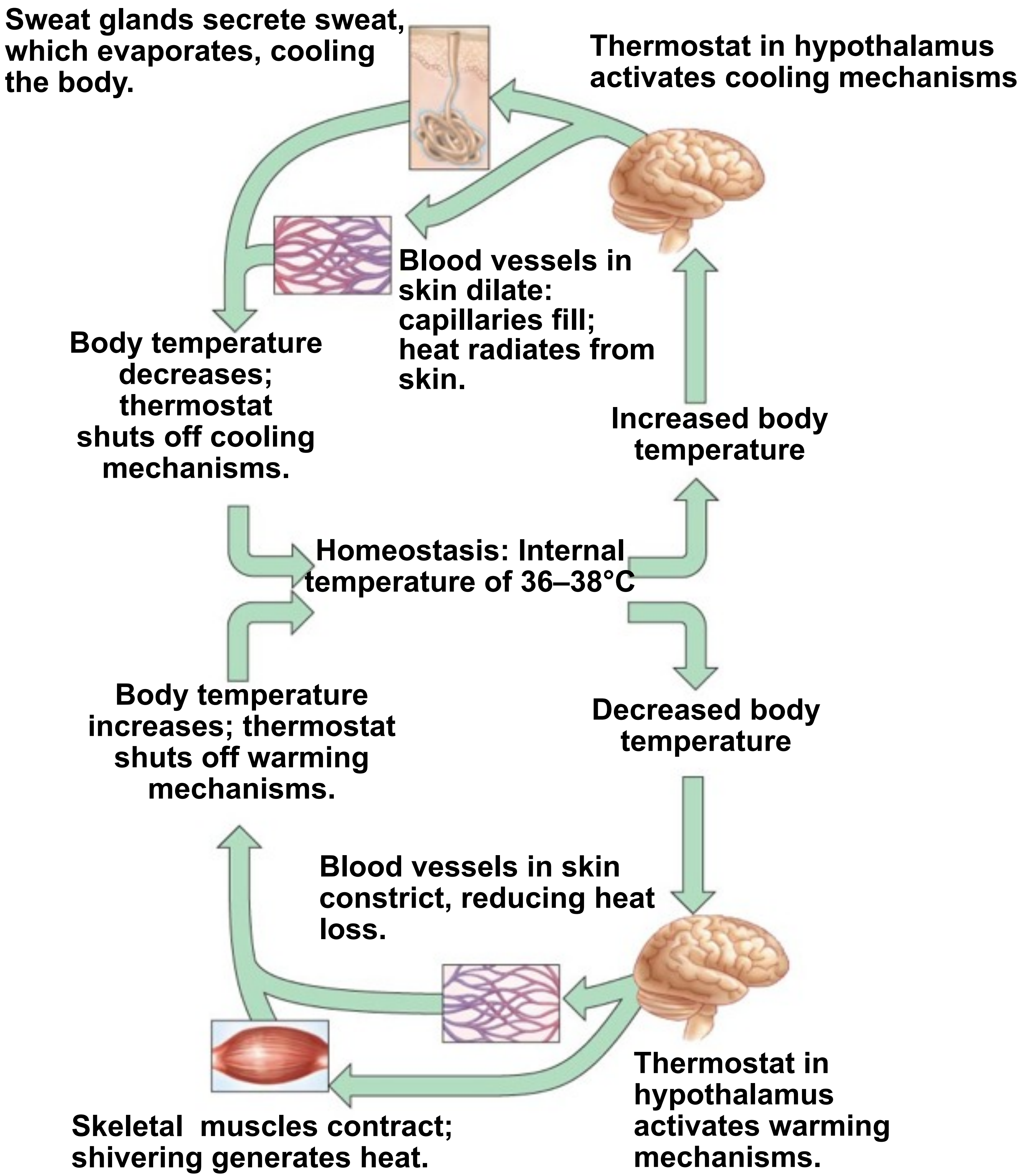


Adding cholesterol can make a viscous membrane more fluid OR it can make a fluid membrane more viscous

Physiological Thermostats & Fever

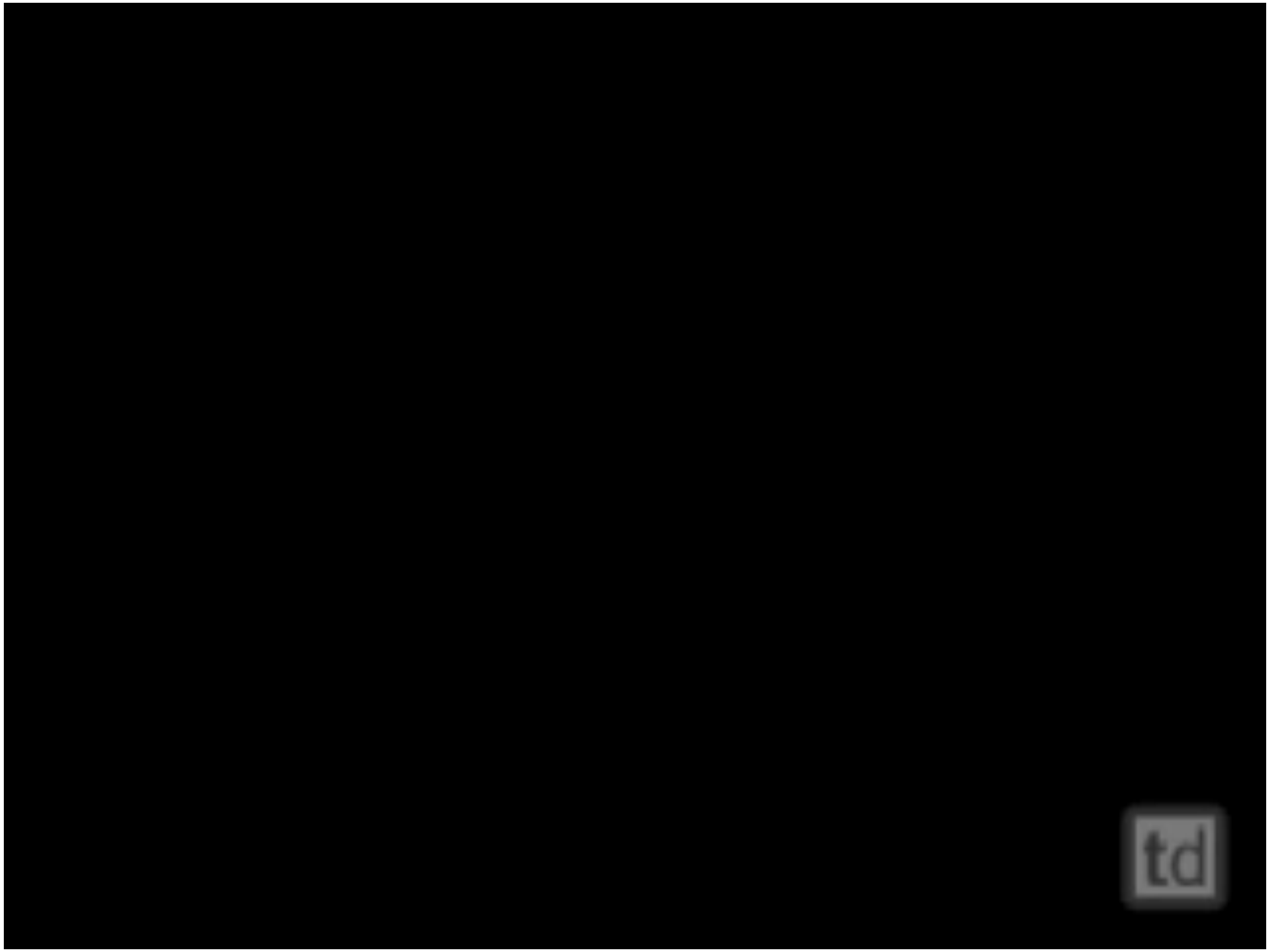
- A complex feedback system is responsible for regulating body temps in mammals.
  - A region in the brain called the *hypothalamus* serves as the body's thermostat.




Sweat glands secrete sweat, which evaporates, cooling the body.
Thermostat in hypothalamus activates cooling mechanisms.
Blood vessels in skin dilate: capillaries fill; heat radiates from skin.
Body temperature decreases; thermostat shuts off cooling mechanisms.
Increased body temperature
Homeostasis: Internal temperature of 36–38°C
Decreased body temperature
Body temperature increases; thermostat shuts off warming mechanisms.
Blood vessels in skin constrict, reducing heat loss.
Thermostat in hypothalamus activates warming mechanisms.
Skeletal muscles contract; shivering generates heat.

Physiological Thermostats & Fever

- Certain bacterial and viral infections bring about an increase in the body's temperature set point...fever.
    - Fever makes it difficult for pathogens to reproduce.



Plants

Thermoregulation

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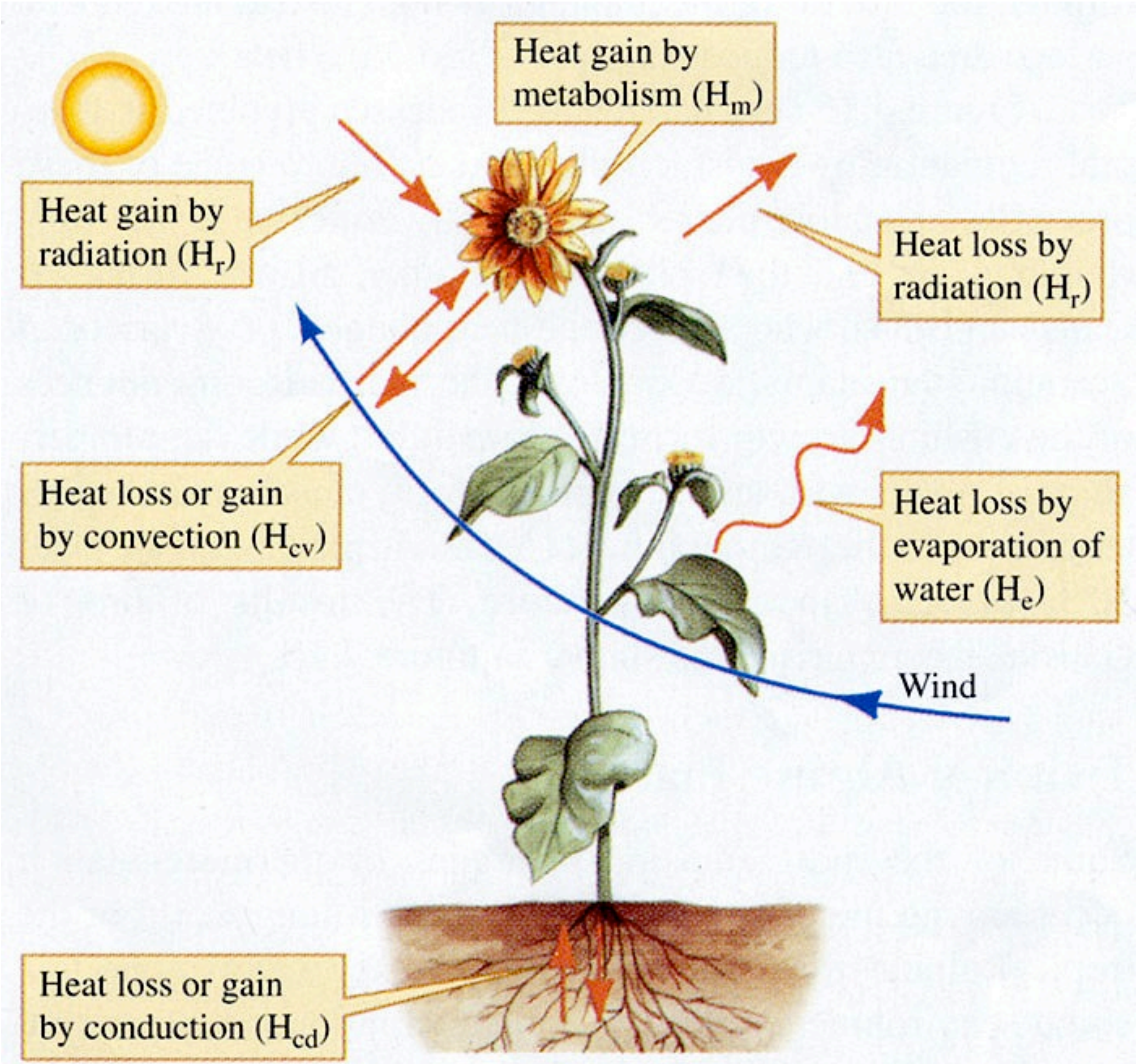
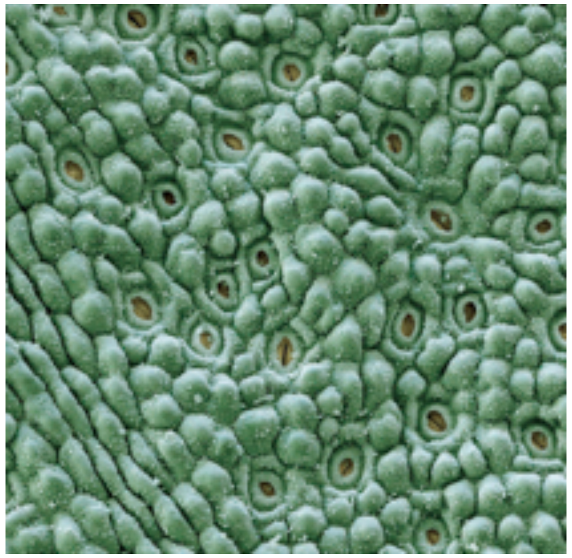
  - **ice can form and puncture membranes**
  - **solubility of gases is effected by temperature**
  - ***Chlorophyll becomes unstable at higher temps**

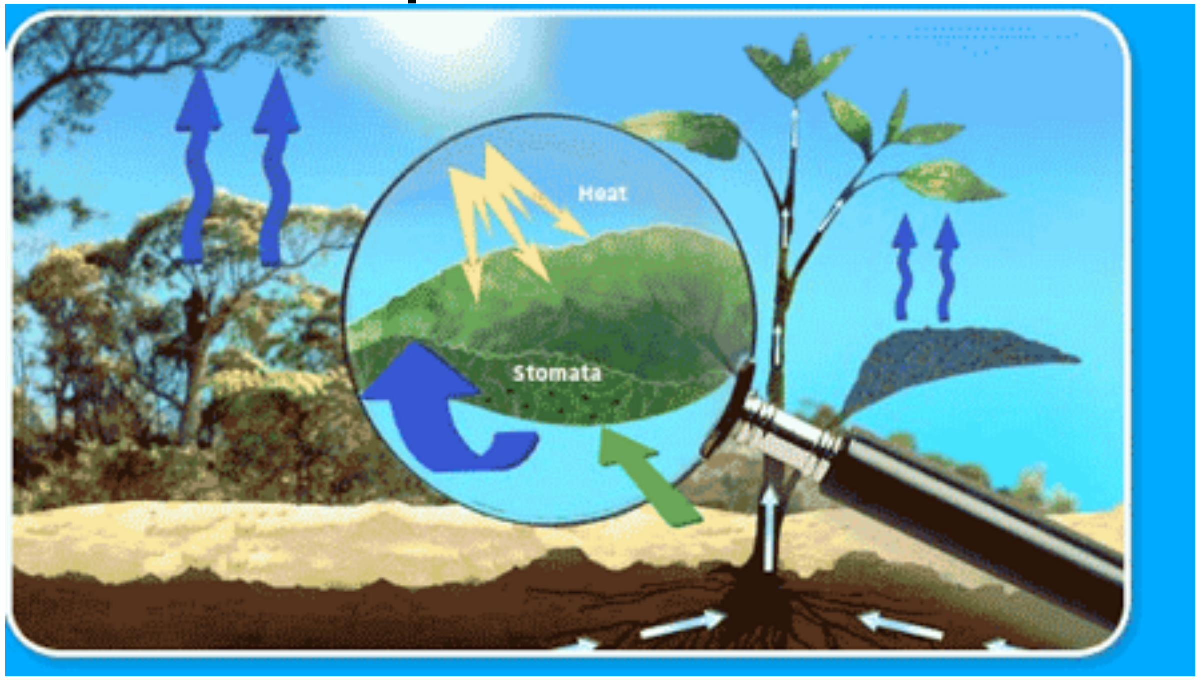
Balancing Heat Loss and Gain



Heat Stress

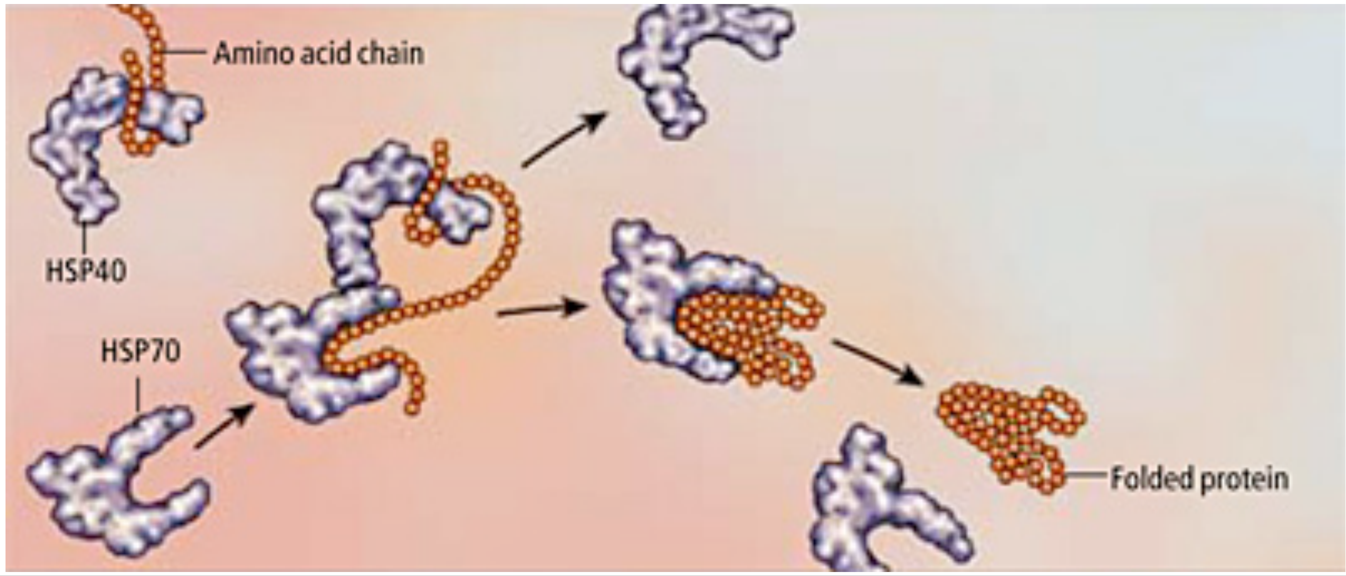
- Excessive heat can harm or kill a plant by denaturing proteins and disrupting metabolism
- Transpiration ("plant sweating") is an adaptation that can keep a leaf 3-10 ℃ below the ambient air temperature
  - however transpiration has its limits, too much water loss can dehydrate a plant and slow its rate of photosynthesis
  - on hot dry days plants are forced to close their stomates to conserve water, this of course reduces evaporative heat loss through transpiration

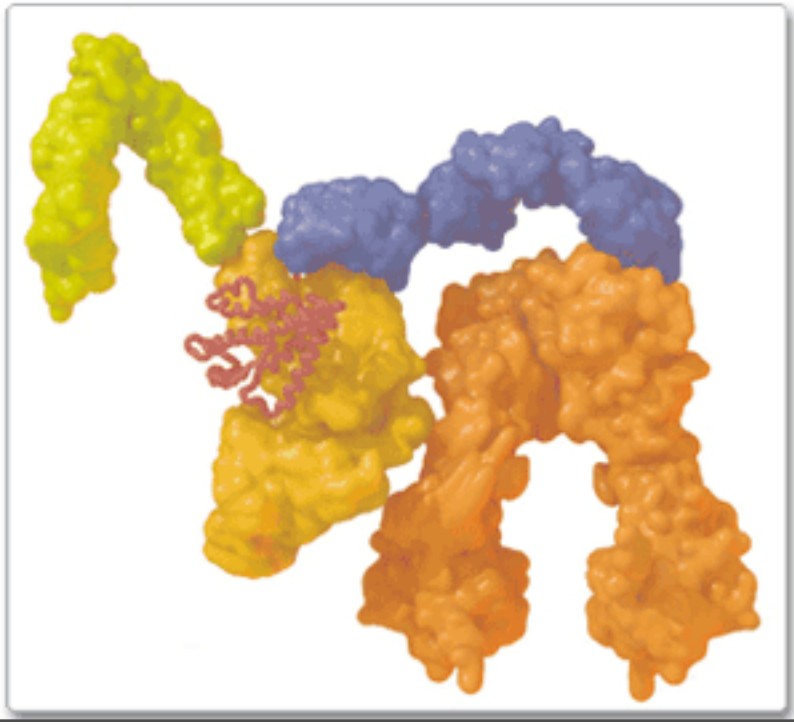




Heat Stress *(continued)*

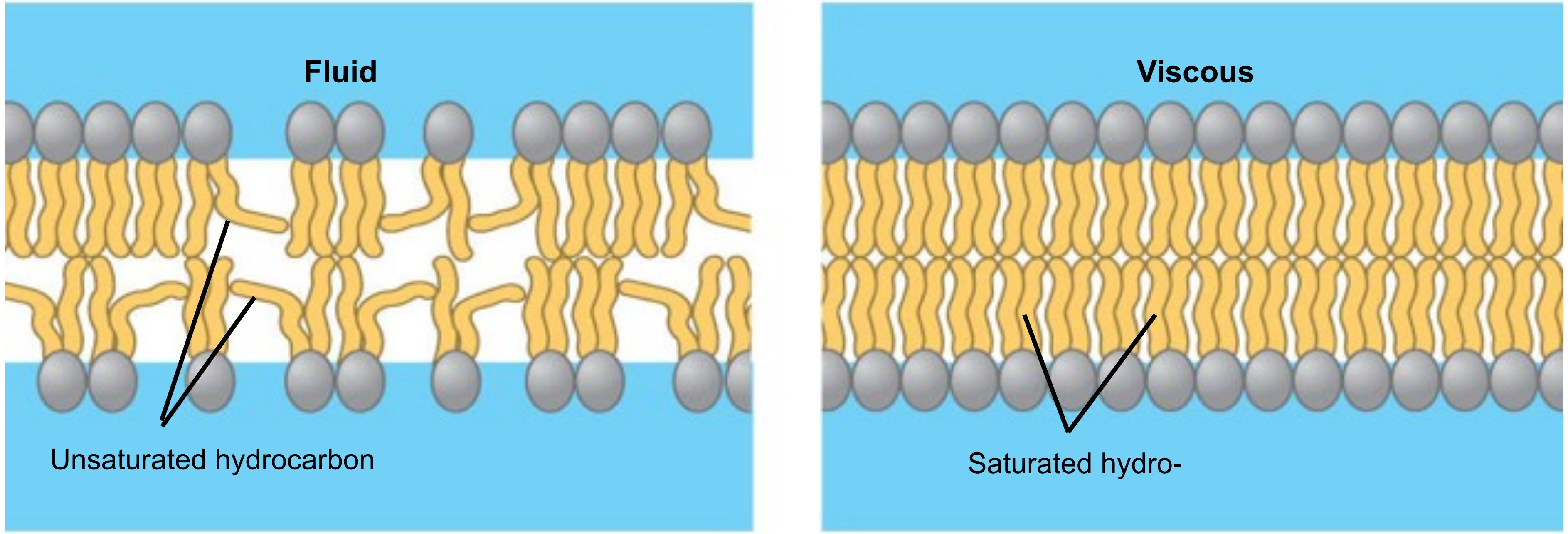
- When transpiration can longer cool the plant leaves a backup mechanism is relied upon...
- Plant cells respond by producing "***heat shock proteins***".
  - These proteins help prevent other proteins from denaturing





Cold Stress

- Cold temperatures (not freezing) most effect a plants plasma membrane.
- Cold temperatures make membranes more viscous and alters the membranes ability to transport materials into or out from cell
  - Plants respond by altering their membrane composition
  - Recall...



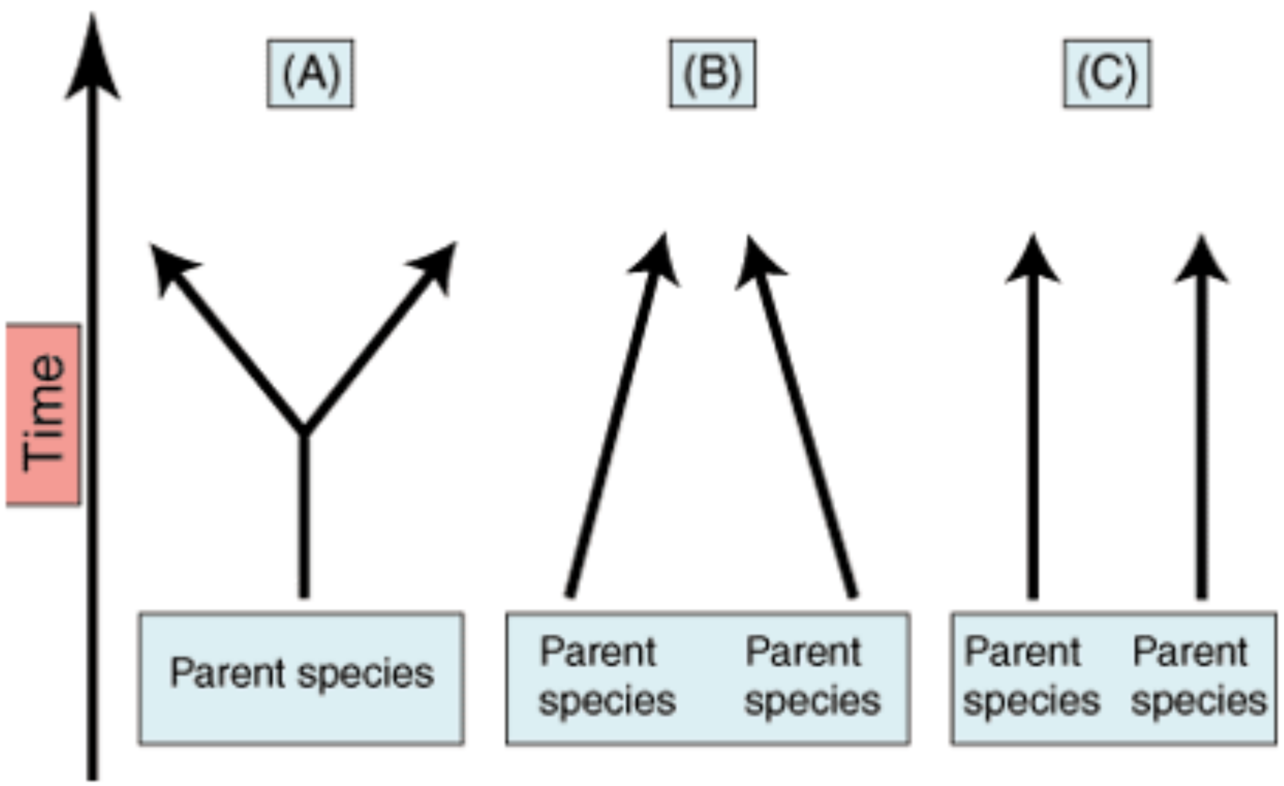
Such modifications takes hours to days which explains why unseasonably cold weather or fast moving cold fronts are so stressful and potentially dangerous

Cold Stress (Freezing)

- Background Information: Adding solutes to water lowers water's freezing point.
  - Water's freezing point is 0 ℃
  - In subfreezing temps the plant cell's cytosol rarely freezes because it contains many solutes
  - The water found in between plant cells and in plant cell's walls however contain far less solutes and will therefore readily freeze.
- The Problem: When this water freezes the water potential outside the cell is lowered and water leaves the cytosol, which causes the solute concentration inside the cell the become harmful and potentially deadly to the cell

Cold Stress (Freezing)

- Solutions: A well hydrated plant is a good start.
  - Plants also contain "antifreeze proteins" first discovered in arctic fish, that prevent ice crystals from forming.
    - These proteins have slightly different conformations but their amino acid sequences are very different from animals' sequences. This suggests *convergent evolution*.



Fungi

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Temperature Stress

- Fungi are eukaryotes and extreme heat and cold pose the same threat to fungi as it did for plants and animals.
- As is turns out there are no unique adaptations for dealing with extreme temps, like plants and animals the adaptations for fungi focus on...
  - Preventing proteins from denaturing or helping them refold in the case that they happen to denature
  - Producing temp "hardy" enzymes whose optimal temperatures are abnormally hot or cold
  - Producing "antifreeze" like compounds that prevent water from freezing
  - Adjusting membrane composition to ensure an adequate rate of material transfer across the membrane

Thermophilic Fungi

- There is little research on temp relationships in fungi.
- Much of the research that does exists is from the food industry where heat is commonly used to prevent fungal growth.
- Fungi can be divided into groups by temp requirements for optimal growth
  - Psychrophiles: optima less than 10 ℃
  - Mesophiles: optima at room temp 18-22 ℃ (most fungi)
  - Thermophiles: optima more than 37 ℃
    (up to 62 ℃, they are the only eukaryotes that can live above 45 ℃)
    - Note: This data does not address fungal spores and their temp tolerance or requirements that is separate issue.

Convert these temps above to Fahrenheit.

Need a hint... (9/5)(x ℃) + 32 or F - 32 (5/9)

Thermophilic Fungi

- Thermophilic fungi are of interest for scientific and commercial reasons.
  - due to their heat tolerant enzymes, for instance some laundry detergents already use these enzymes
  - enzymes have long been used in the food and dairy industry
  - they are the chief component in compost piles
  - they are only approx. 30 species out of 50,000 that can withstand extremely high temps
- Unfortunately the information on thermophilic adaptations is limited because most work continues on the practical applications side of things.

Protists

Thermoregulation

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    - **ice can form and puncture membranes**
    - **solubility of gases is effected by temperature**
    - ***like plants photosynthetic algae is limited in upper temps due to chlorophyll's unstable nature at higher temps**

Temperature Stress

- Protists are eukaryotes and extreme heat and cold pose the same threat to protists as it did for plants, animals and fungi.
- As is turns out there are no unique adaptations for dealing with extreme temps, like plants, animals and fungi the adaptations for protists focus on...
  - Preventing proteins from denaturing or helping them refold in the case that they happen to denature
  - Producing temp "hardy" enzymes whose optimal temperatures are abnormally hot or cold
  - Producing "antifreeze" like compounds that prevent water from freezing
  - Adjusting membrane composition to ensure an adequate rate of material transfer across the membrane

Temperature Stress

- Some photosynthetic protists have adapted to cold environments.
- ex. Watermelon snow

watermelon snow? red snow?

- Pink snow with a slight scent of watermelon!
- Green algae (*Chlamydomonas nivalis*), takes a red color due to secondary red carotenoid pigments that mask the green chlorophyll
    - the red pigments better protect against harmful UV radiation
    - the red pigment also absorbs more heat which melts surrounding snow and provides water for photosynthesis
- This algae thrives in freezing water
- However in winter snow covers the algae and the algae becomes dormant until spring.

Bacteria

Thermoregulation

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      (every 10 degree C sees a 2-3 fold decrease in reaction rate)
    - membrane fluidity changes with temperature
      (effects the rate of transport of materials in and out of cells)
    - ice can form and puncture membranes
    - solubility of gases is effected by temperature

Temperature Stress

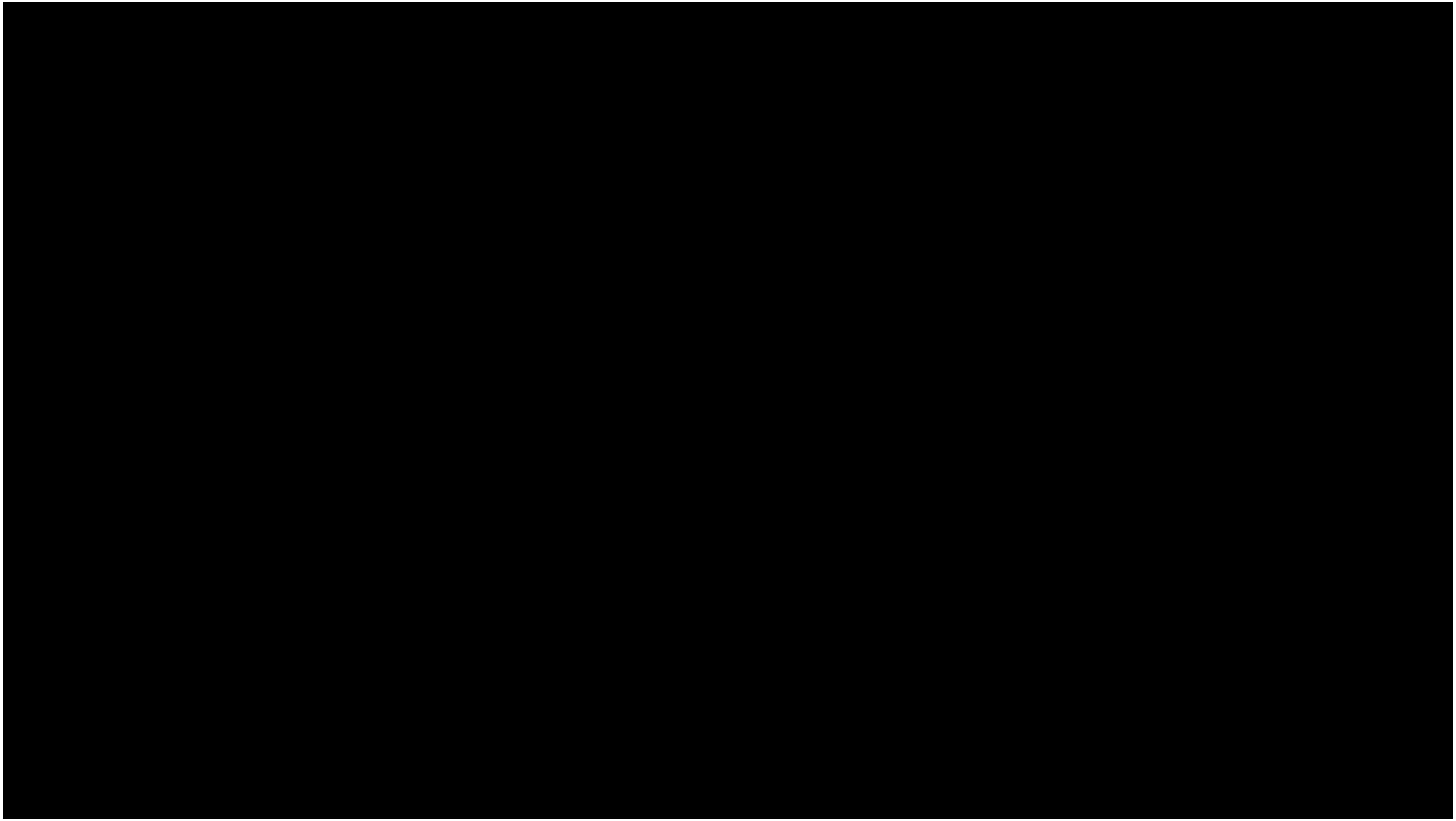
- Bacteria are prokaryotes and extreme heat and cold pose the same threat to bacteria as it did for all other cells and organisms.
- The adaptations for dealing with extreme temps are similar to those seen in other forms of life, the adaptations for bacteria focus on...
  - Preventing proteins from denaturing or helping them refold in the case that they happen to denature
  - Producing temp "hardy" enzymes whose optimal temperatures are abnormally hot or cold
  - Producing "antifreeze" like compounds that prevent water from freezing
  - Adjusting membrane composition to ensure an adequate rate of material transfer across the membrane
  - **Some bacteria have an adaptation where their DNA exists in a "relaxed" state that prevents it from unraveling**

Extreme Thermophilic Bacteria

- Thermophilic bacteria have adapted to the most extreme temperatures!
  - Bacteria have been found living in temps as high as 121 ℃ and as low -20 ℃
- Bacteria can be divided into groups by temp requirements for optimal growth
  - Psychrophiles: optima less than 20 ℃ (range 0-20)
  - Mesophiles: optima ~40 ℃ (range 10-50)
  - Thermophiles: optima ~ 65 ℃ (range 45-80)
  - Hyperthermophiles: optima ~100 ℃ (range 80-120)

What happens to water at 0 ℃ and 100 ℃ ?

Extreme Thermophilic Bacteria



Where Are High-Temperature Environments?

Hot Springs

- Yellowstone National Park
- Japan
- Russia
- Iceland
- New Zealand

Deep-Sea Hydrothermal vents

- Found at mid-ocean ridges (Mid-Atlantic Ridge, East Pacific Rise)

Deep Ocean Hydrothermal Vents

Hot Springs & Geothermal Features

Yellowstone National Park is home to the world's largest

Steamboat Geyser – The World's Largest!

- 9000 Hot Springs
- 500 Geysers
- 400 Fumaroles
- 100 Mudpots

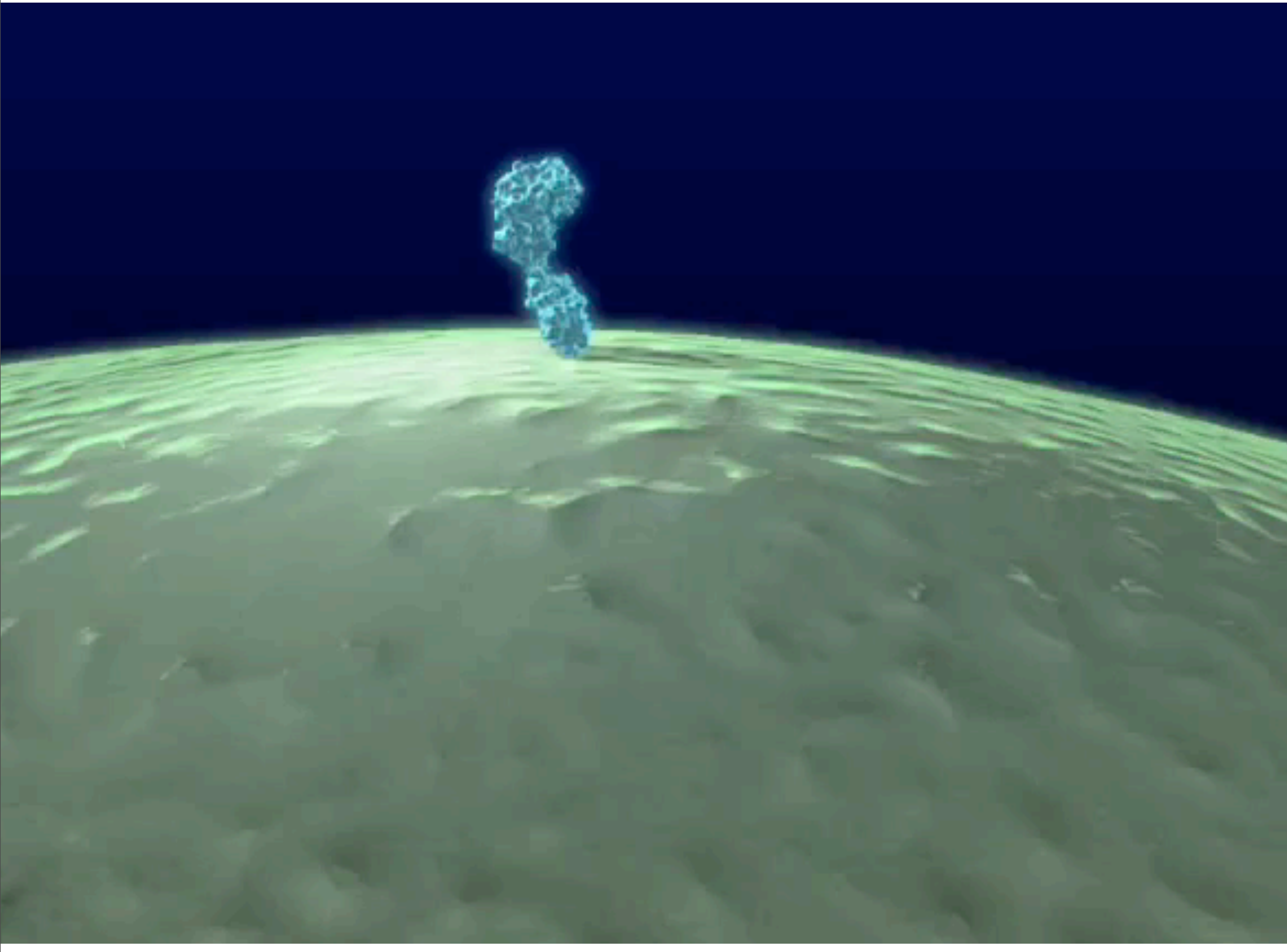
Grand Prismatic Spring, Yellowstone

A Protein Summary

Recall that Nucleic acids are also adversely effected by extreme temps however we will only focus on proteins in this unit

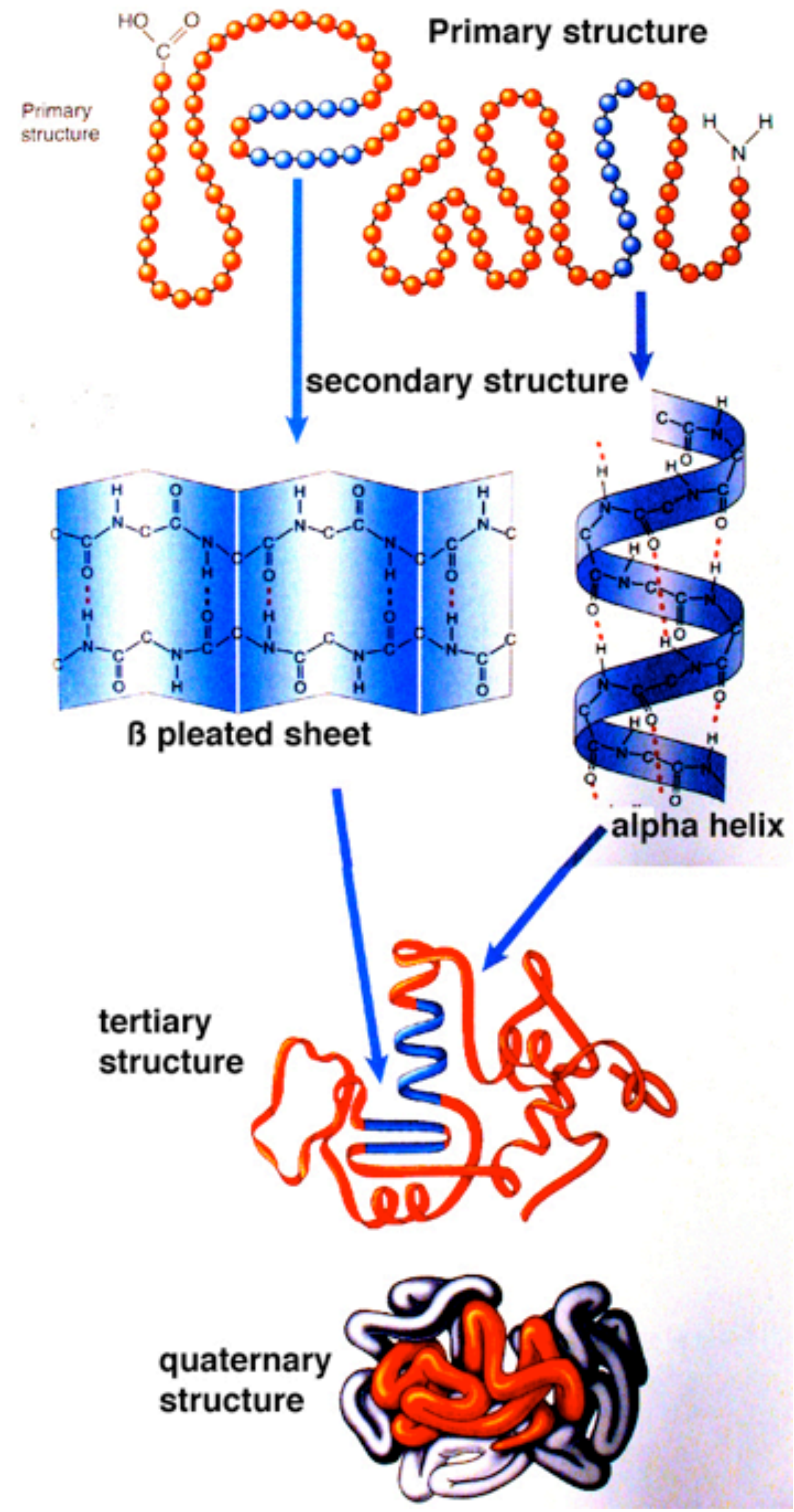
B. Protein Structure and Function

- **Functions of proteins depend on their architecture.**
  - **This architecture is dependent upon the amino acid sequence.**
- **Proteins are more than just a polypeptide chain, proteins must be twisted, folded and coiled into a specific shape.**
- **The twisting, folding and coiling is held in place by a variety of bonds between the groups on the amino acids.**
- **Proteins generally take one of two shapes:**
  - **Round...** ***globular proteins***
  - **Linear...** ***fibrous proteins***
- **In almost every case the function of a protein depends on its ability to recognize and bind with some other molecule.**



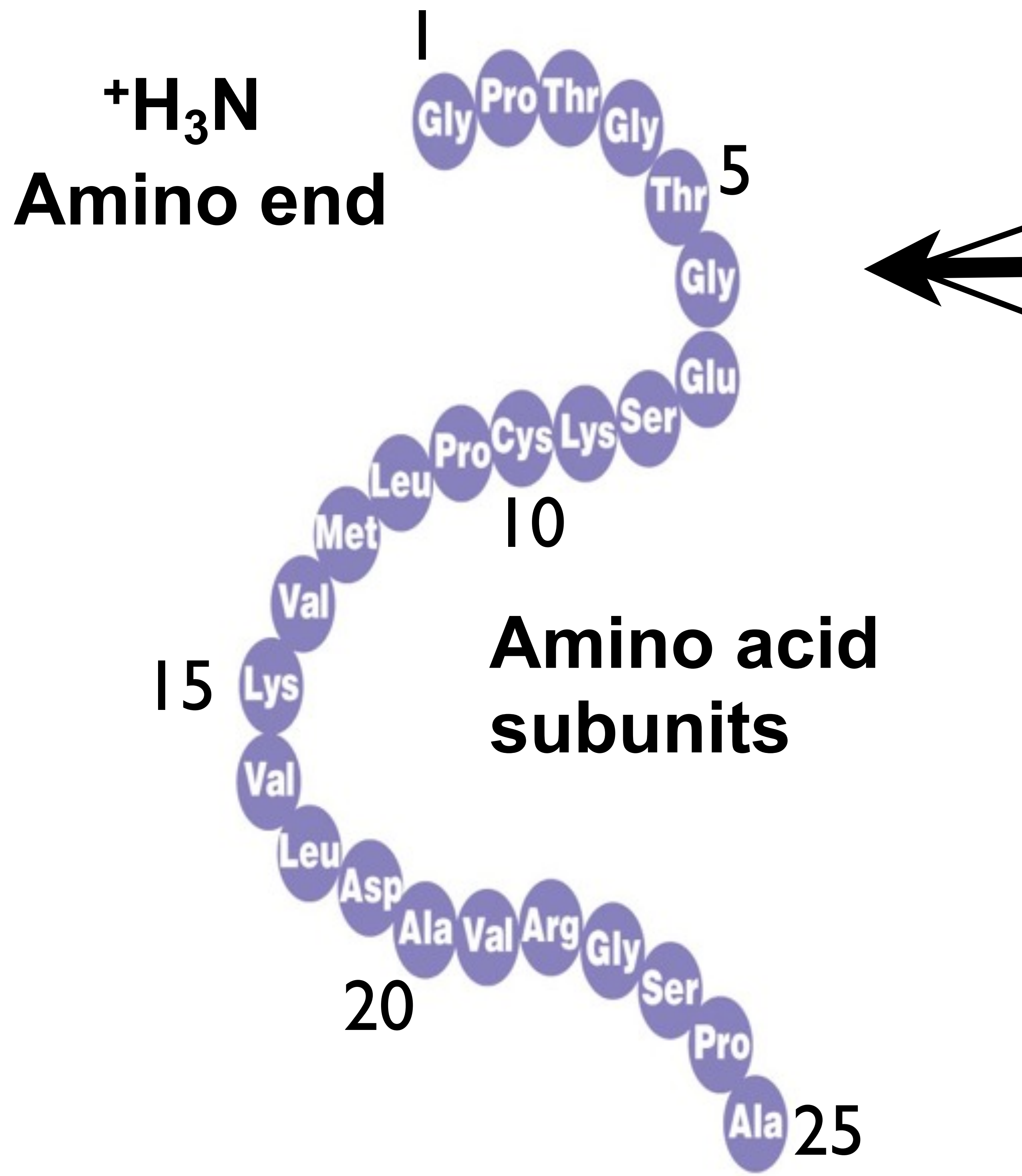
1. Four Levels of Protein Structure

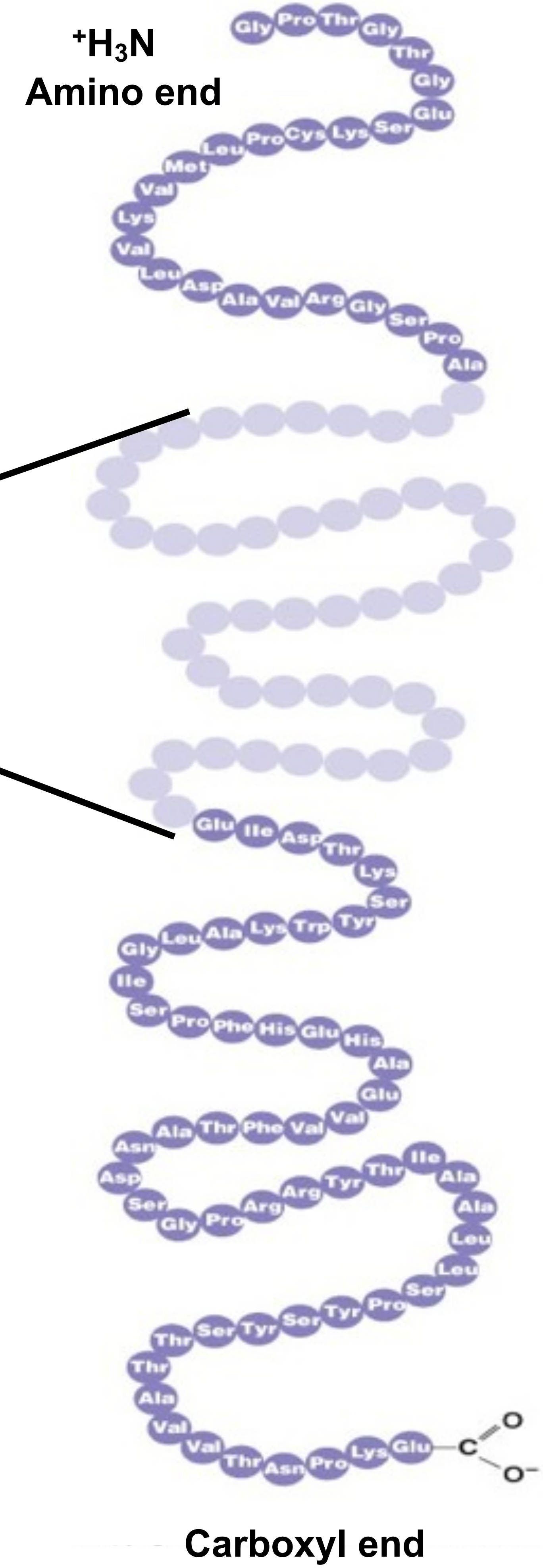
- With a goal to understand a proteins function its productive to begin by dissecting its structure.
- All proteins have levels of structure: *primary, secondary* and *tertiary*. Some have proteins have a fourth level, *quaternary*.



Primary Structure

Linear Chain of Amino Acids

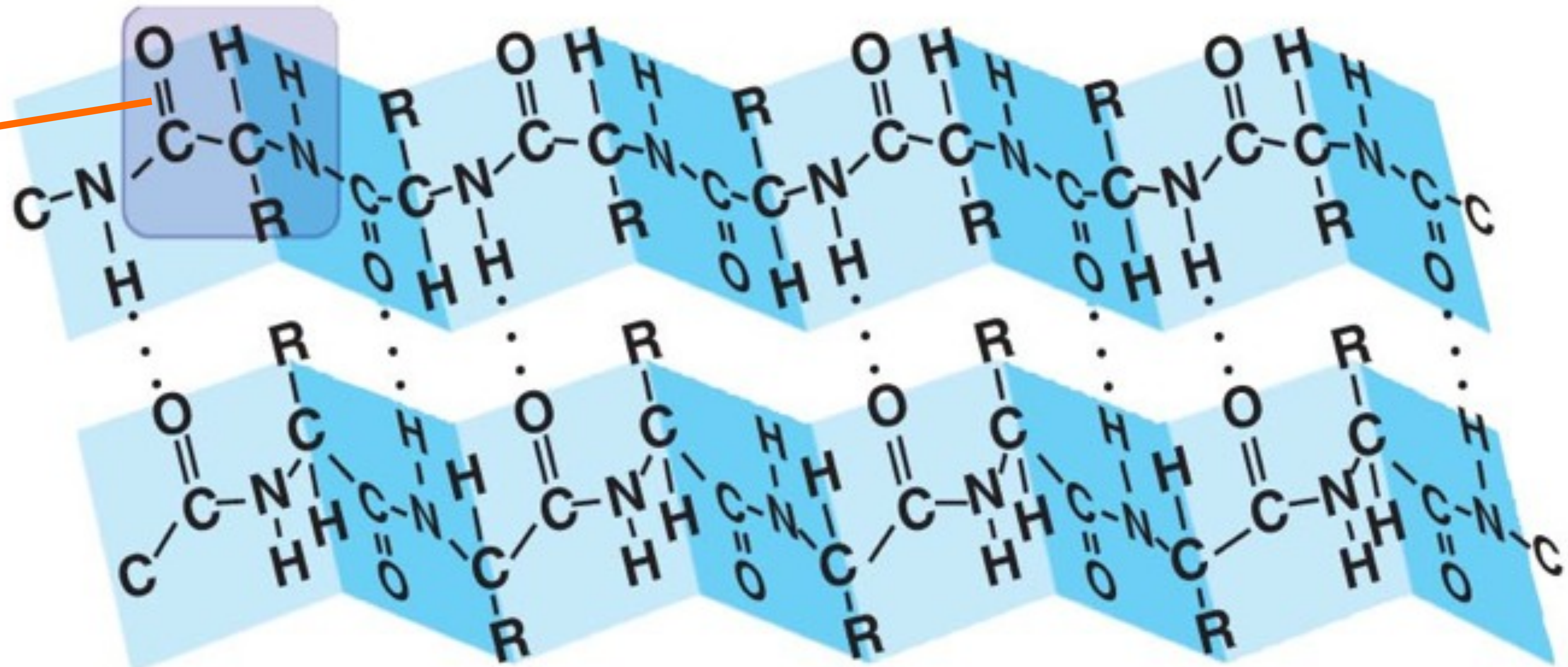




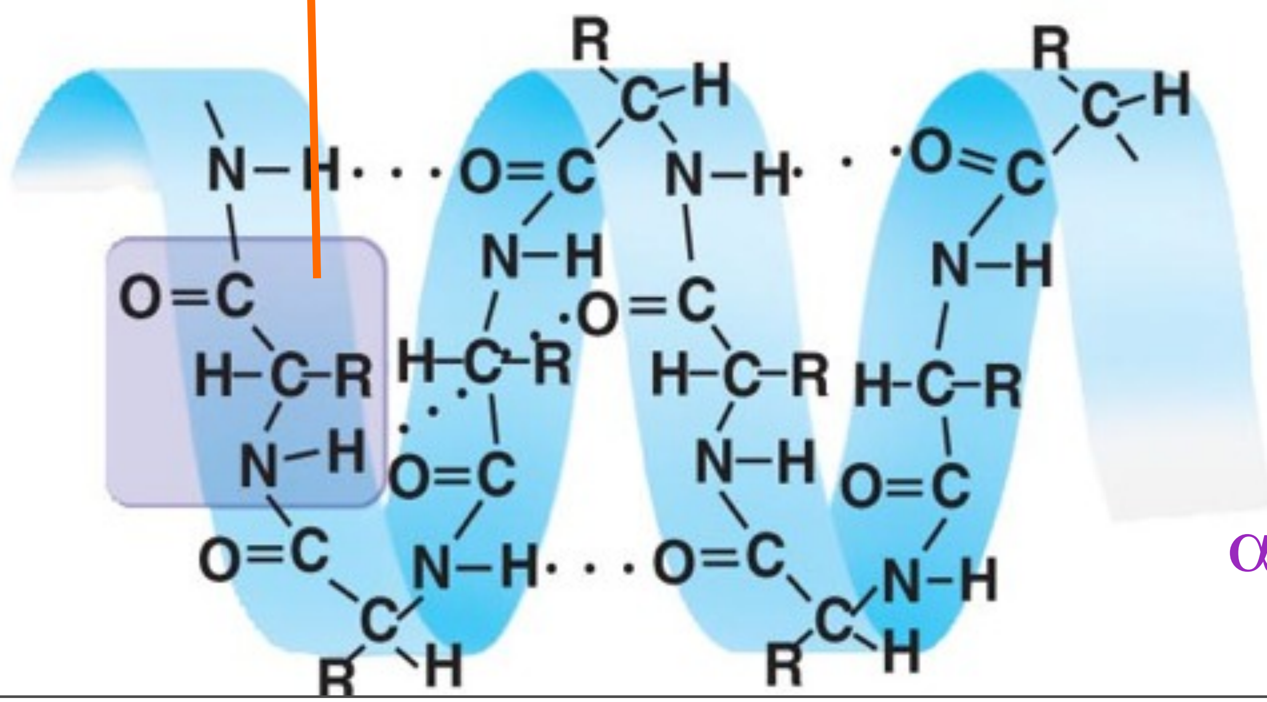
Secondary Structure

Regions stabilized by hydrogen bonds between polypeptide chains

Examples of amino acid subunits



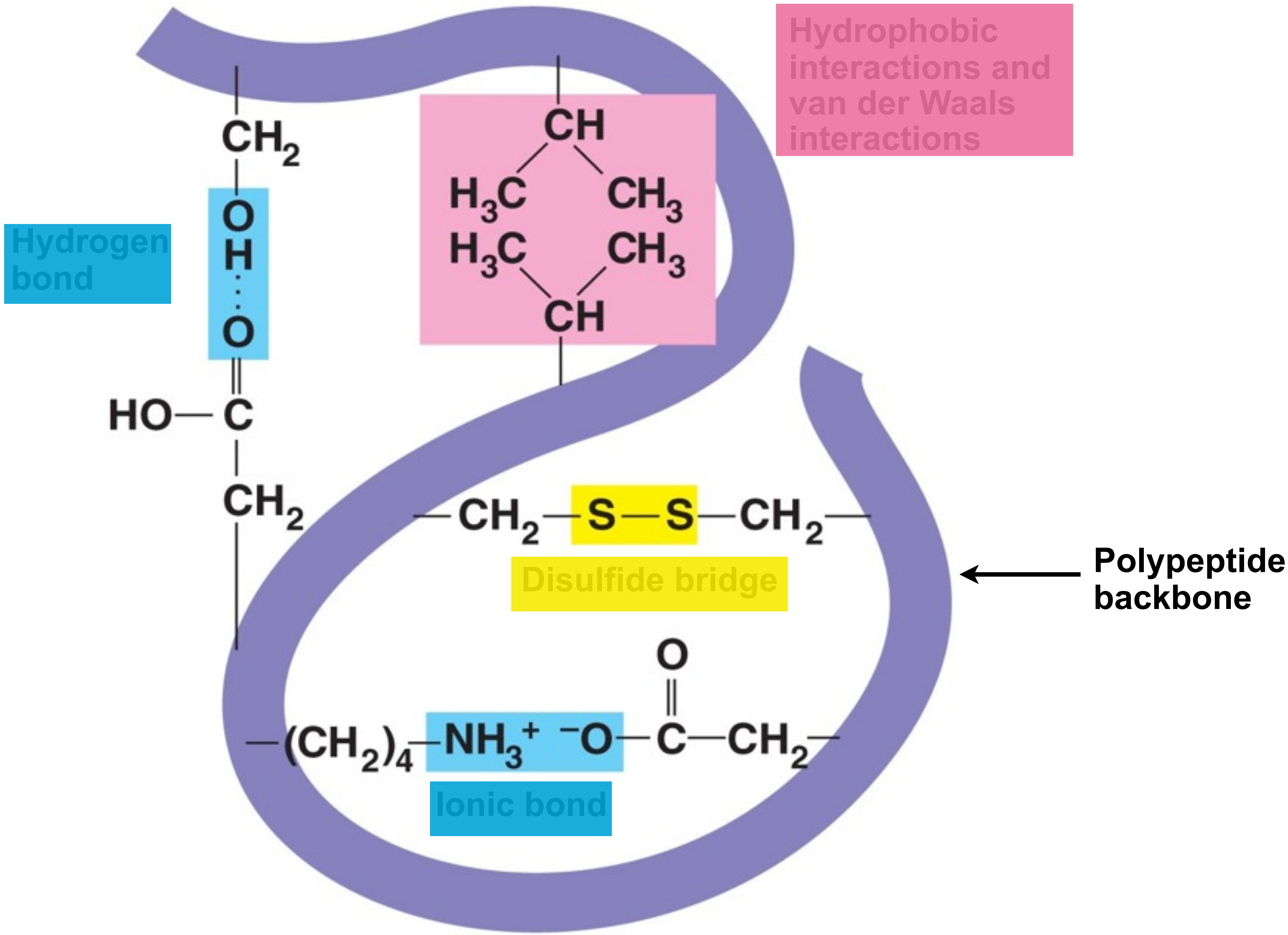
β pleated sheet



α helix

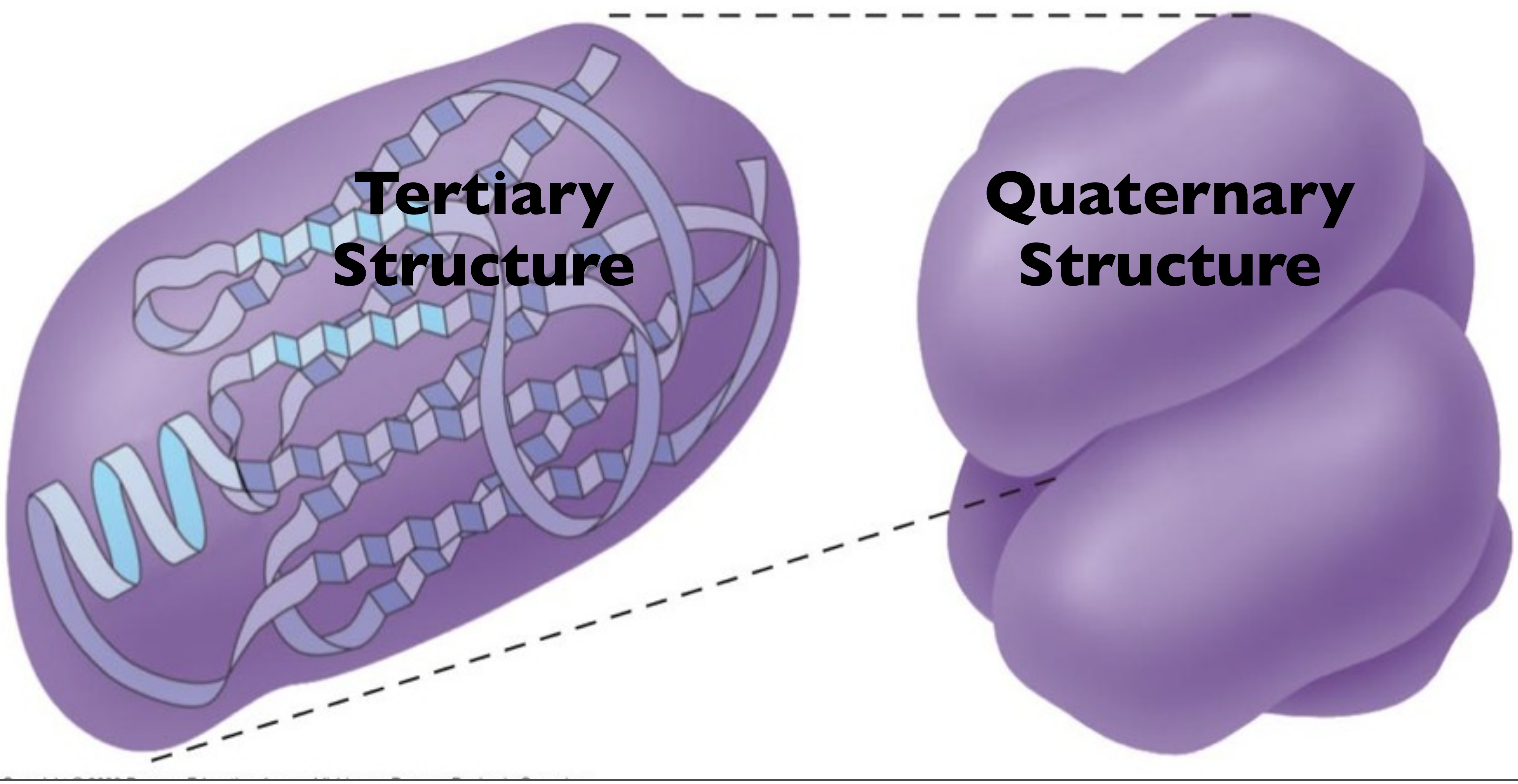
Tertiary Structure

Overall 3-D Shape



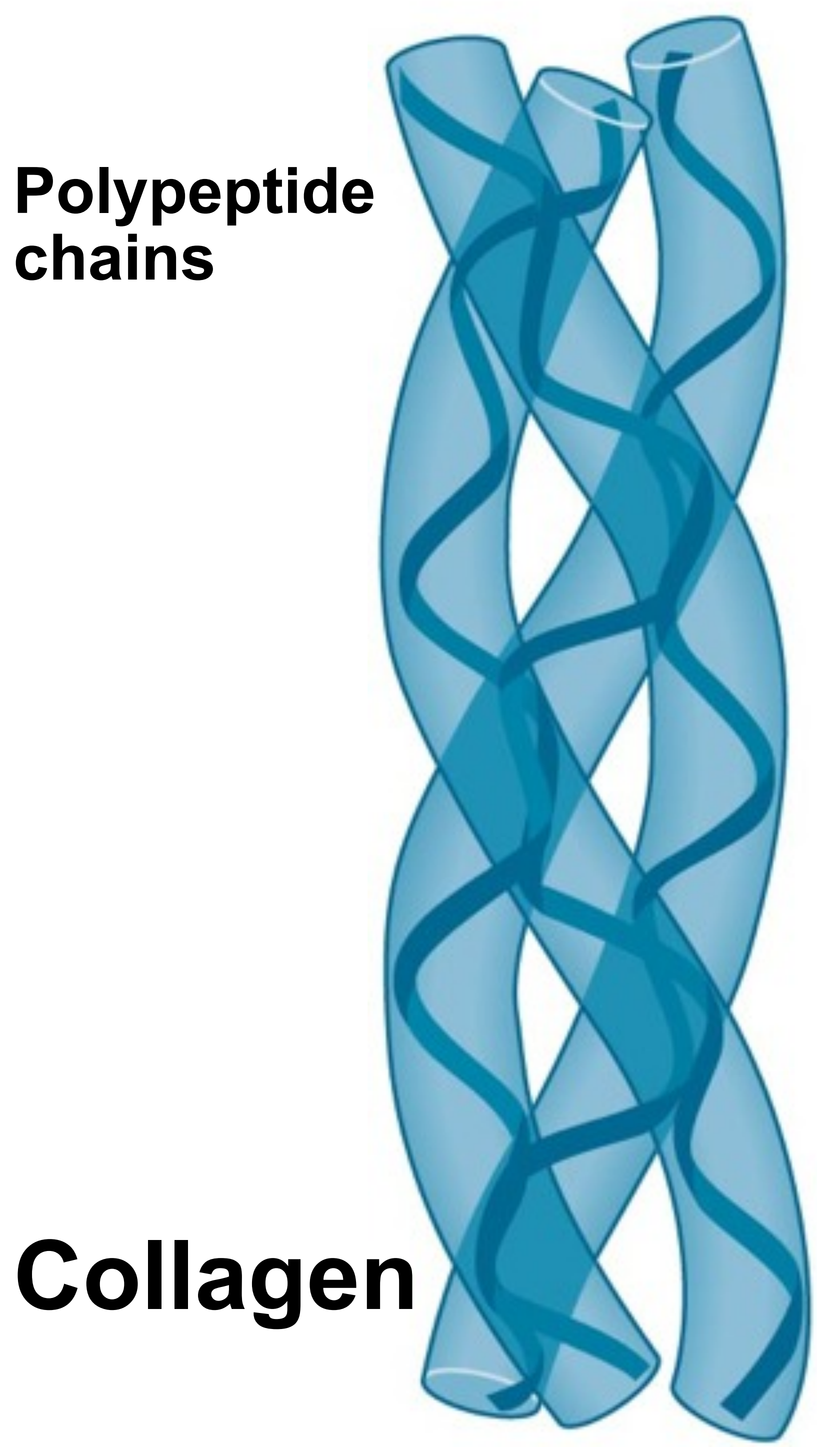
Tertiary Structure

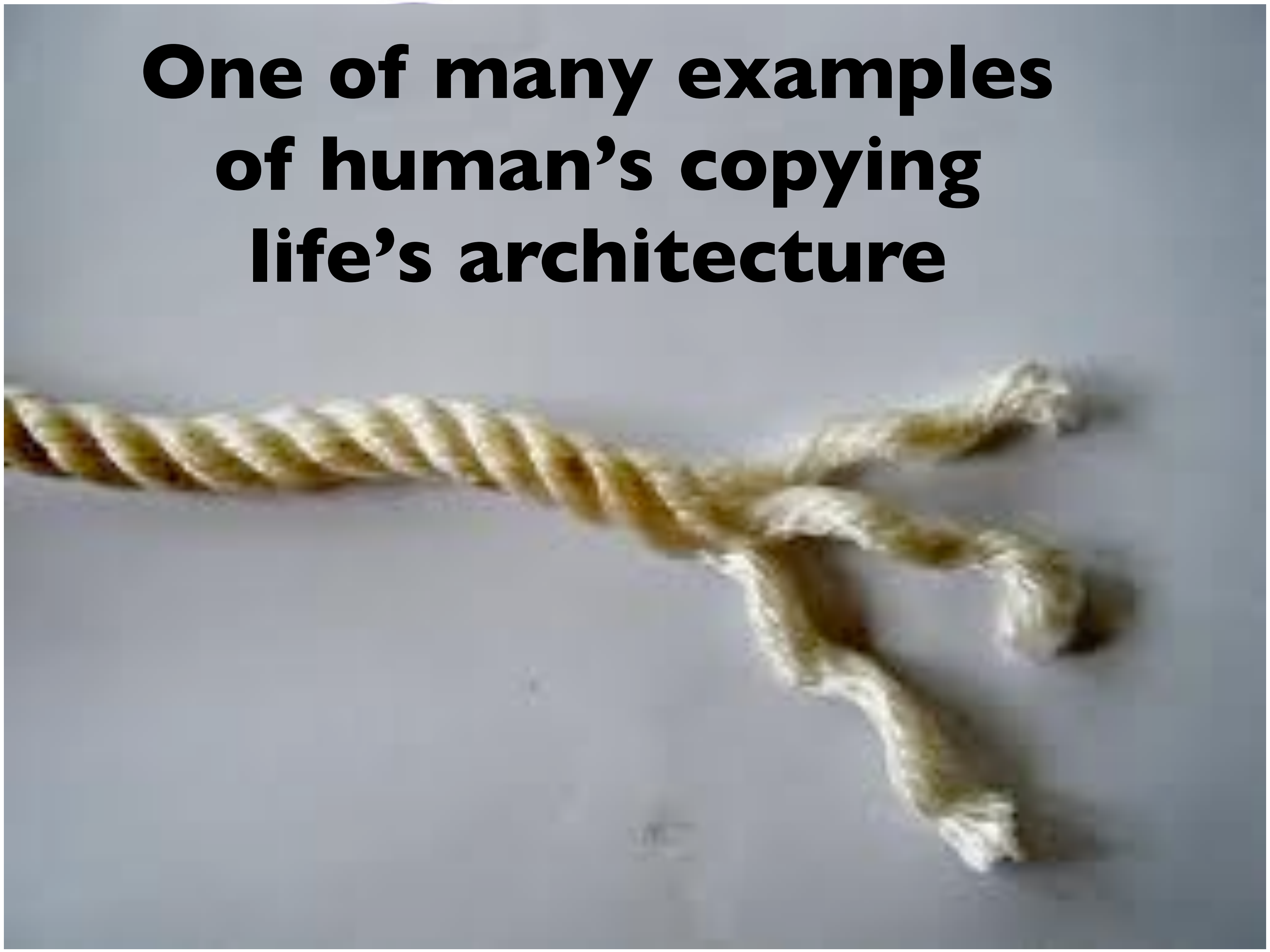
Some tertiary proteins come together and form larger proteins



Quaternary Structure

Association of multiple polypeptides forming a functional protein





Another Look at Protein Folding

Protein Denaturation