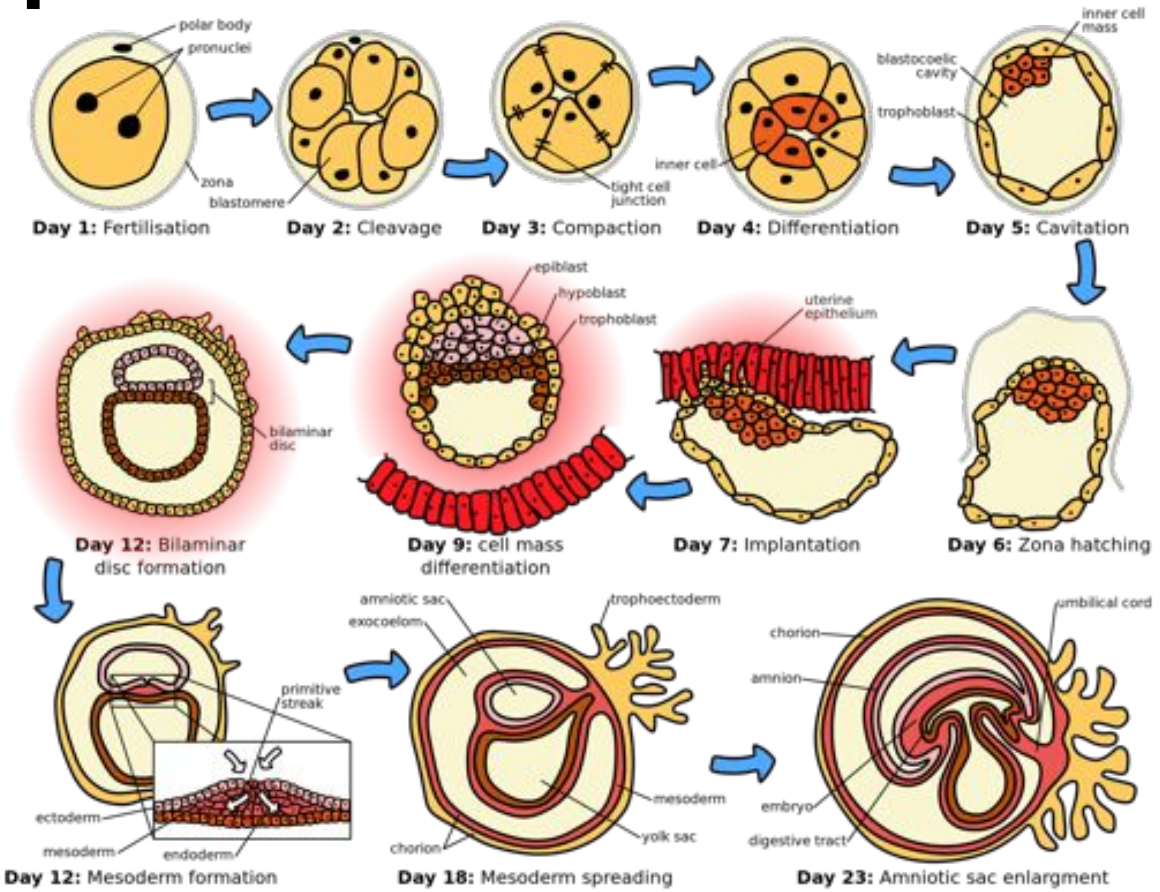
Domain 5: Regulation

5.1: Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms.

1. DEVELOPMENT

Development is Regulated

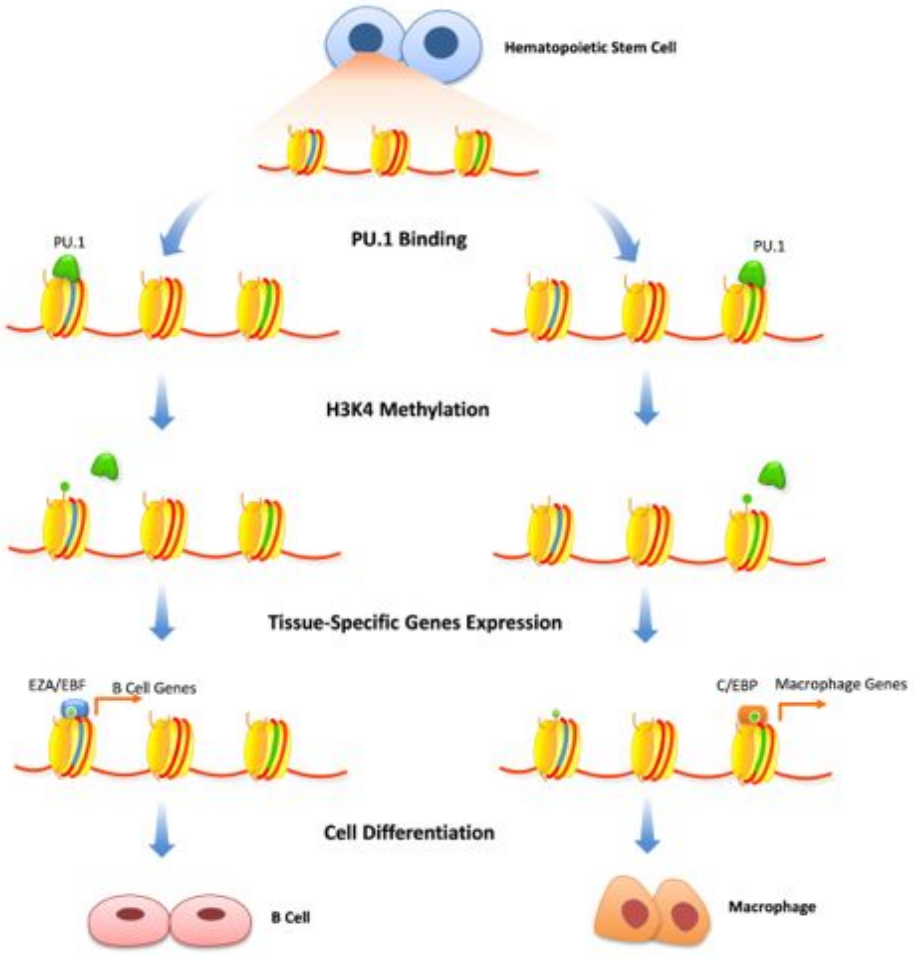
The development of an organism is coordinated by sequential changes in **gene expression**.



Differentiation

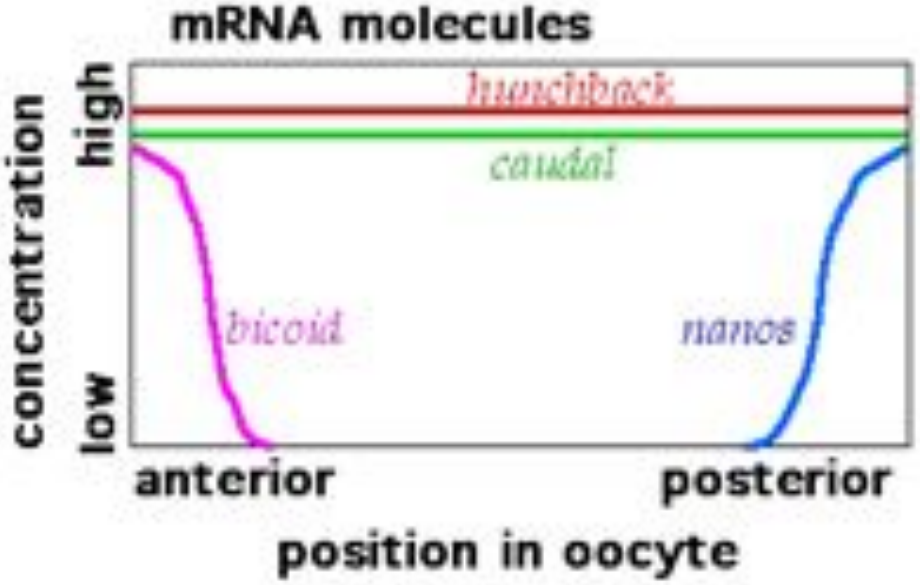
During development, cells differentiate into many different cell types.

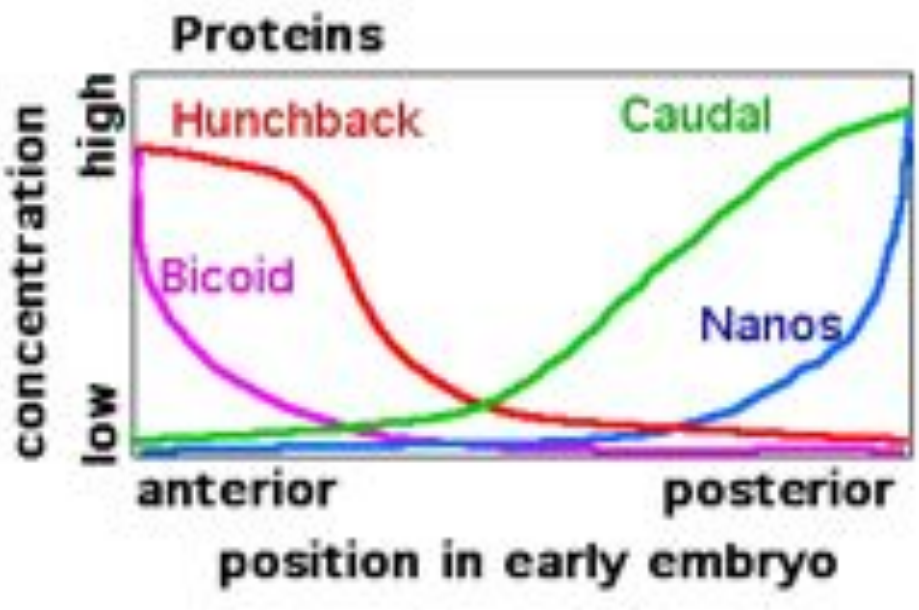
This is accomplished by the expression of cell type-specific proteins.



Pattern Formation

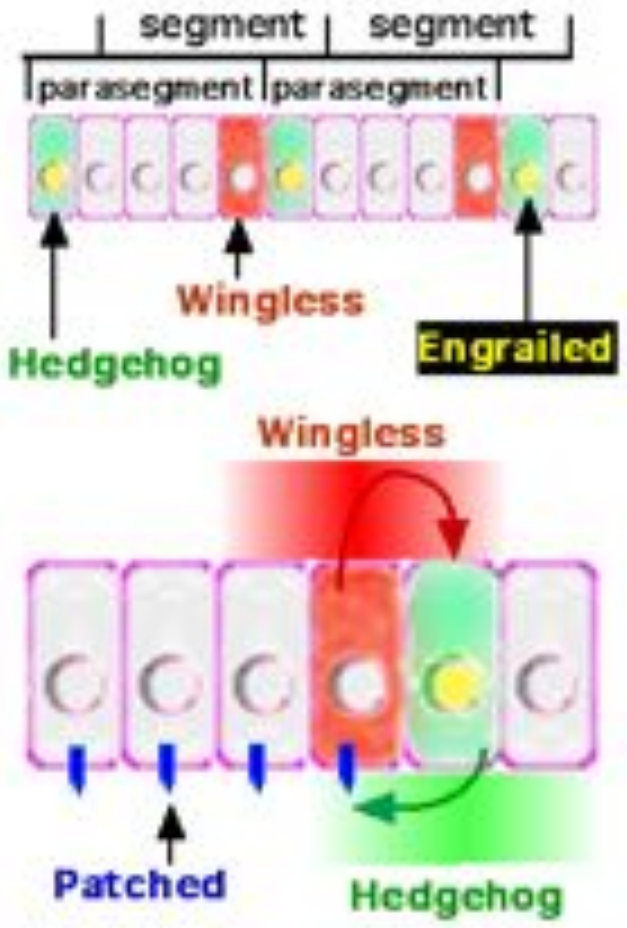
Cells need to establish their position in the developing organism. This is established through protein gradients.





Induction

Local signals communicated among populations of cells to control their development



Environmental Cues

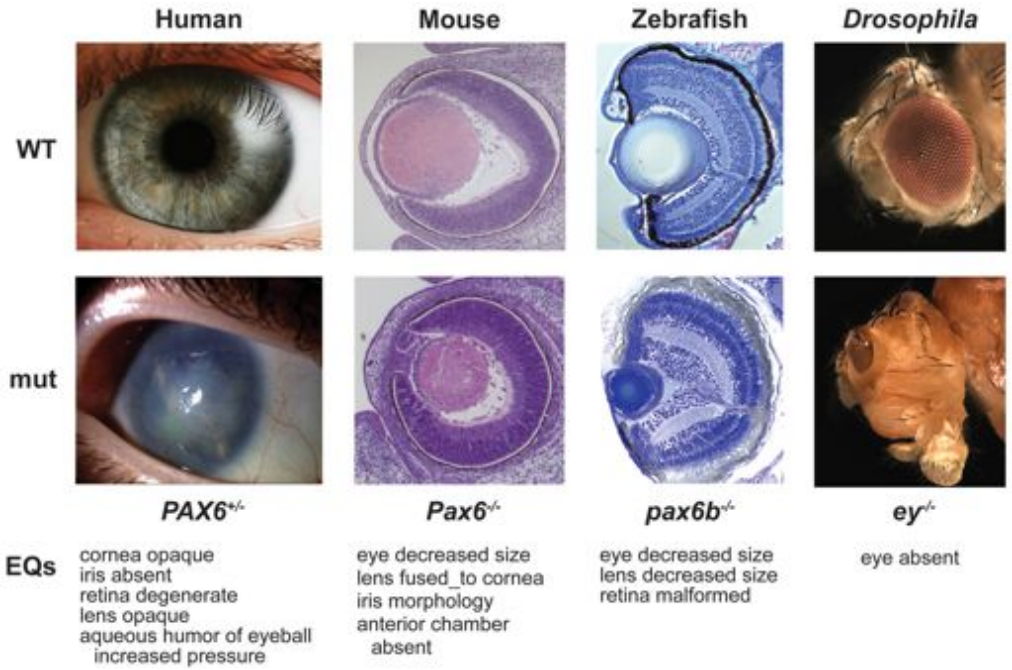
The presence of particular molecules and conditions in the local environment is required for development to proceed properly.

Ex. The conditions of the uterus.

Ex. The role of temperature and moisture in seed development.

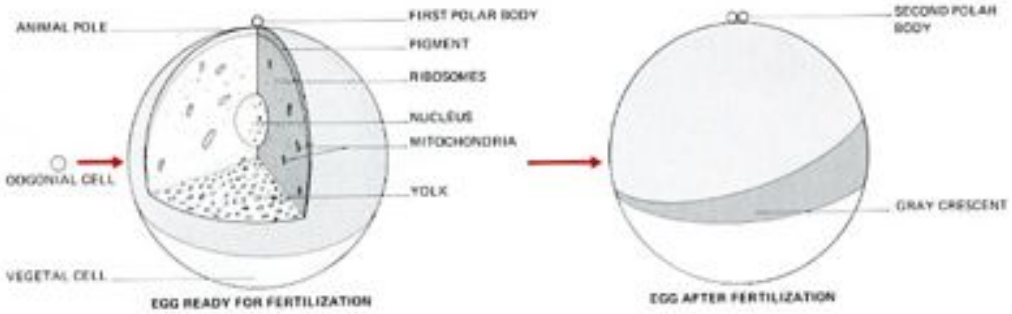
Experimental Evidence

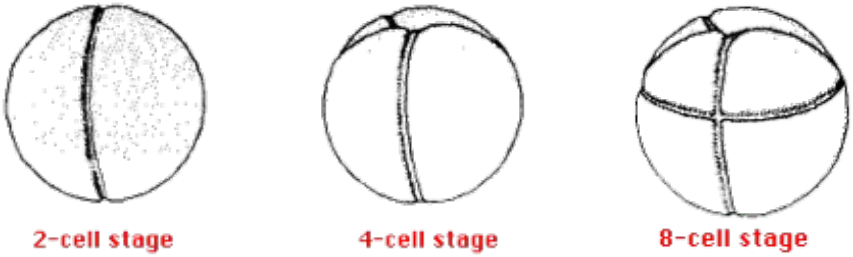
Developmental Mutants: Mutations in normal developmental pathways lead to malformations in embryonic development

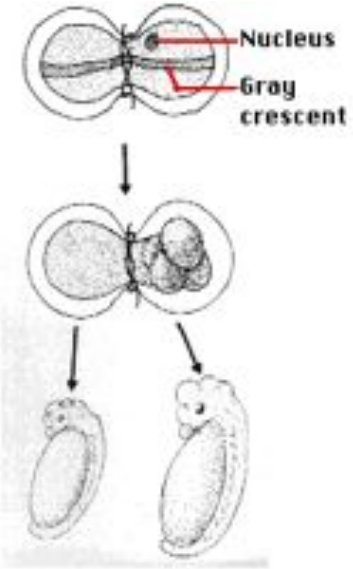


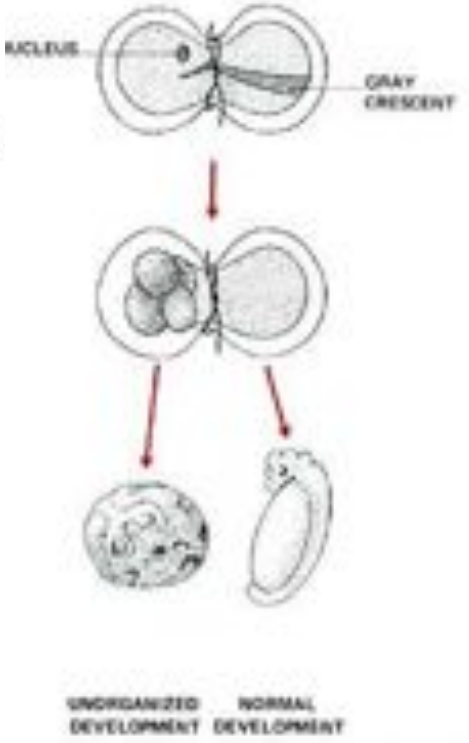
Experimental Evidence

Transplantation Experiments: Moving regions of a developing embryo affects normal pattern formation.





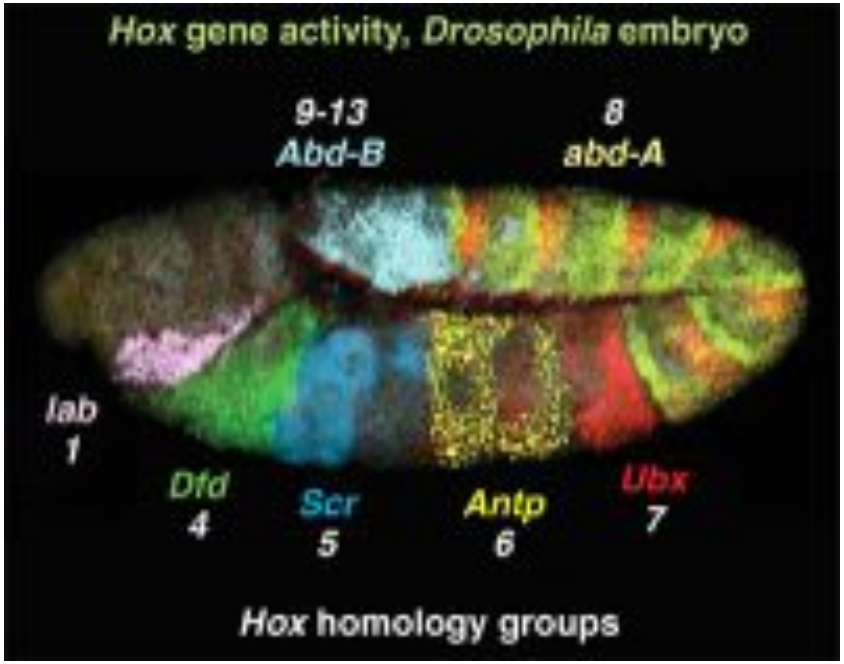




Experimental Evidence

Transplantation Experiments: Moving regions of a developing embryo affects normal pattern formation.

Insertion of reporter genes helps determine what genes are active where and when.



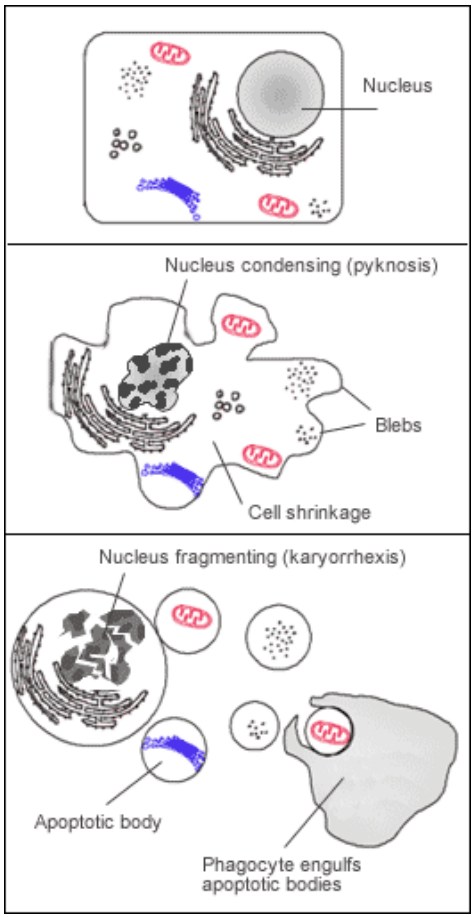
Turning On AND Turning Off

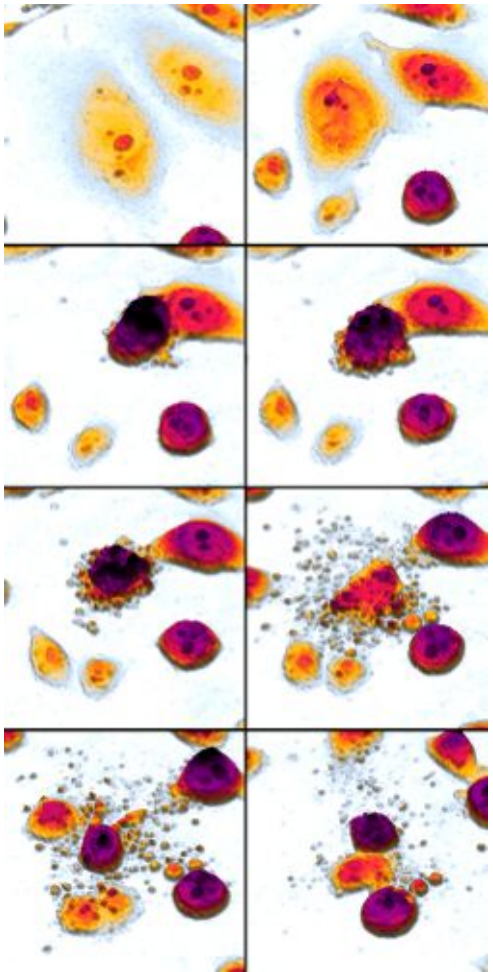
Genes must be both turned on and turned off at appropriate times and locations in the developing organism.

Transcription factors, and **micro RNA's** both function in regulating gene expression.

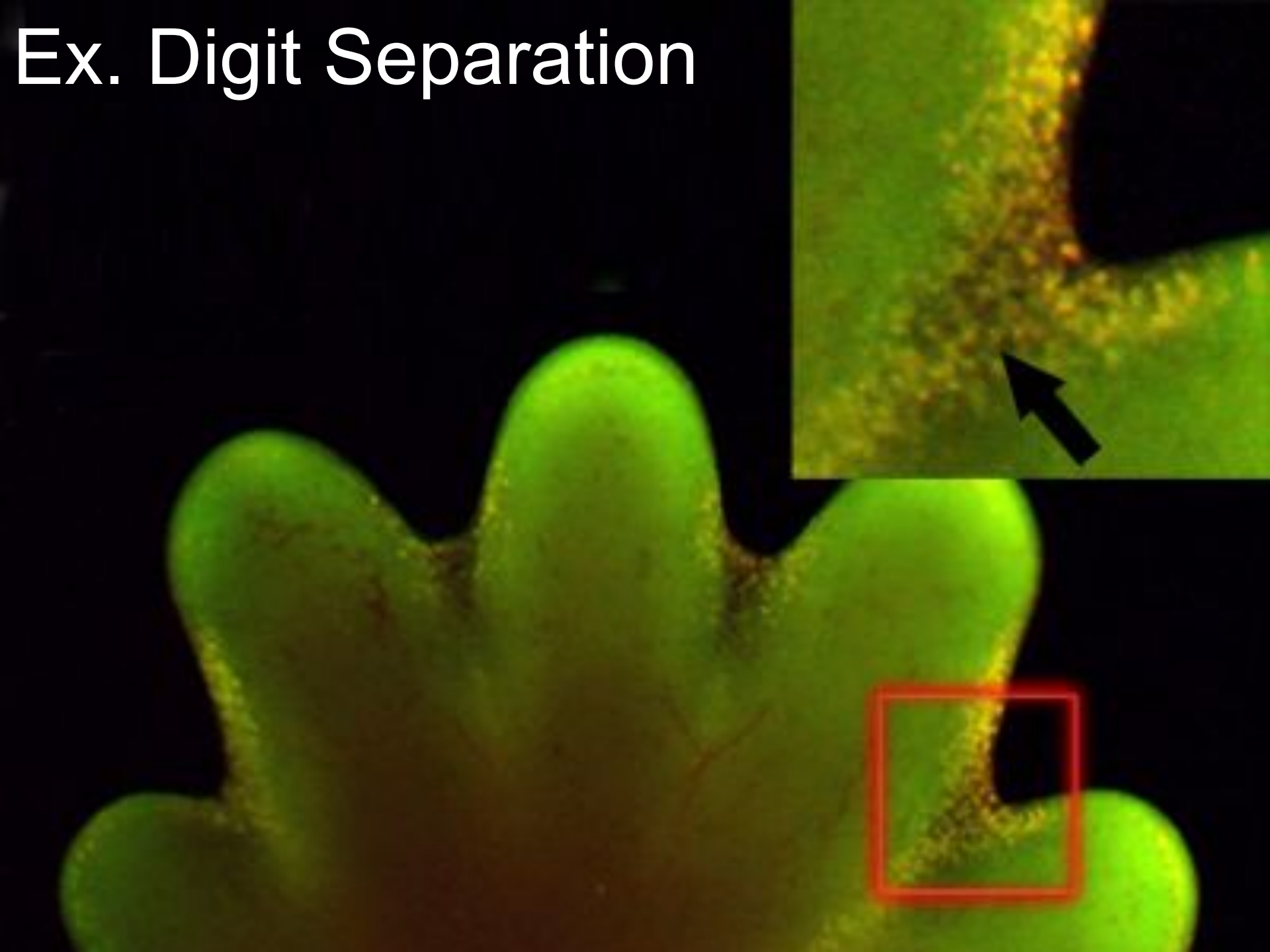
Apoptosis

"**Programmed cell death**": Important role in defining borders and openings in the developing organism.





Ex. Digit Separation



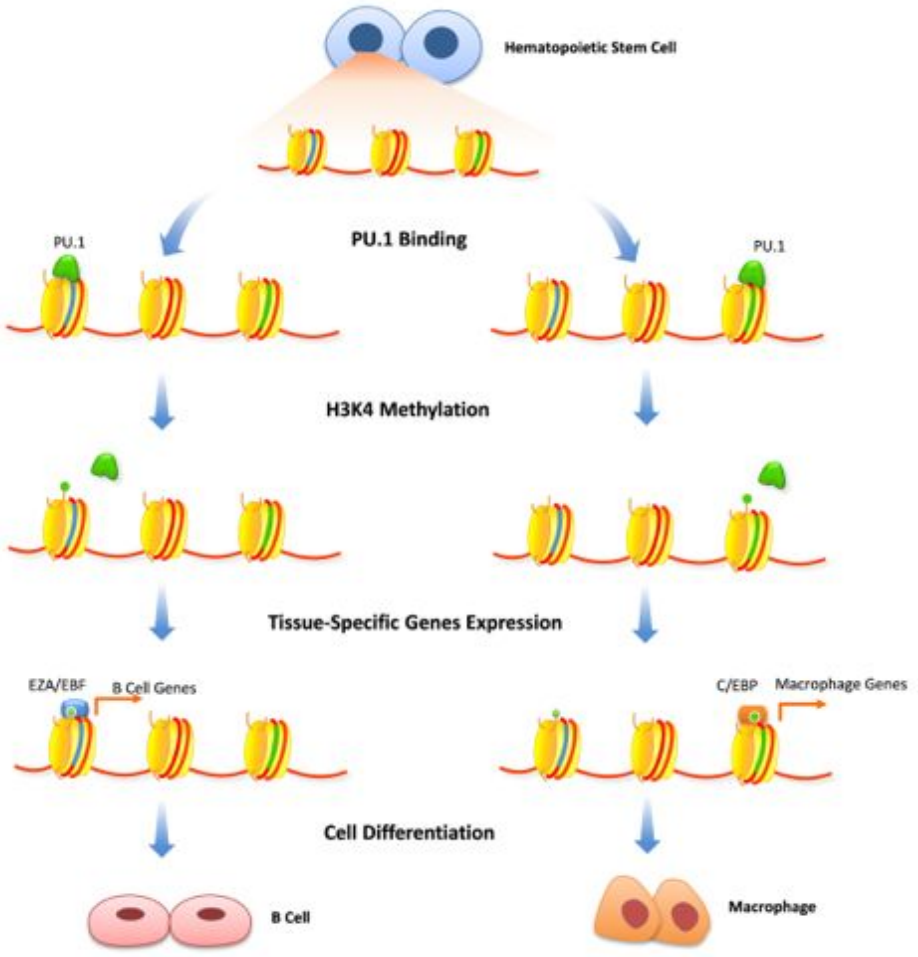
5.2: Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs.

1. DIFFERENTIATION

Differentiation

Refers to the development of cells with identical genomes into different cell types.

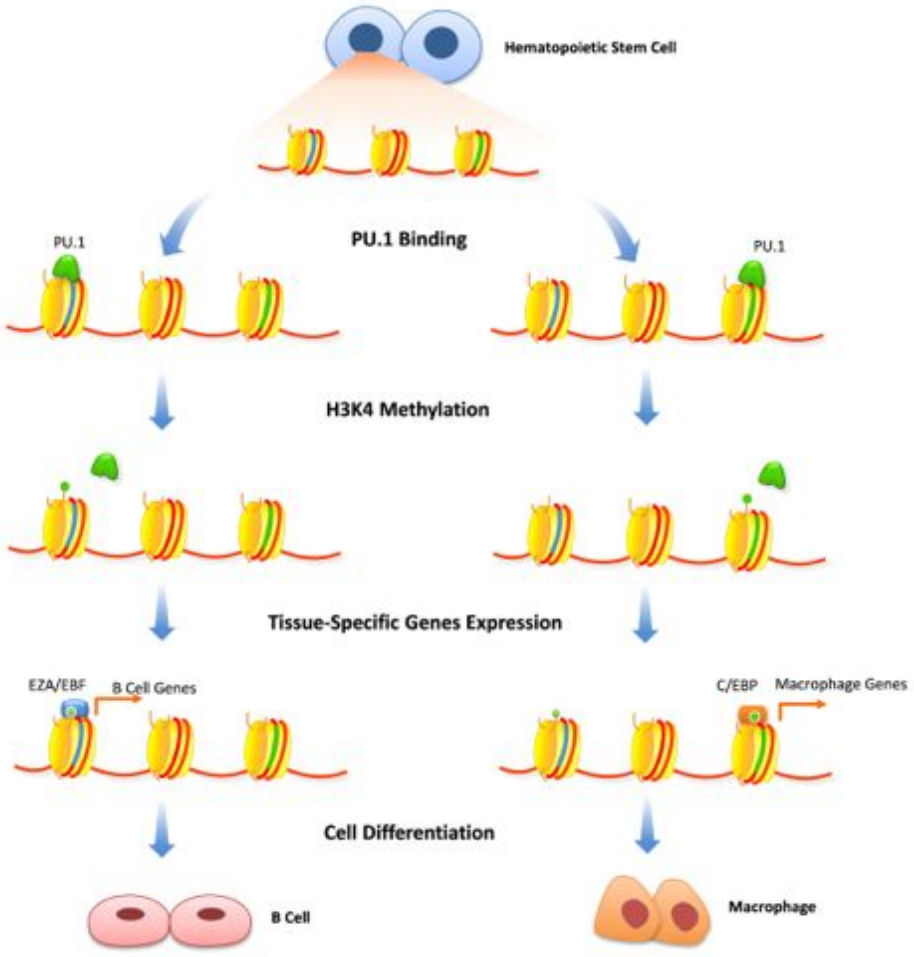
Accomplished by the expression of cell type-specific proteins.



Control of Differentiation

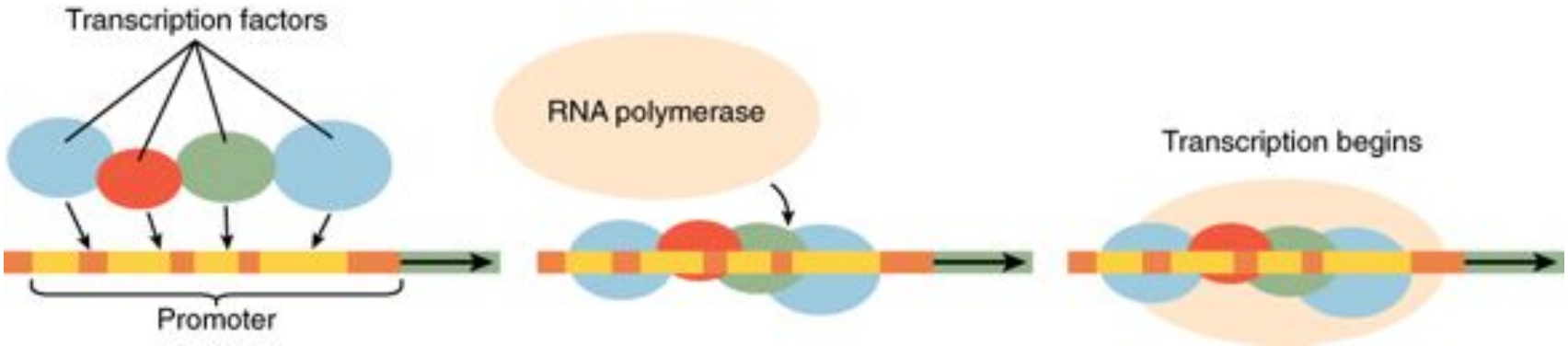
Differentiation is regulated by internal and external cues.

These cues “switch” specific genes “on” and “off” at specific times.



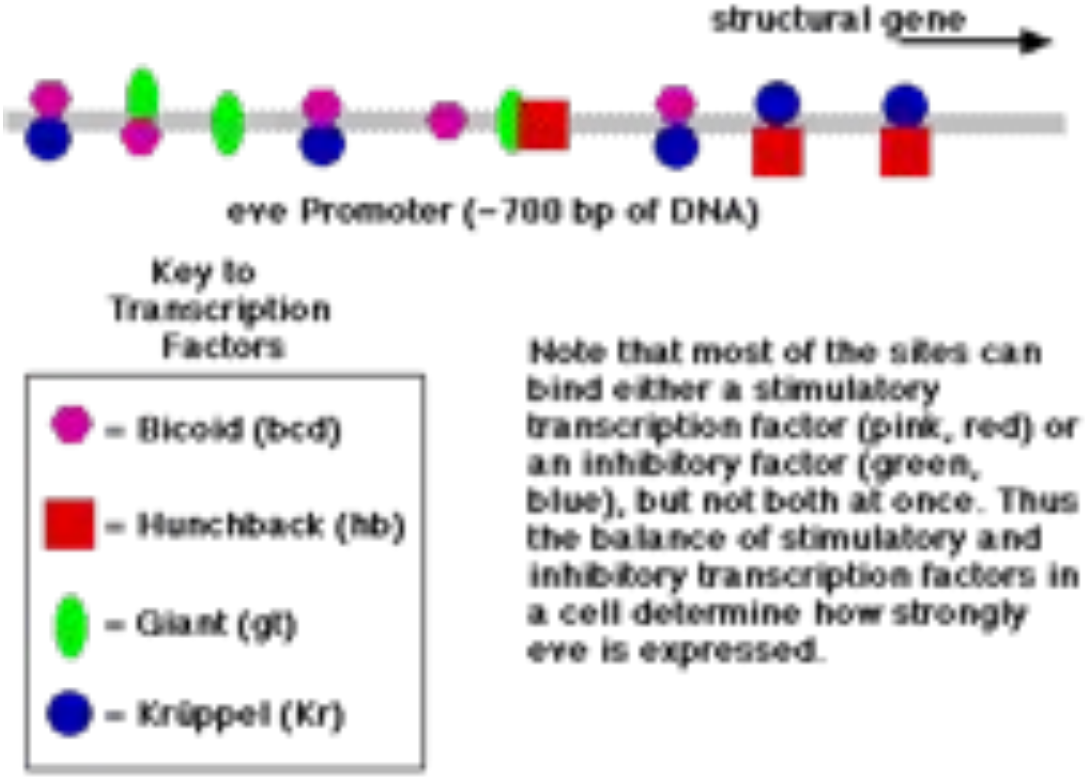
Internal Cues

Various transcription factors must be present inside a cell to allow for specific genes to be expressed.



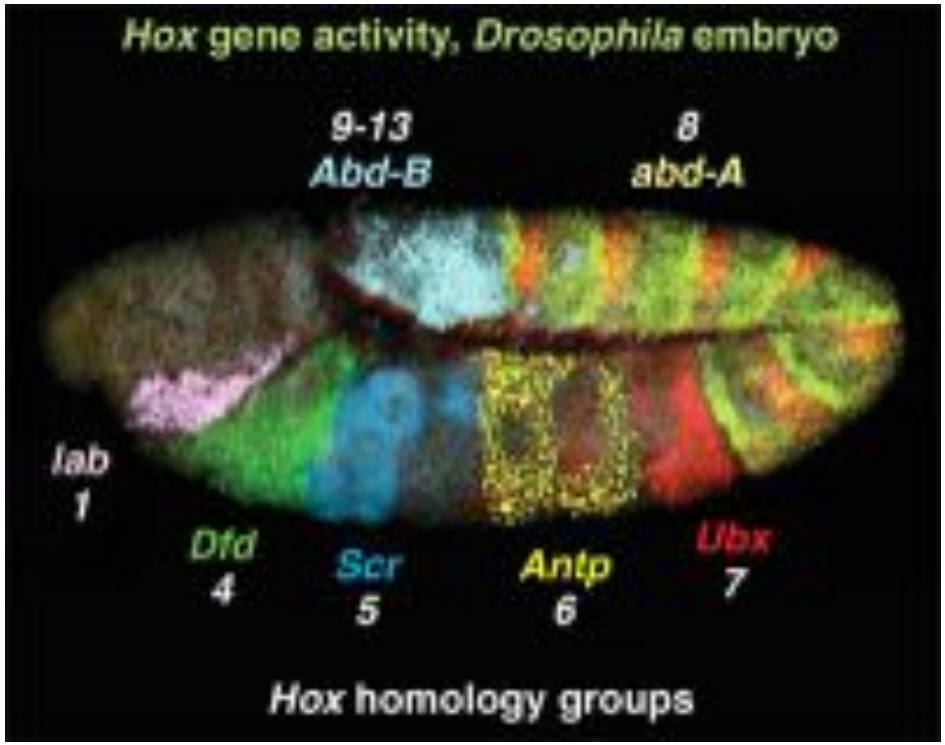
On and Off

Transcription factors can be either stimulatory or inhibitory.

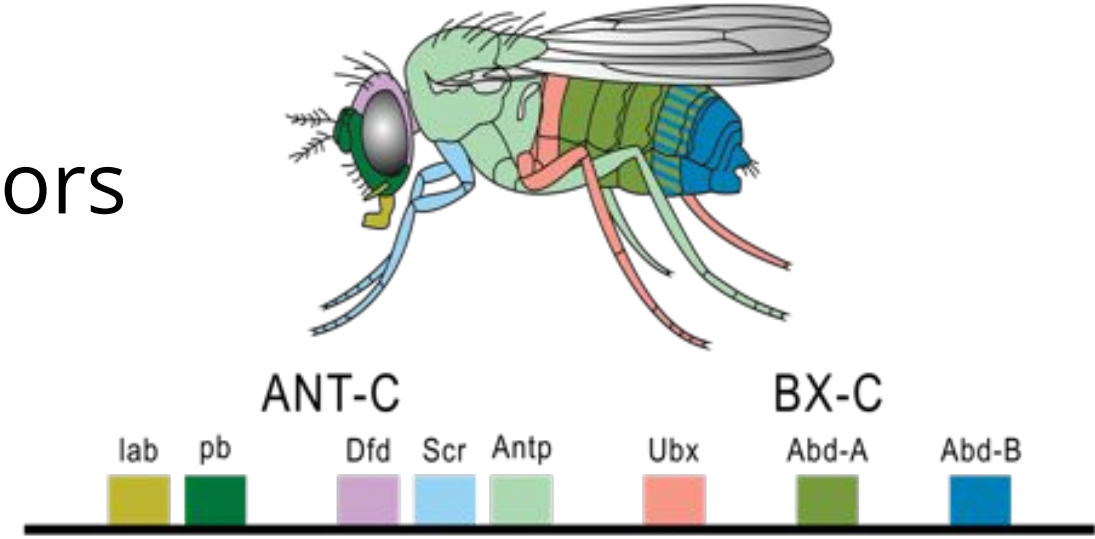


Ex. Hox Genes

A family of related genes that serve as master regulators of animal development in all animals on the planet.

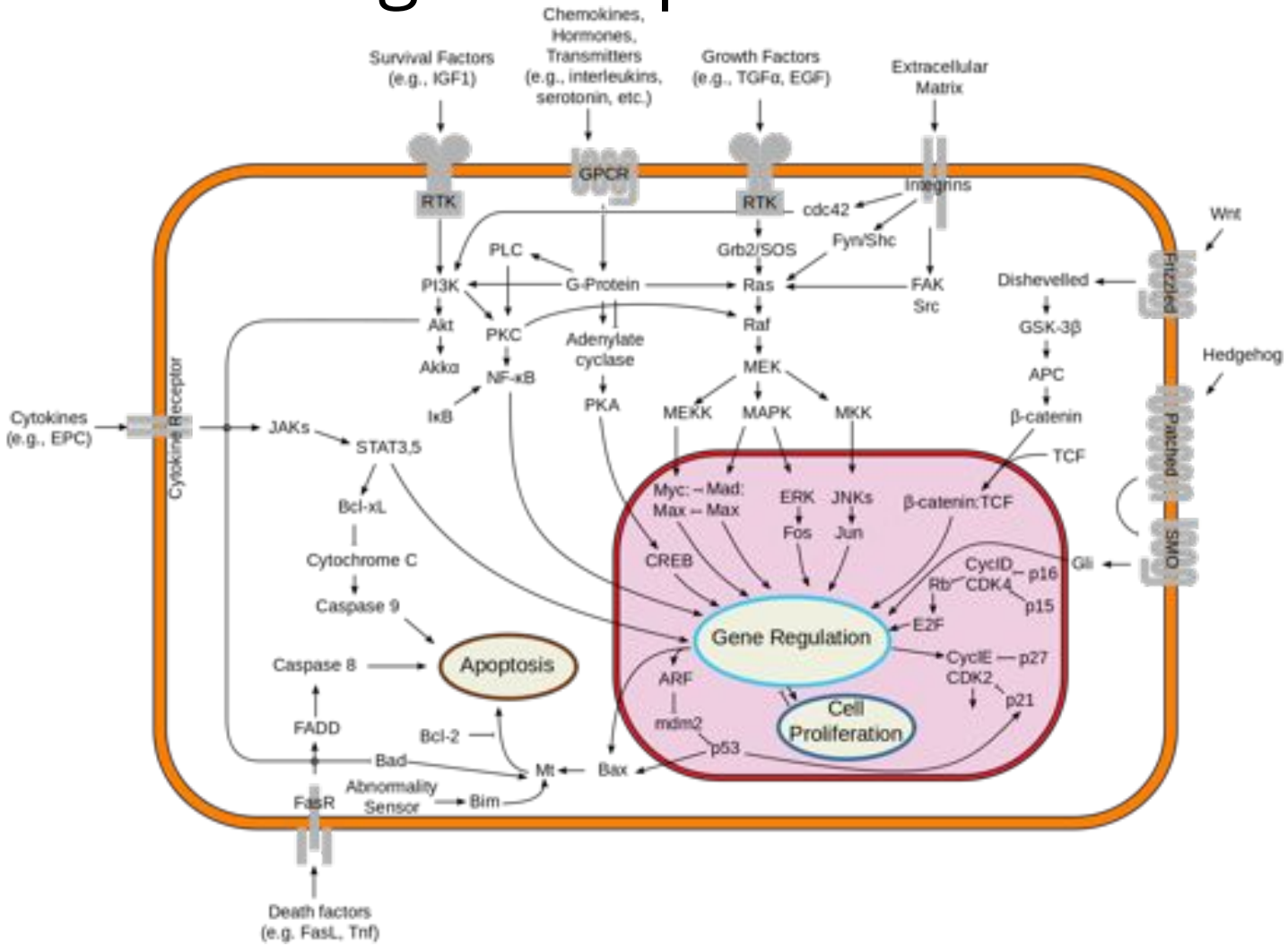


"transcription factors for transcription factors."



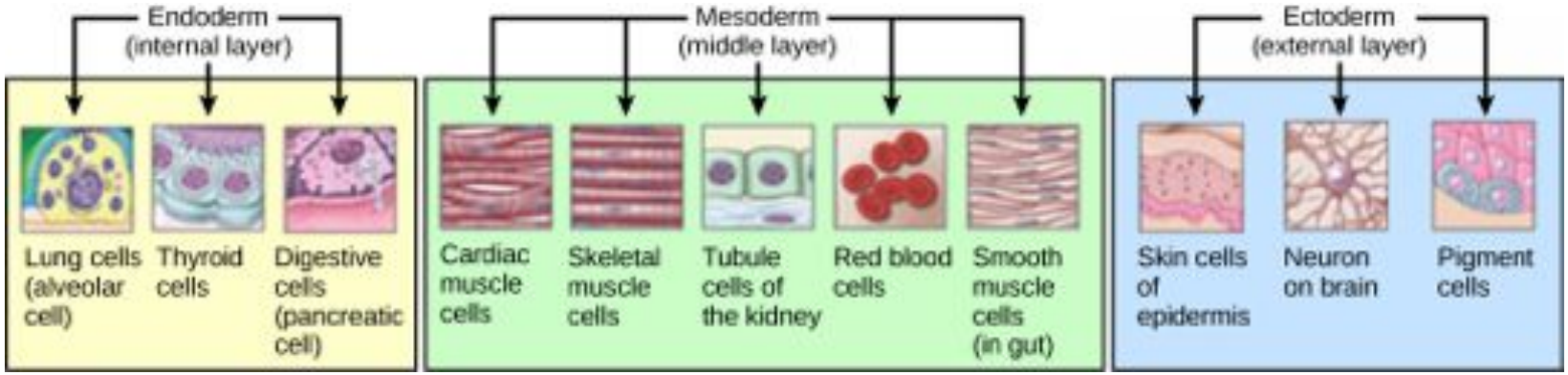
External Cues

External cues signal to cells, causing cells to alter their gene expression.



Differentiation leads to Divergence

As cells differentiate, the proteins that they express commit them to particular "**fates**". These fates are normally irreversible.



Don’t Forget The Environment

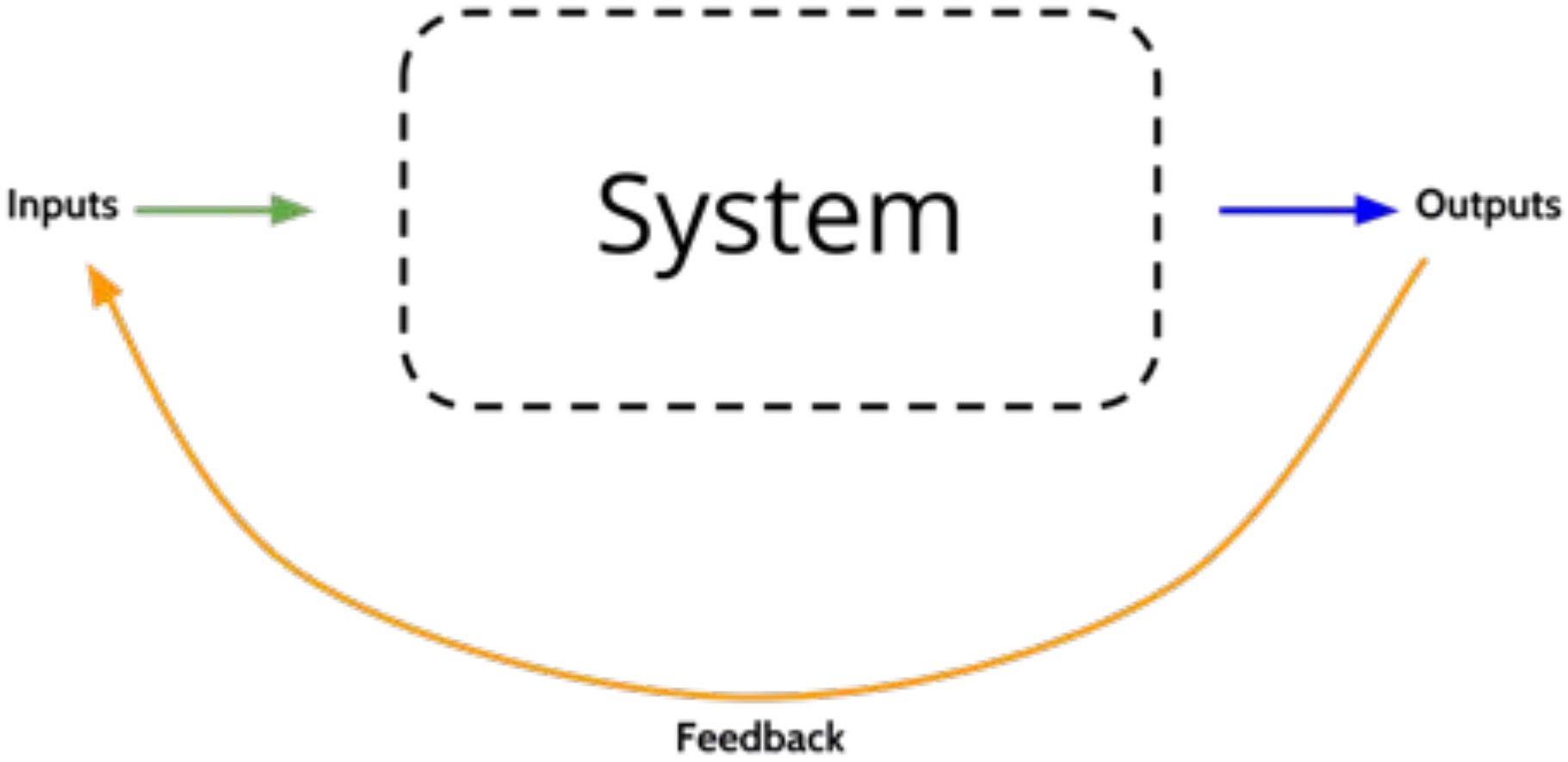
The environment of the cell also plays a major role in determining cell differentiation by contributing to gene expression.

5.3: Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.

1. FEEDBACK LOOPS

Feedback

Feedback is a property of all open systems.



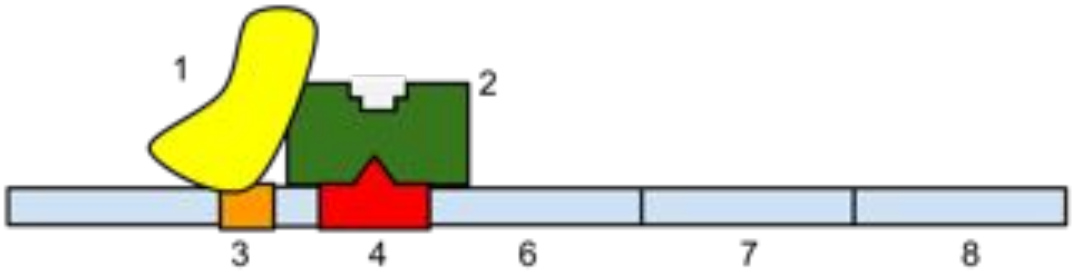
Negative Feedback

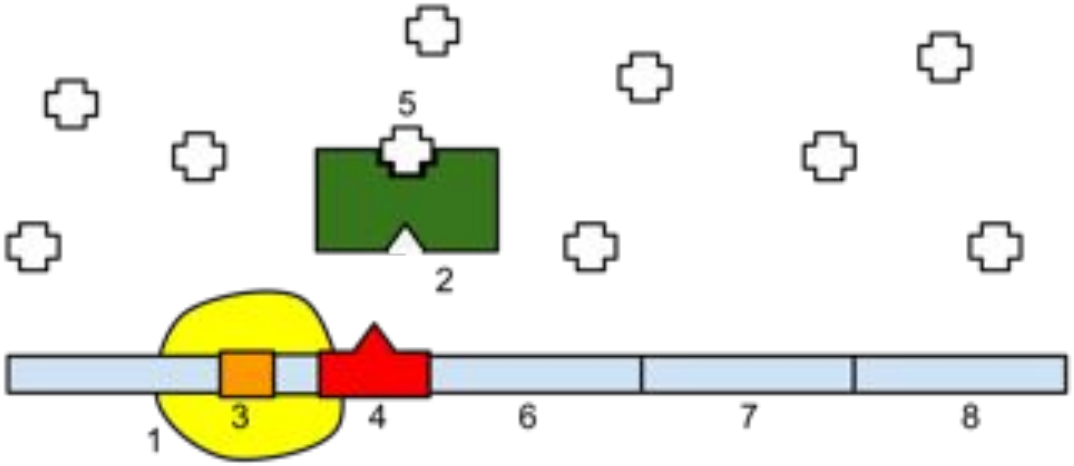
Negative feedback: any situation where the output of a process decreases the occurrence of that process.

Regulatory in nature.

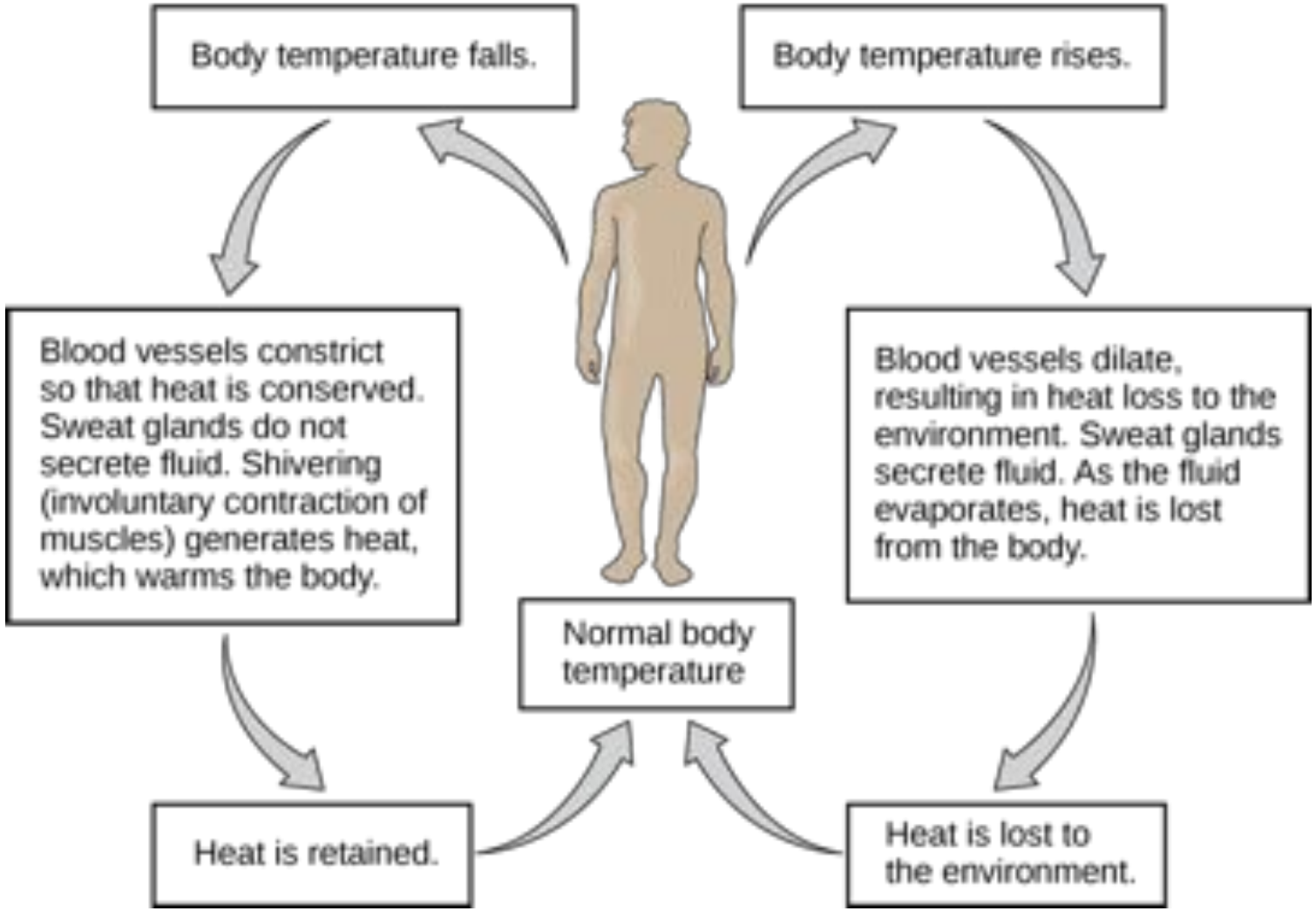
Negative feedback maintains homeostasis of the system.

Ex. Operons

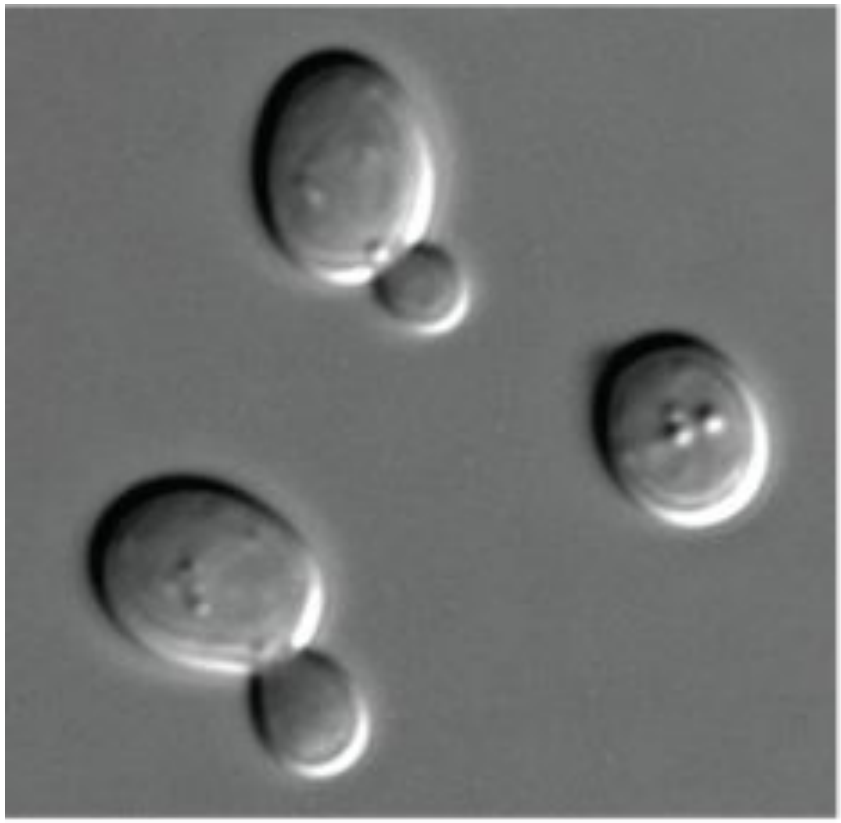


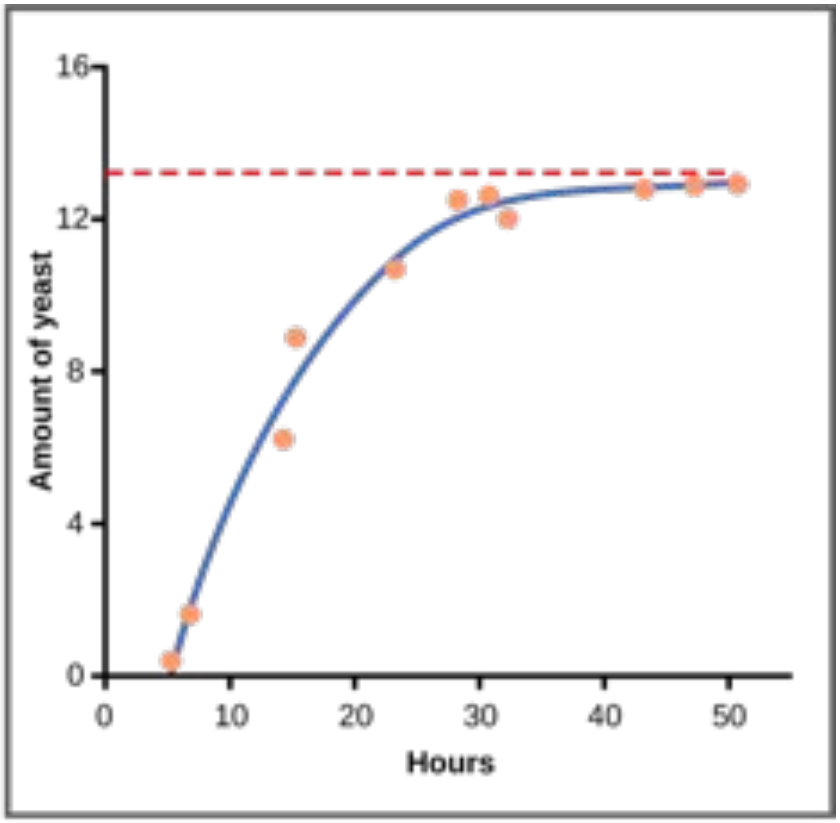


Ex. Temperature Regulation in Mammals



Ex. Population Growth





(a)

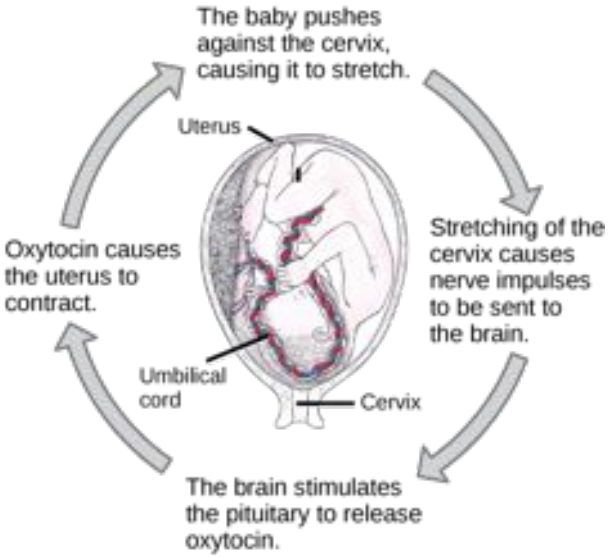
Positive Feedback

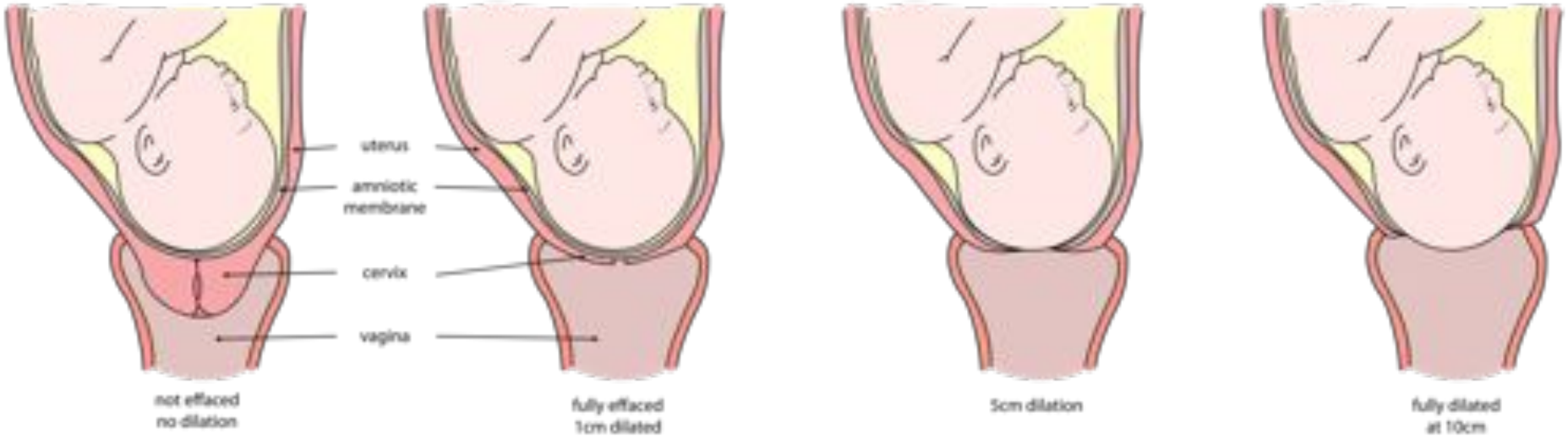
Positive feedback: any situation where the output of a process increases the occurrence of that process.

Amplifying in nature.

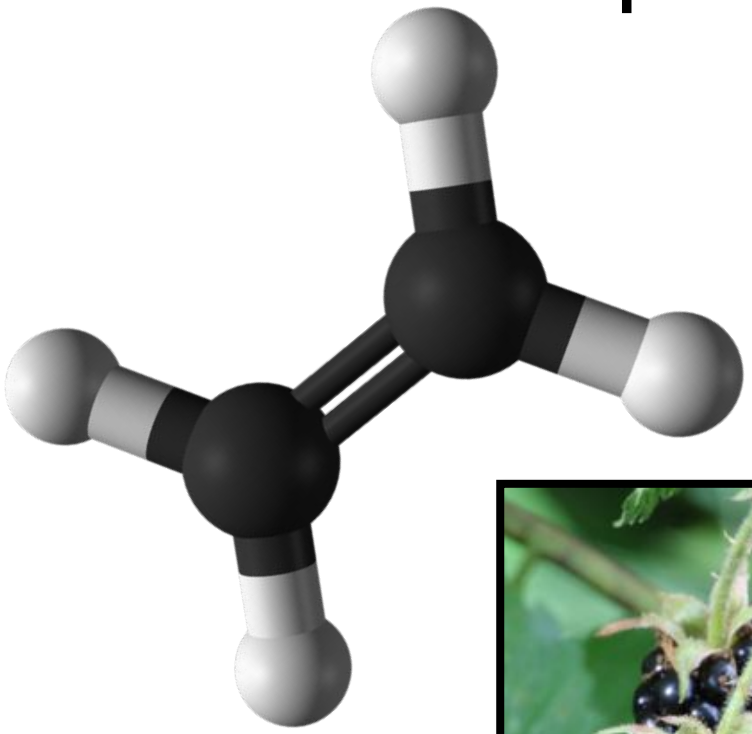
Positive feedback causes transformation in the system.

Ex. Animal Birth





Ex. Fruit Ripening



5.4: Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments.

1. DIVERGENCE

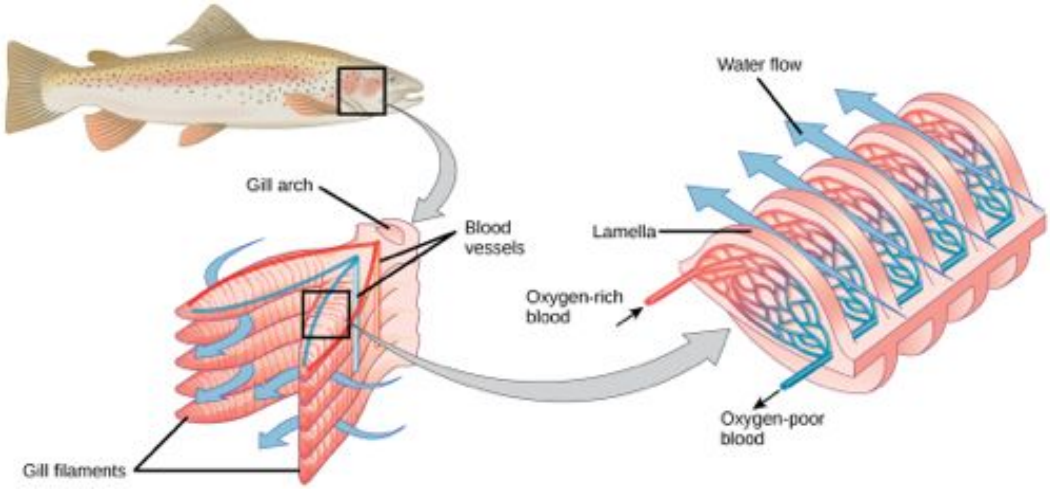
Adaptation Leads to Divergence

The different requirements of the environments that organisms occupy has largely driven divergence in homeostatic mechanisms.

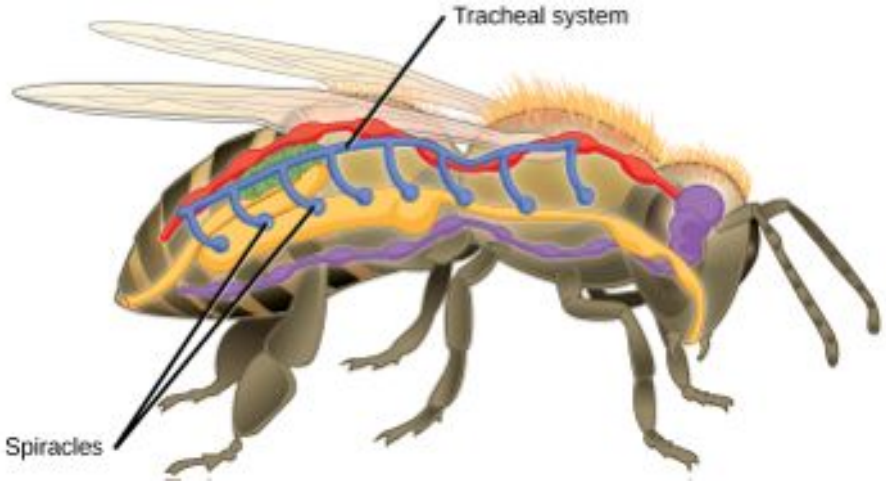
Ex. Animal Respiratory Systems

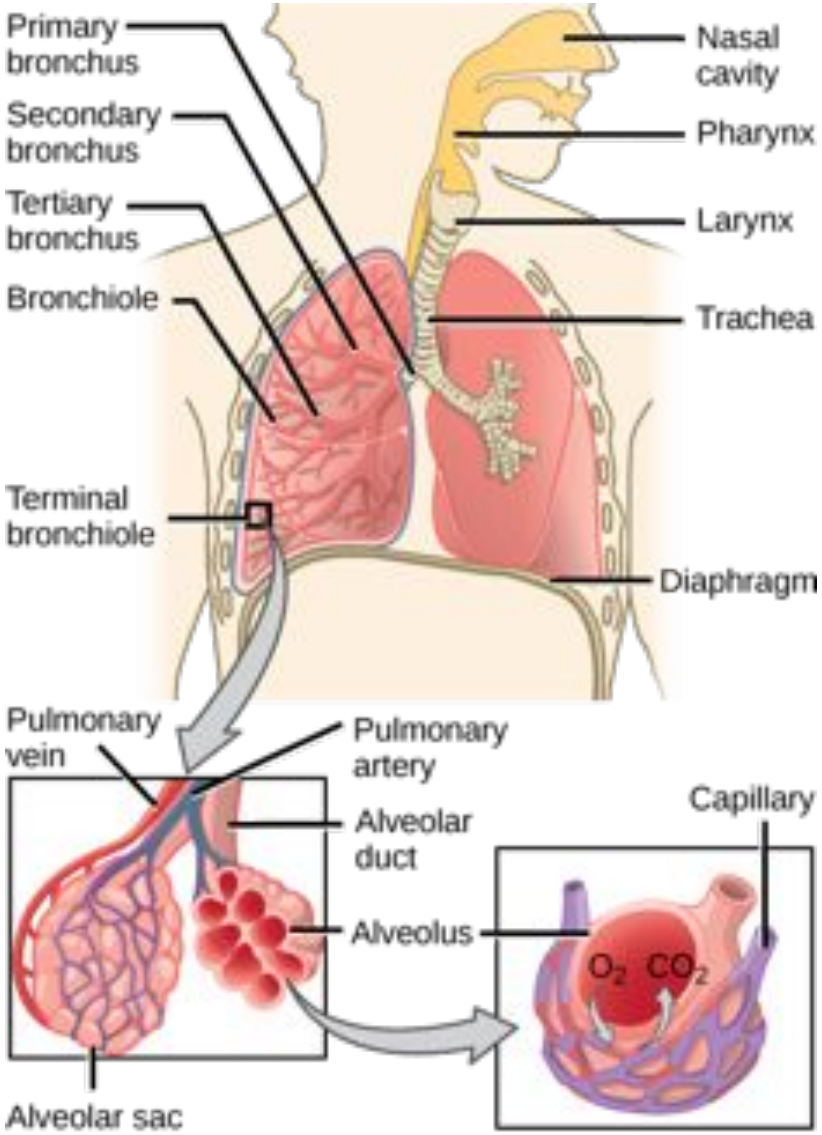
Respiration must occur across a thin, moist, capillary-rich surface membrane.

Aquatic animals have external respiratory membranes (skin, gills).



Terrestrial animals have internalized their respiratory membranes (spiracles, lungs)

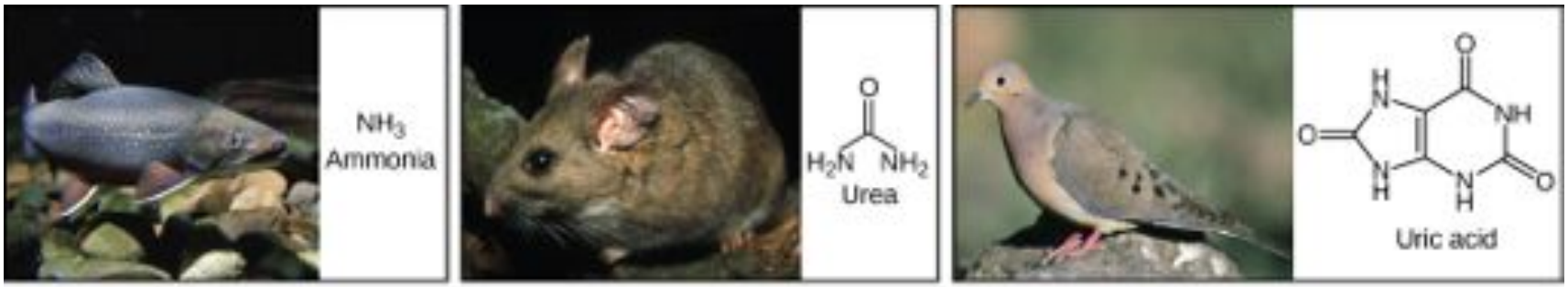




Ex. Animal Nitrogenous Waste

Nitrogenous waste (from protein and nucleic acid breakdown) must be excreted from the body.

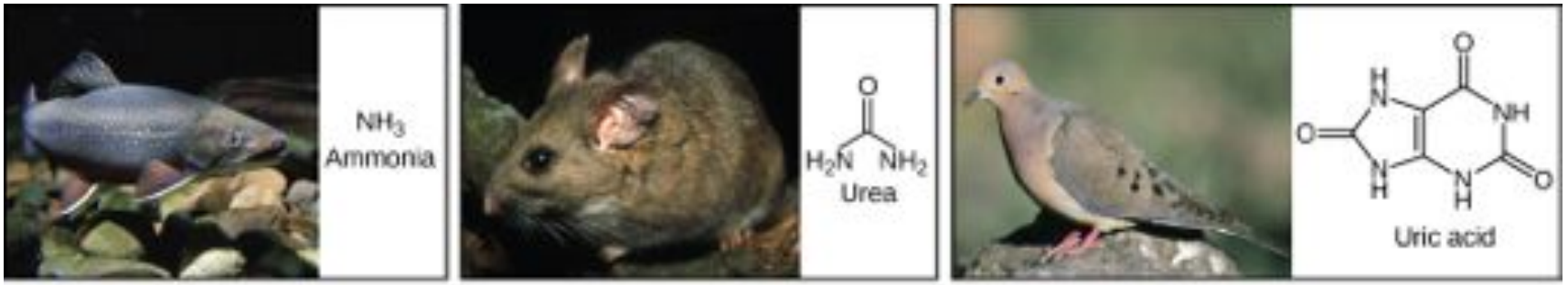
Different animals convert nitrogenous waste to different molecules



(a) Many invertebrates and aquatic species excrete ammonia.

(b) Mammals, many adult amphibians, and some marine species excrete urea.

(c) Insects, land snails, birds, and many reptiles excrete uric acid.



(a) Many invertebrates and aquatic species excrete ammonia.

(b) Mammals, many adult amphibians, and some marine species excrete urea.

(c) Insects, land snails, birds, and many reptiles excrete uric acid.

An organism's nitrogenous waste form reflects how limiting water is in the environment of that organism:

Ammonia is the most toxic, and must be immediately diluted and excreted.

Urea is less toxic, and does not need to be diluted as greatly, or excreted as quickly.

Uric Acid and can be excreted as a solid.

5.4: Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments.

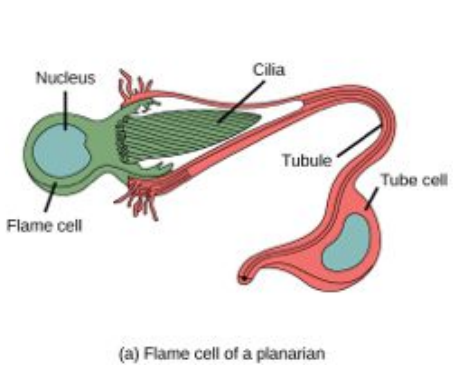
2. COMMONALITIES

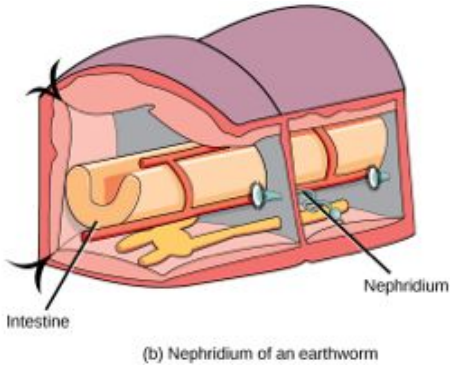
Common Ancestry and Convergence Explains Similarities

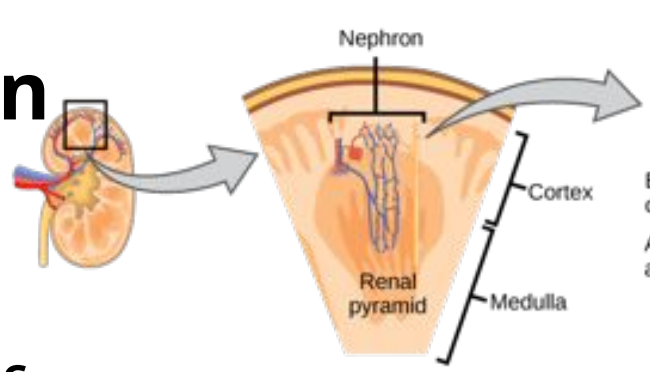
Similarities in homeostatic control mechanism reflect common ancestry and convergent evolution.

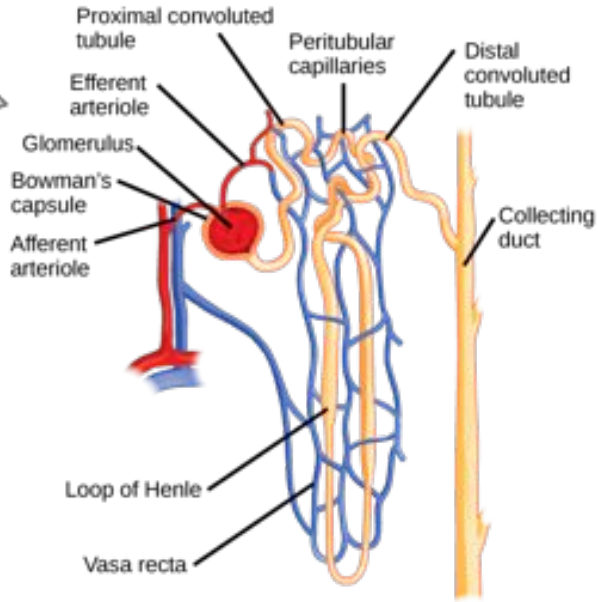
Ex. Animal Excretory System

There are a variety of excretory systems, but all involve **filtration** of waste from the blood, followed by **reabsorption** of components of the filtrate before excretion.



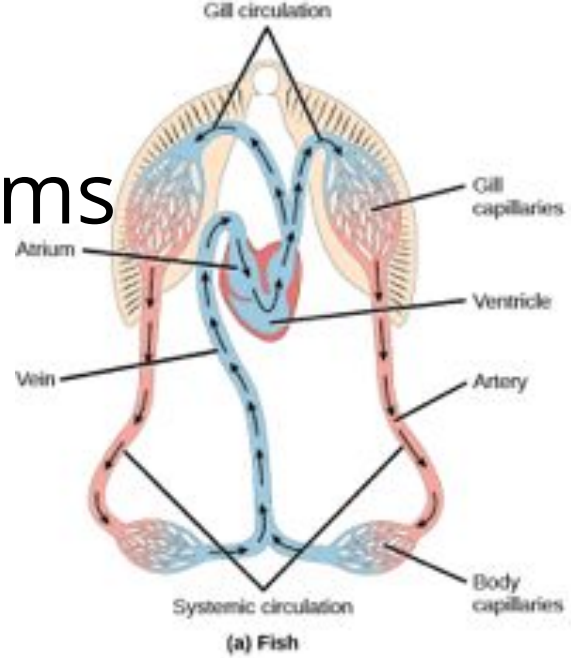


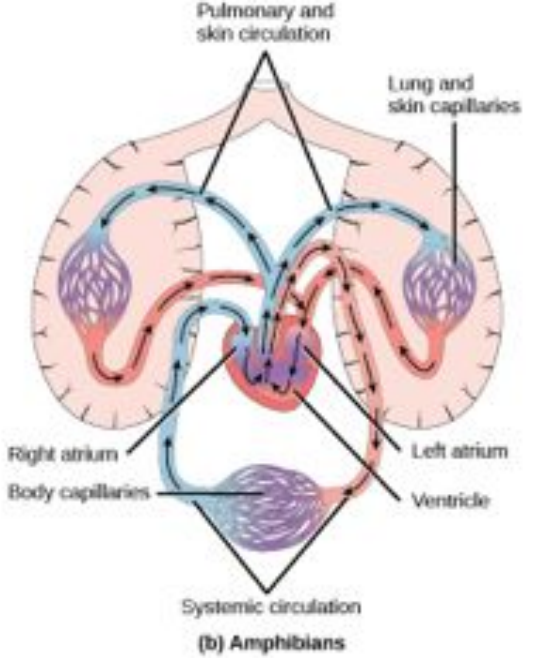


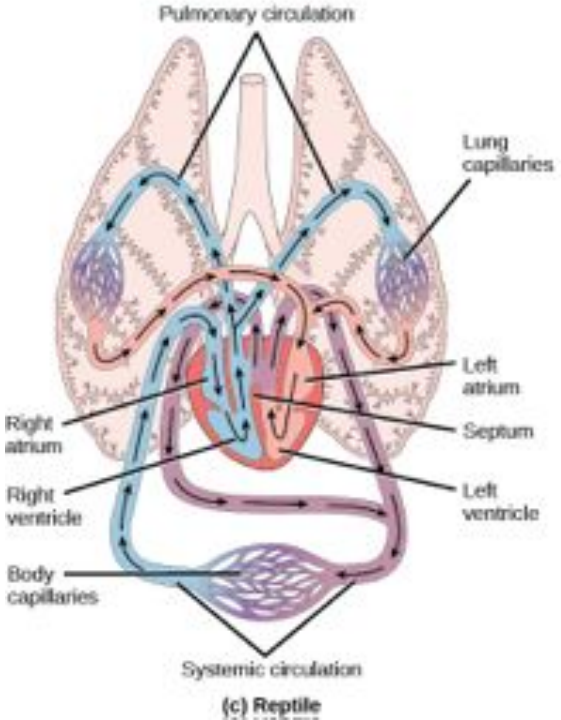


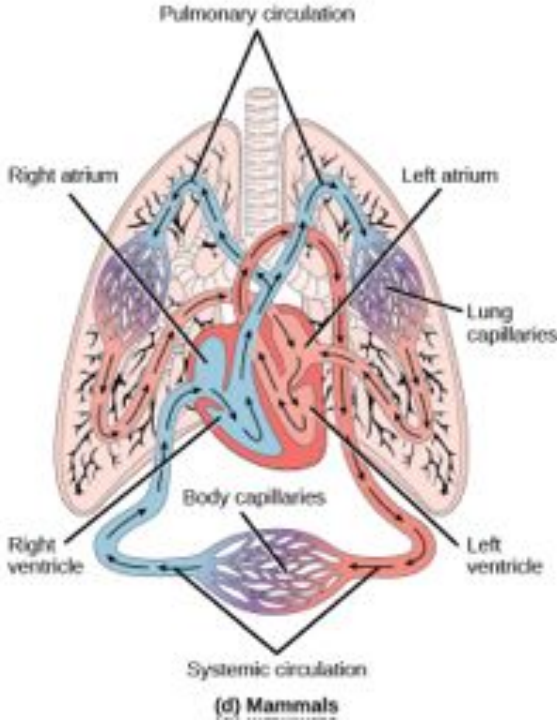
Ex. Vertebrate Circulatory Systems

All vertebrate circulatory systems are **closed**, and use a single **heart** to pump blood from the body to the respiratory system and back.









5.5: Biological systems are affected by disruptions to their dynamic homeostasis.

1. EFFECTS OF DISRUPTIONS

Homeostasis is a System Property

All levels of biological organization are able to exist at a homeostatic stability.

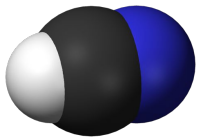
Anything that moves the system away from homeostasis can be considered a "**disruption**".

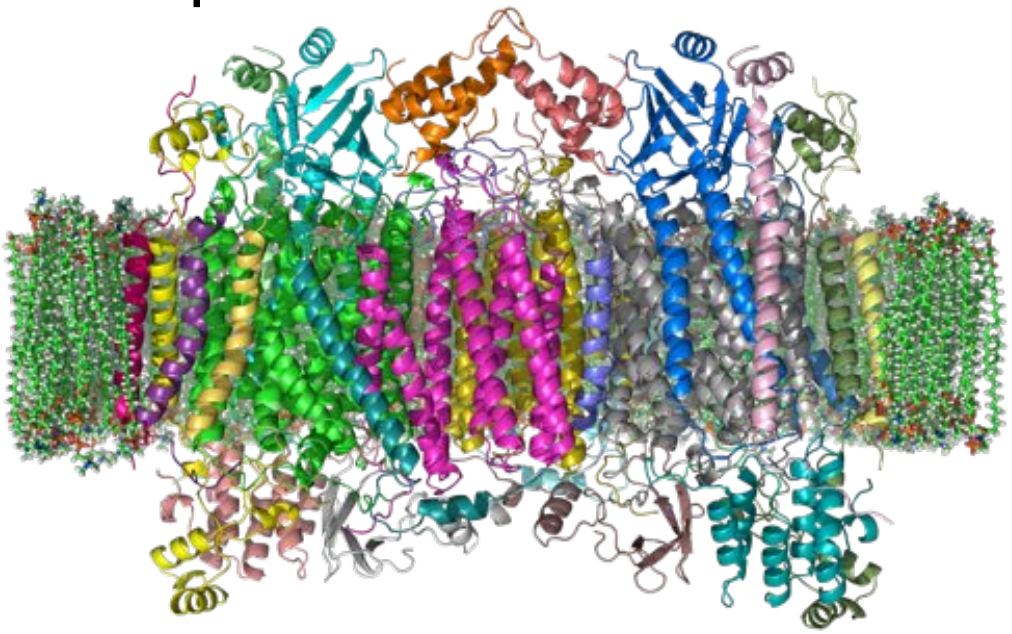
Disruptions to homeostasis at any level of the system will affect other levels of the system as well.

Molecular Disruptions

Toxins: substances that interfere with specific metabolic processes or destroy cells.

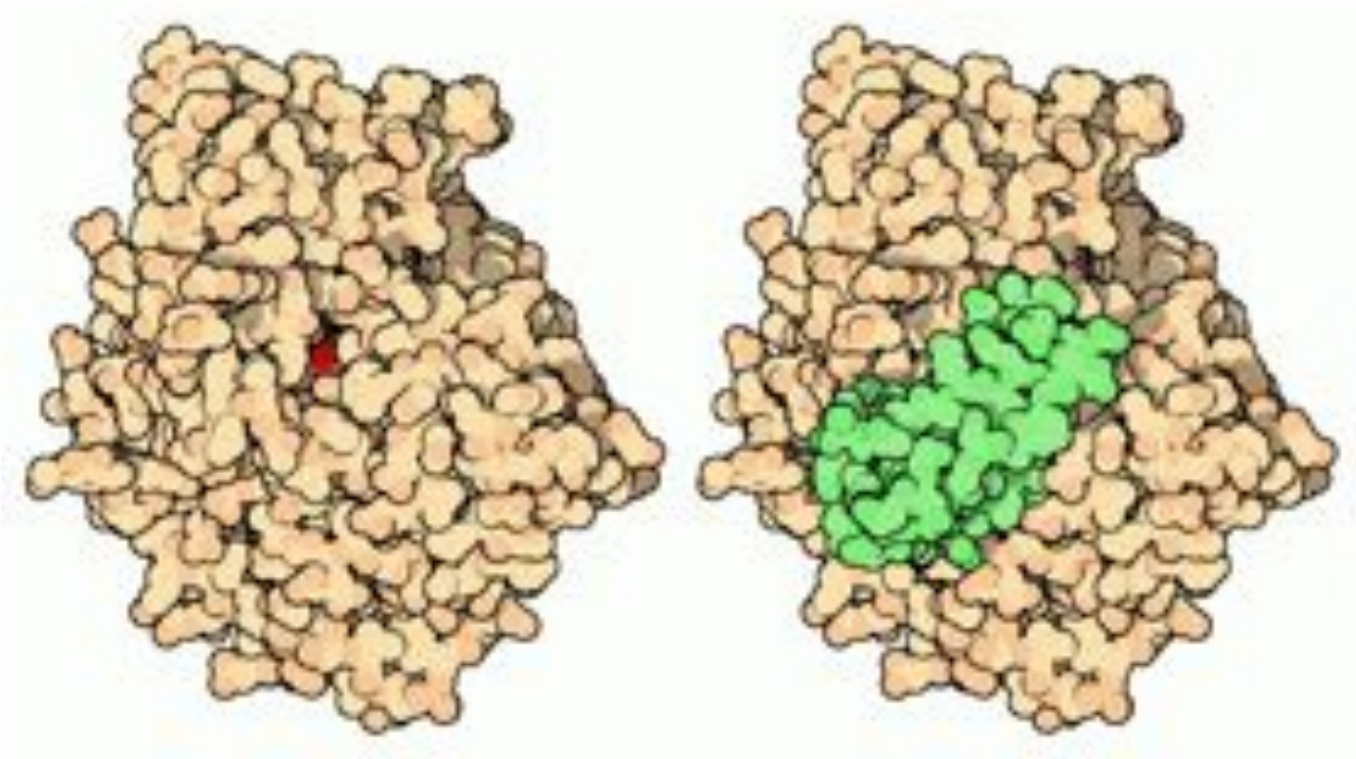
Ex. Cyanide interrupts the function of cytochrome c oxidase (in the mitochondrial ETC), stopping cellular respiration.





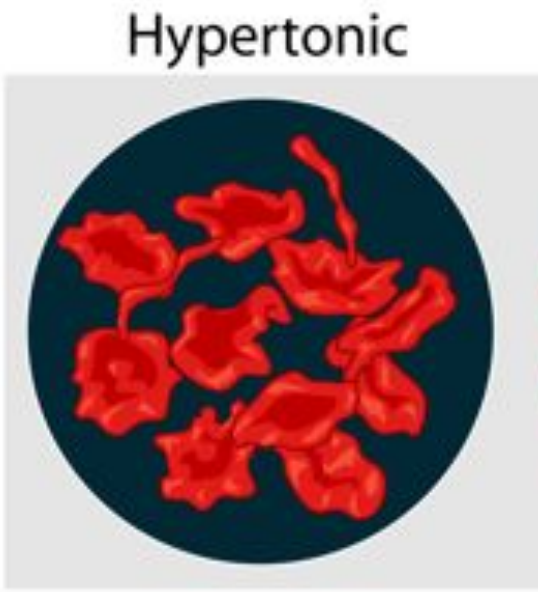
Note: Not to scale.

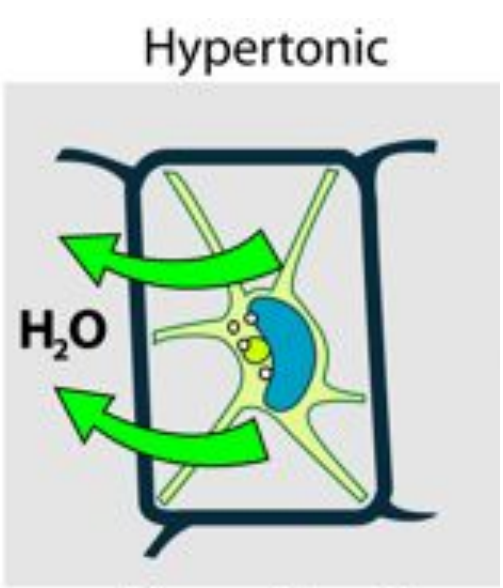
Ex: A snake venom toxin blocks removal of acetylcholine from synapses, preventing communication between nerves and muscles.



Ex. Dehydration

The changes in tonicity that accompany a loss of water lead to shifts in molecular concentration that make it difficult for cellular work to continue.

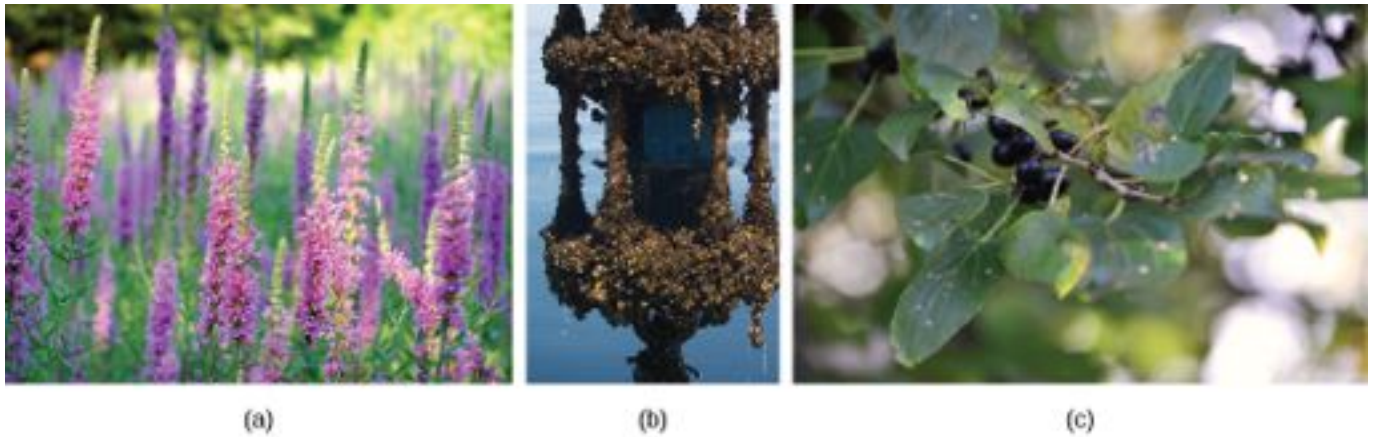




Ecosystem Disruptions

Disruptions to ecosystems can adversely affect the balance of abiotic and biotic conditions in the ecosystem.

Ex. Invasive Species

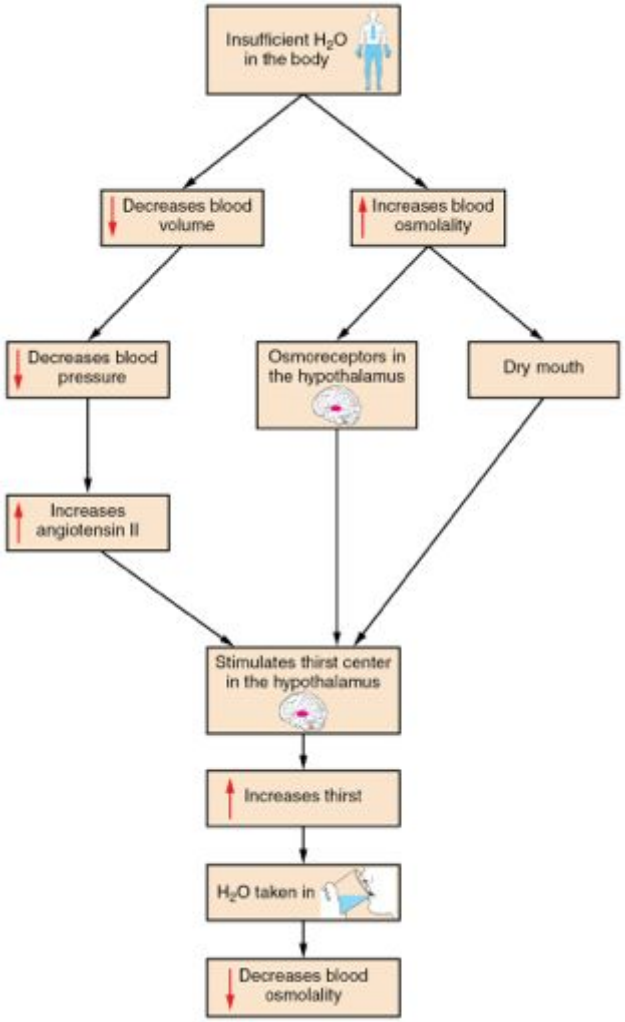


Ex. Disturbance

Natural and Human disturbances cause large-scale, rapid changes to the structure of the ecosystem.

Restoration of Homeostasis

Biological systems are all able to use feedback mechanisms to respond to disruptions, and rebound IF the disruption is not too large and rapid for those mechanisms to function.



5.6: Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis.

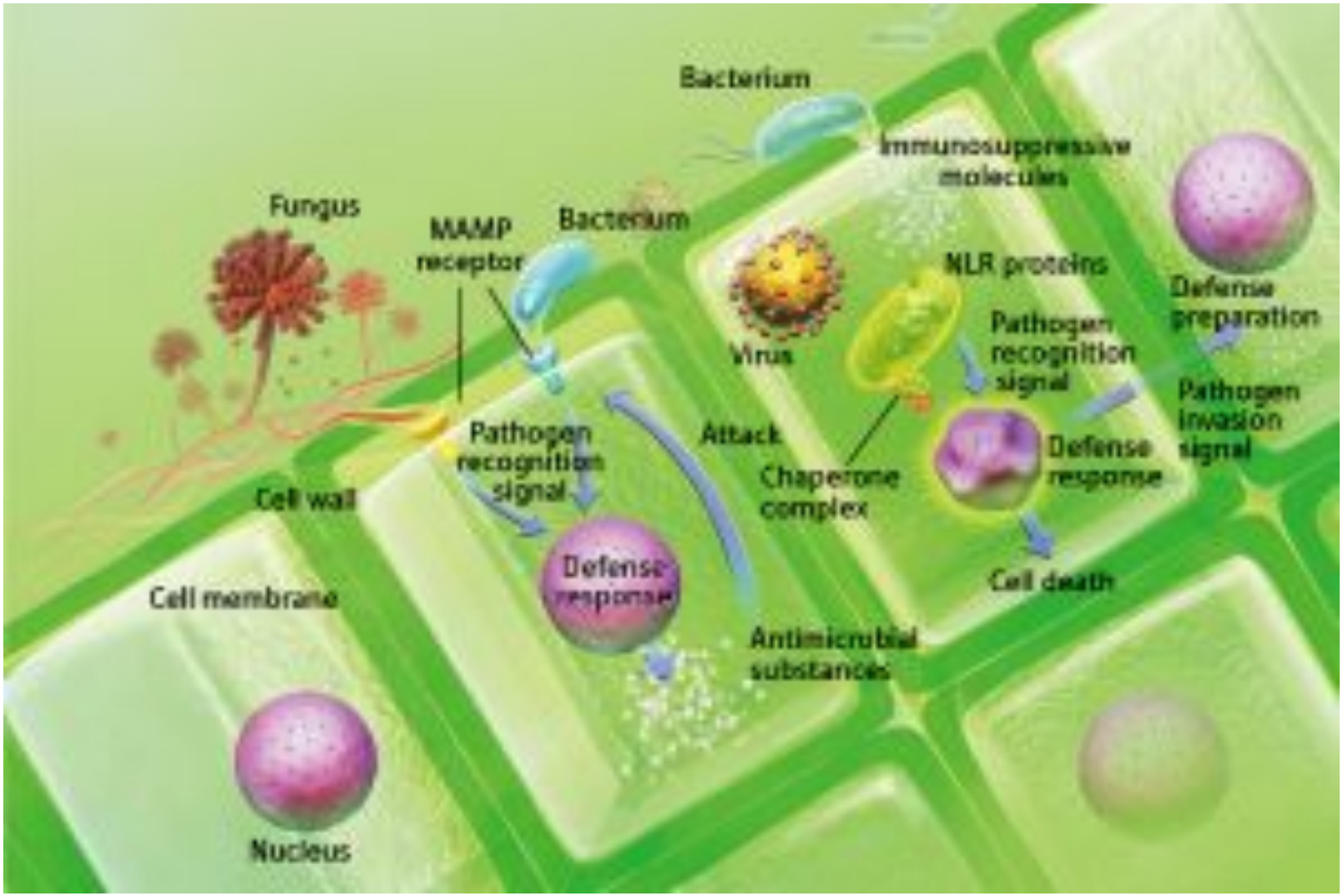
1. IMMUNE SYSTEMS

Non-specific Defenses

All organisms have non-specific defenses.

"**Pattern Recognition Particles**": All organisms have receptors that recognize and respond to molecules that are present in general classes of pathogens.

Defense Responses in Plants

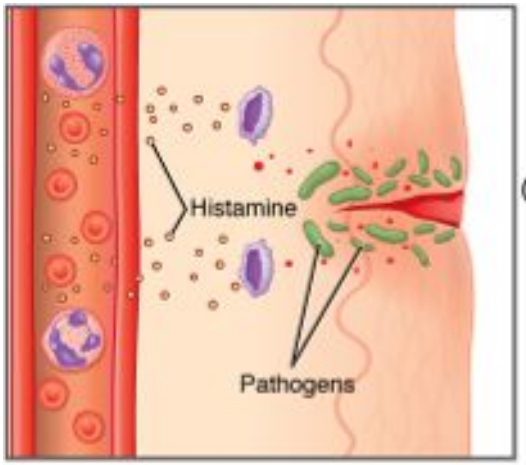


Non-specific vertebrate defenses

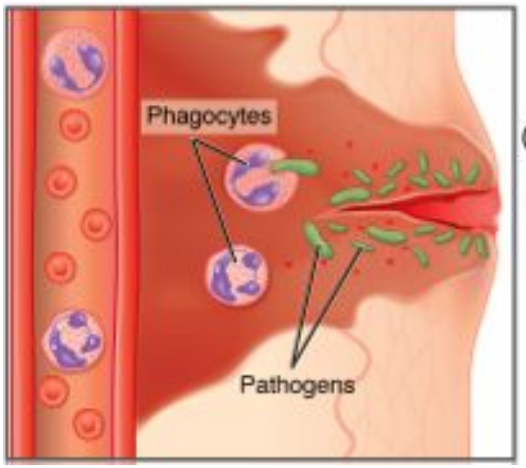
Vertebrates have a variety of external and internal defenses.

External: Skin, mucous, tears, sweat (lysozyme).

Internal: Inflammatory response



① Mast cells detect injury to nearby cells and release histamine, initiating inflammatory response.



② Histamine increases blood flow to the wound sites, bringing in phagocytes and other immune cells that neutralize pathogens. The blood influx causes the wound to swell, redden, and become warm and painful.

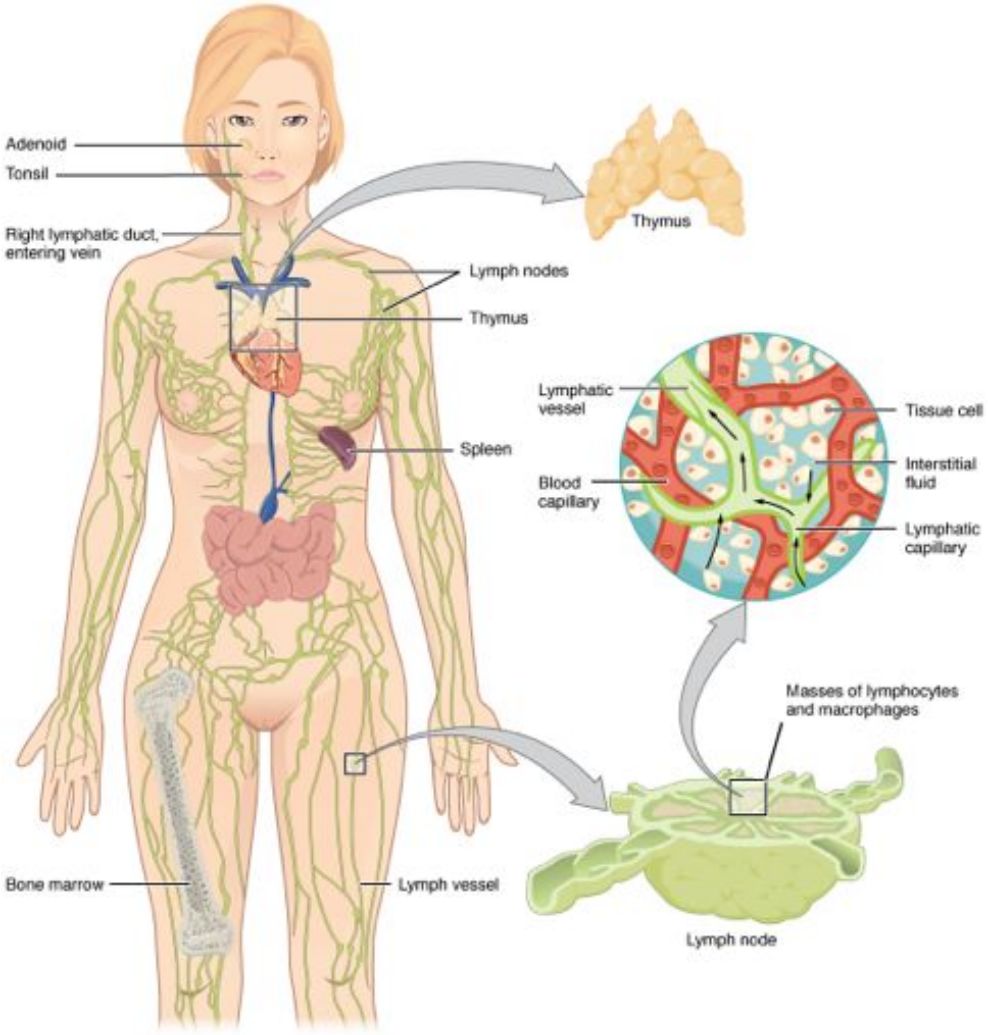
Mammalian Specific Immunity

Mammals have a highly developed specific immune system.

Controlled by **lymphocytes** (B and T cells)

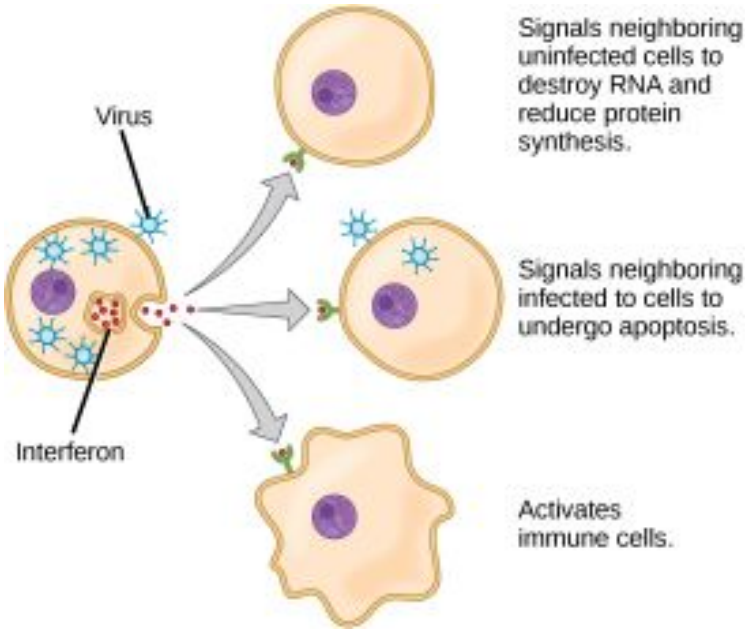
2 major divisions:

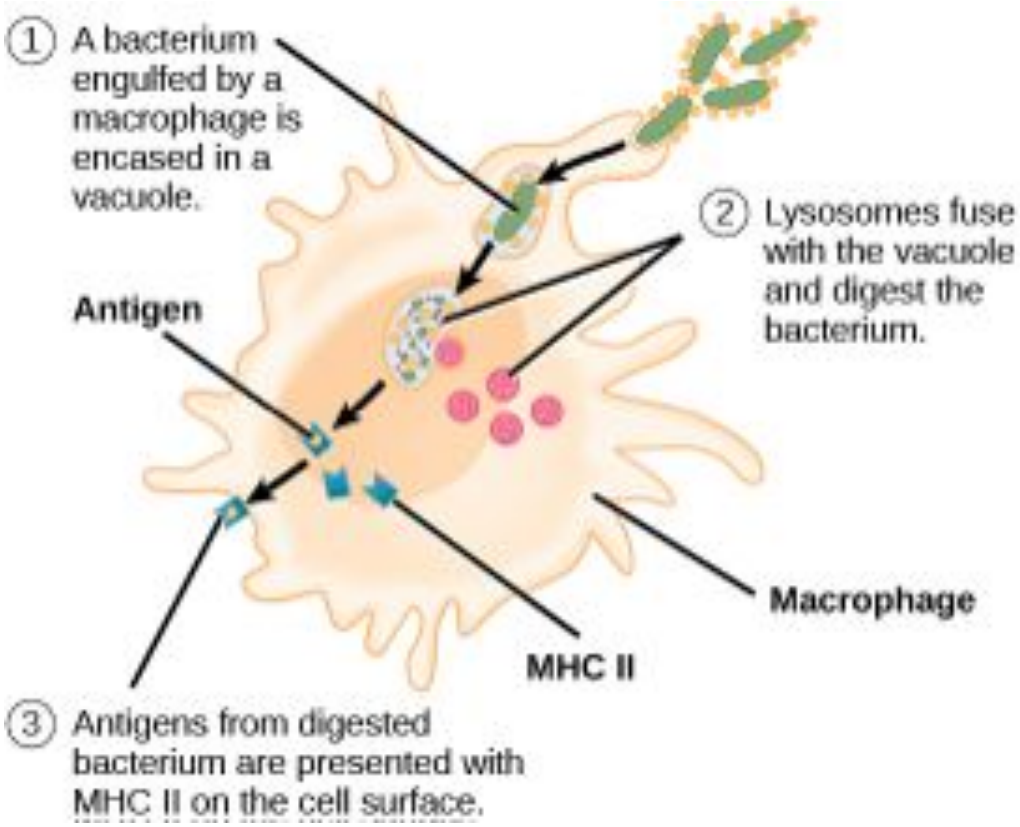
- **Cell-mediated.**
- **Humoral.**



Specific and Non-Specific Interactions

The **specific immune response** is triggered when non-specific **phagocytes** present molecules from pathogens ("**antigens**") to lymphocytes:

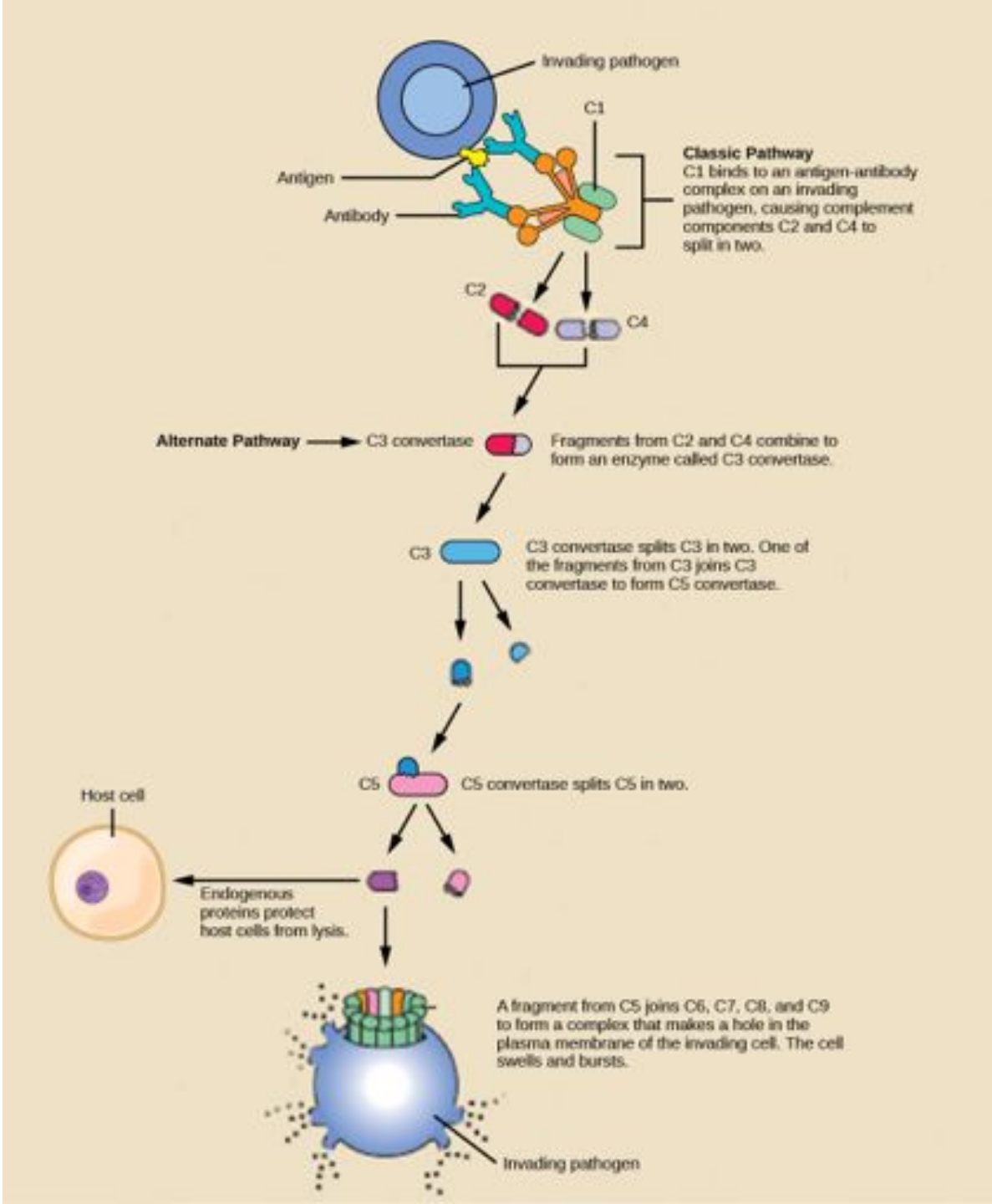




Cell-Mediated Response

Specific T-cells are developed to target specific antigens.

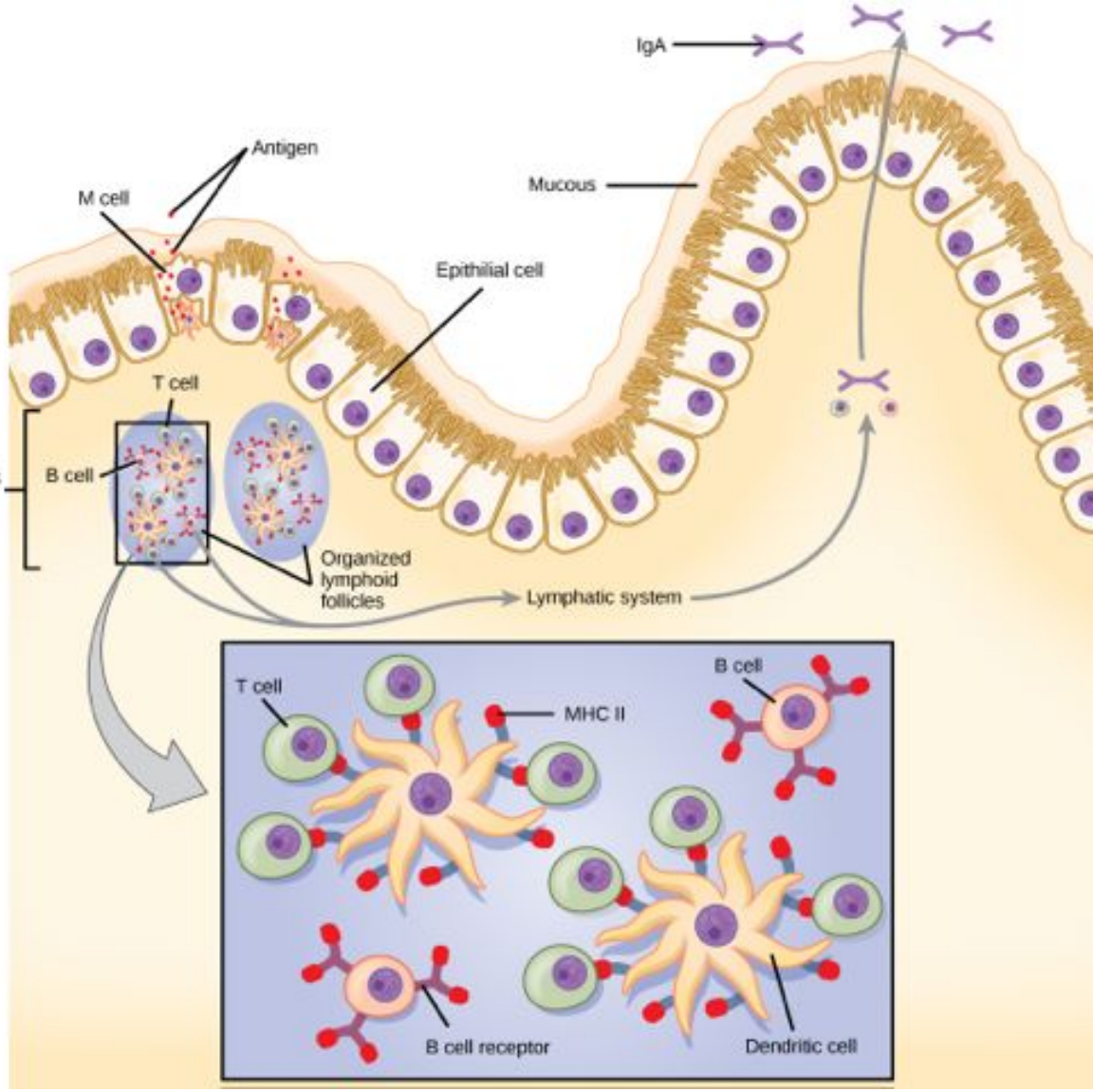
These T-cells trigger the destruction of those pathogens, and infected cells through cell-cell interactions.



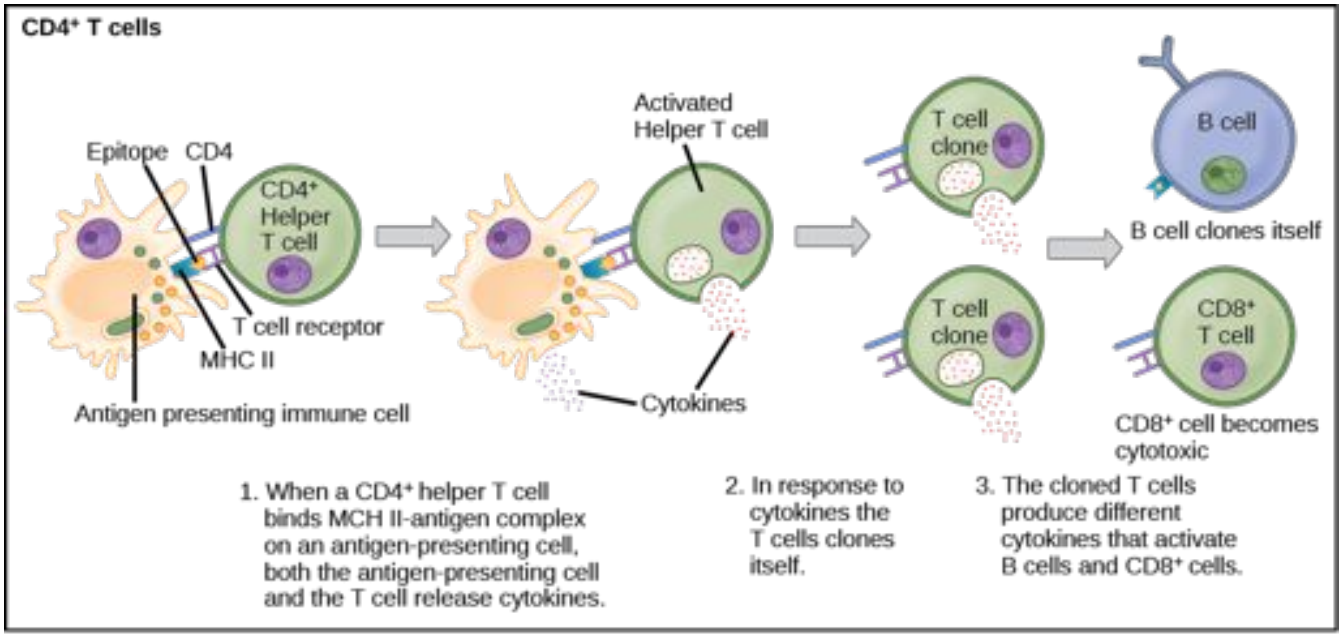
Humoral Response

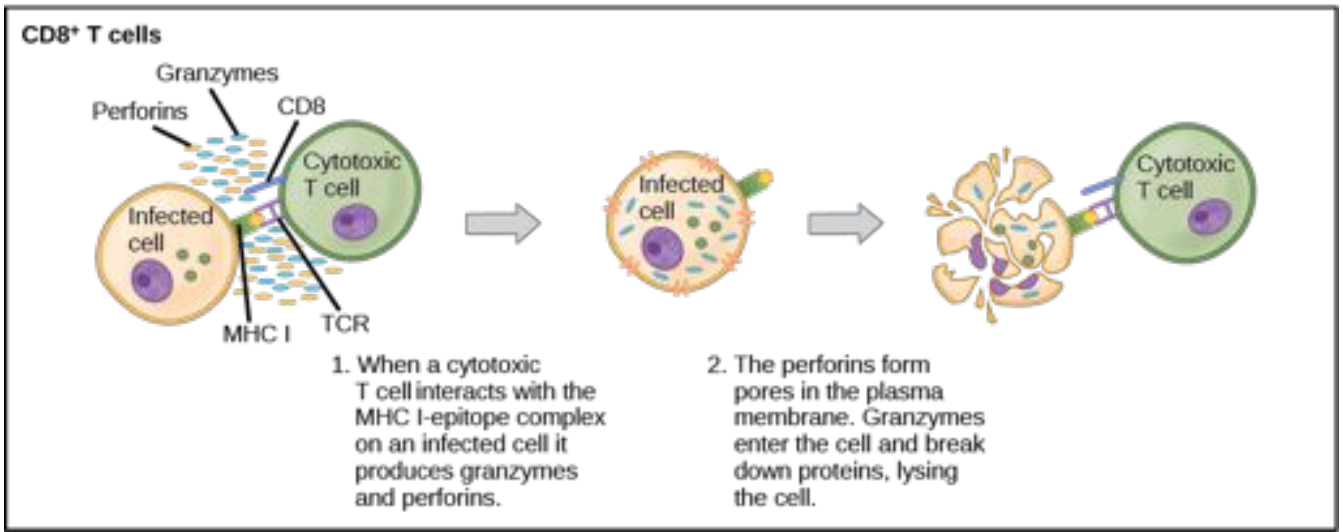
Specific B-cells are developed that produce and secrete **antibodies** that bind to specific antigens.

These antibodies bind to the antigens on pathogens and target them for destruction by T-cells, phagocytes, or prevent them from continuing their life cycle.



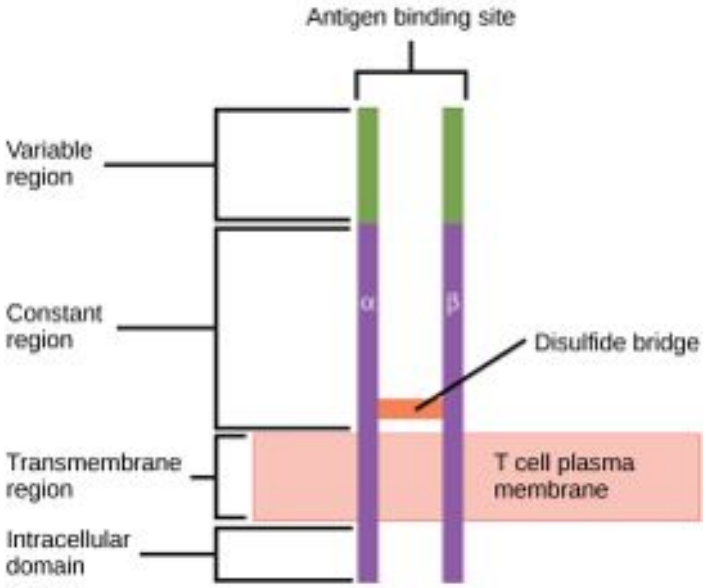
Other lymphocytes support the action of the specific response.

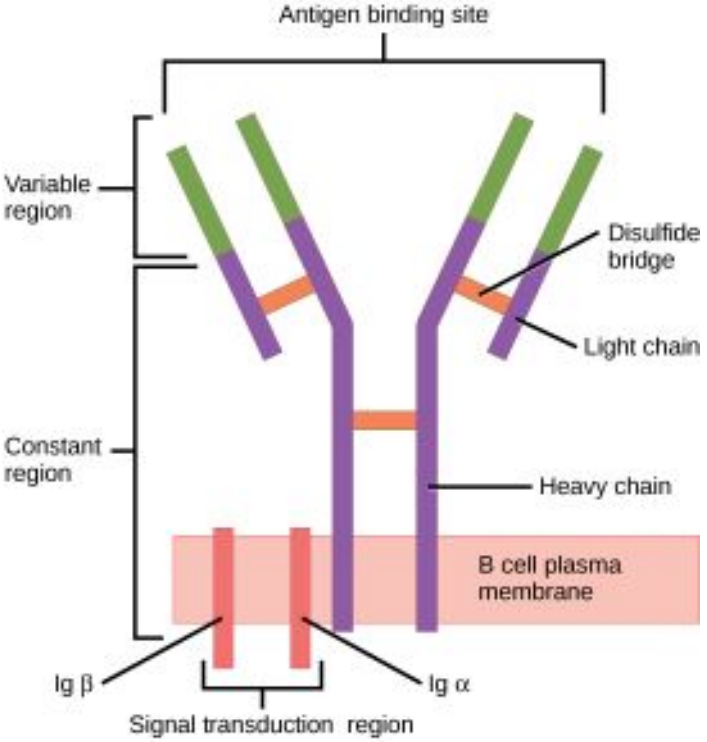




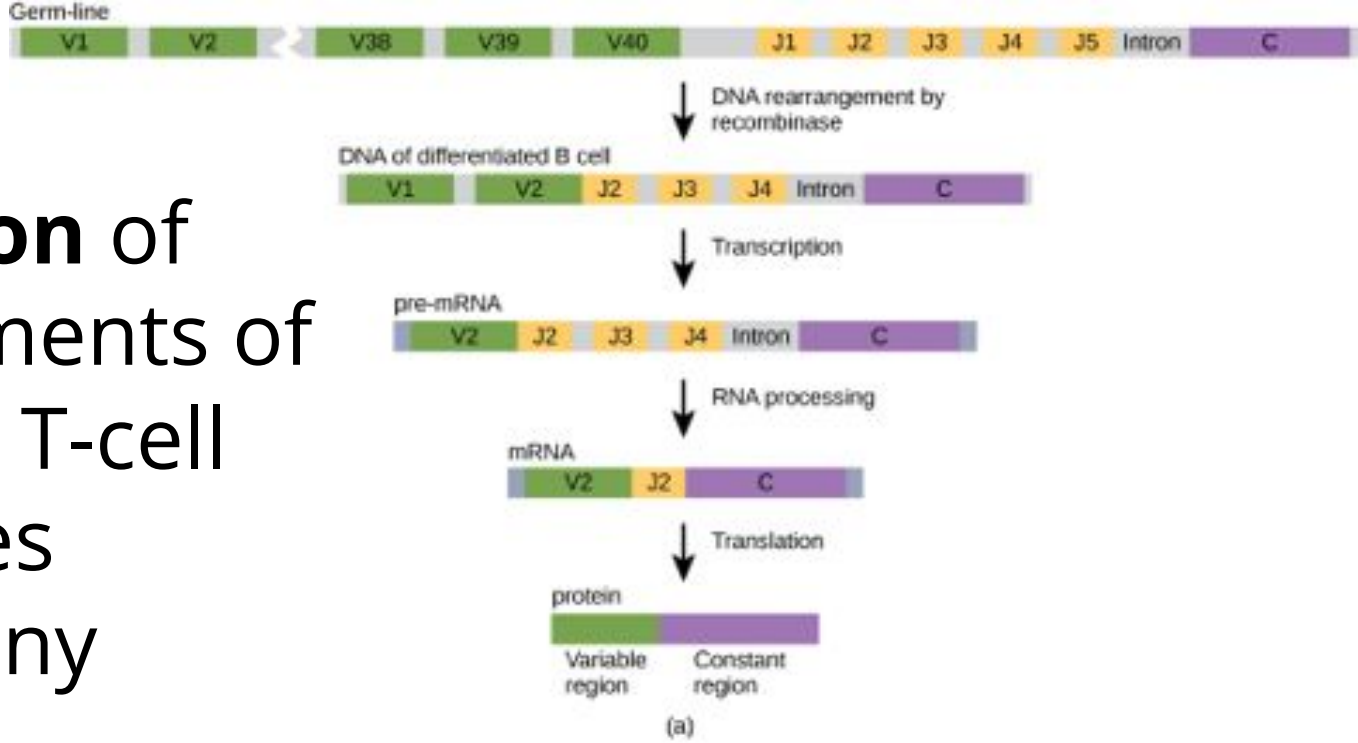
Antibody Structure

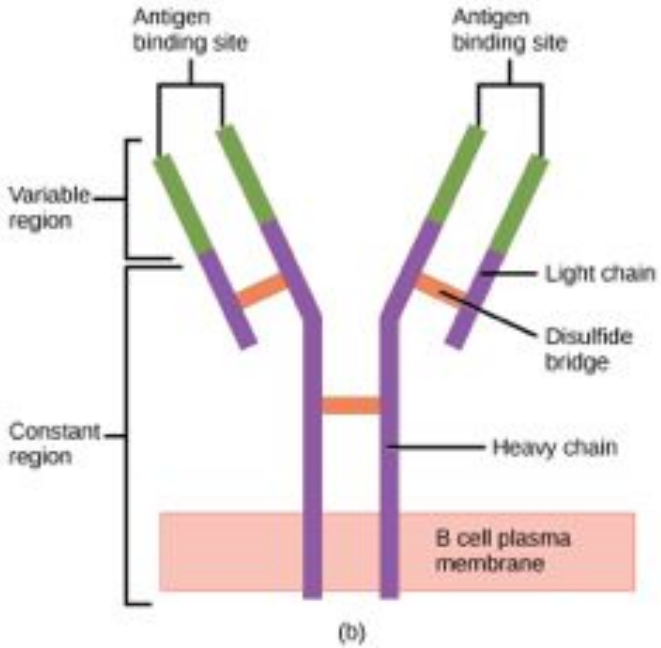
T-cells and B-cells have specific receptors on their cell membranes that respond to specific antigens.





Somatic recombination of different segments of the B-cell and T-cell receptor genes generates many thousands of different possible antigen binding sites.

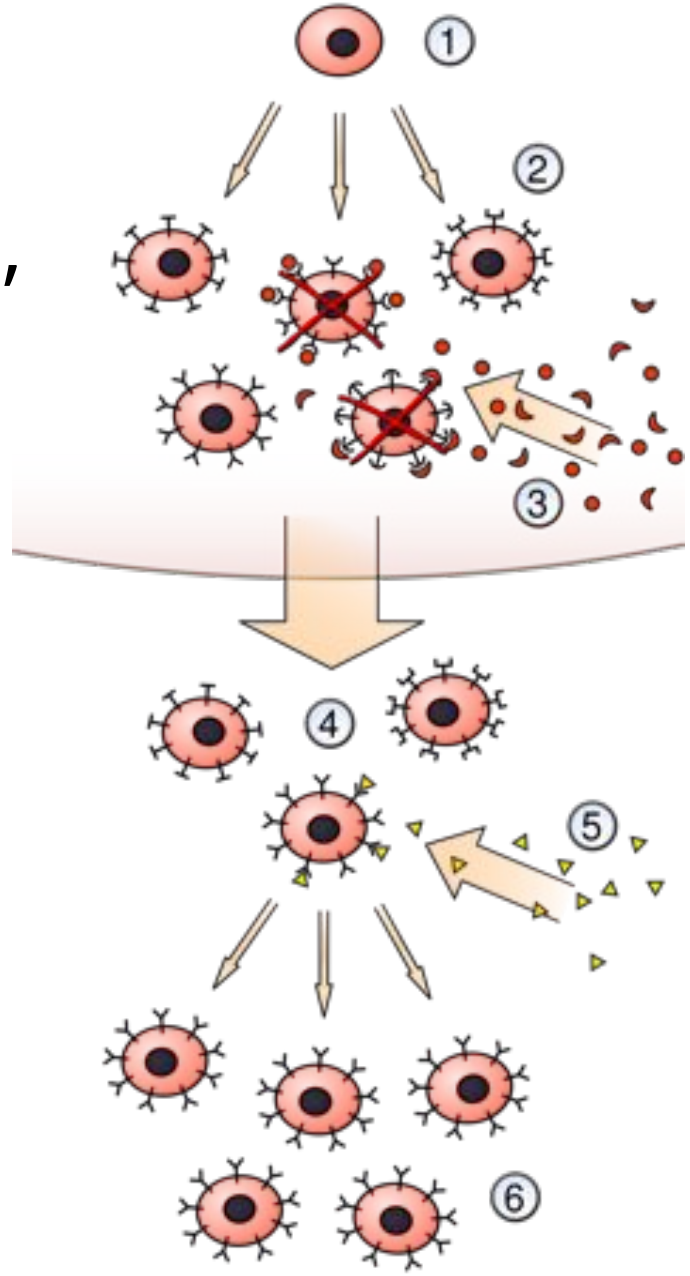




Clonal Selection

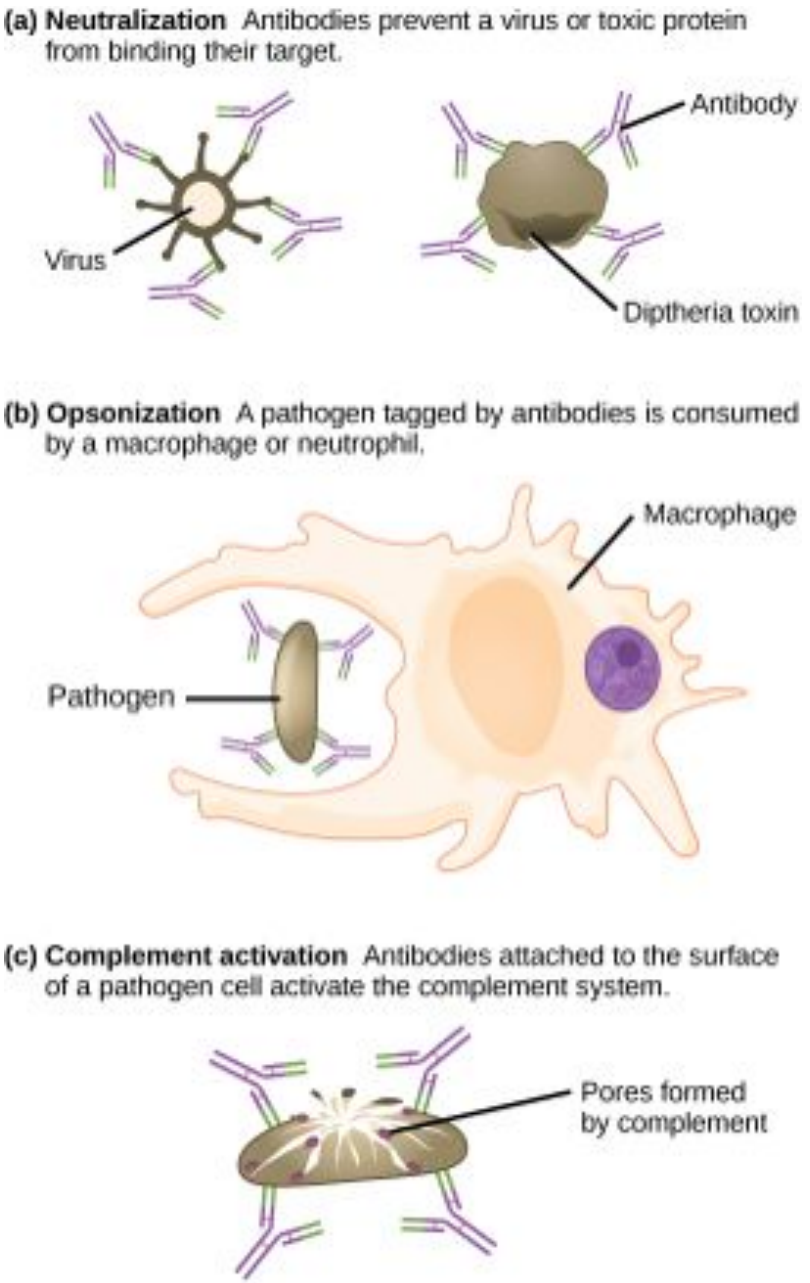
When lymphocytes mature, any who have receptors that react with “self” molecules are eliminated.

When lymphocytes are presented with an antigen, only those with reactive receptors are allowed to reproduce.



Antibody Action

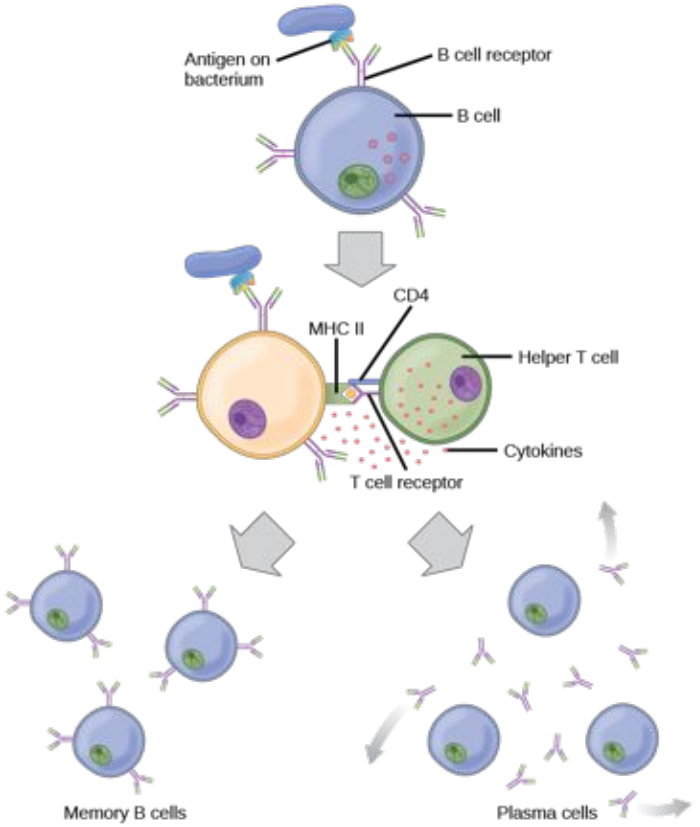
Antibodies work by preventing pathogens from infecting cells, and identifying pathogens to phagocytic cells.

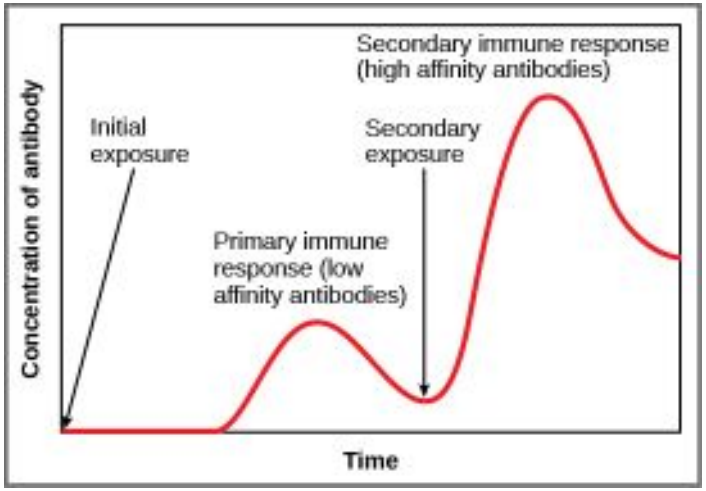


Immunological Memory

Whenever the immune system is exposed to an antigen, and a specific response is generated, a population of lymphocytes with reactive receptors will remain alive and available in the immune system for future exposure to the same antigen.

Subsequent exposures will trigger a faster and larger immune response.





5.7: Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection.

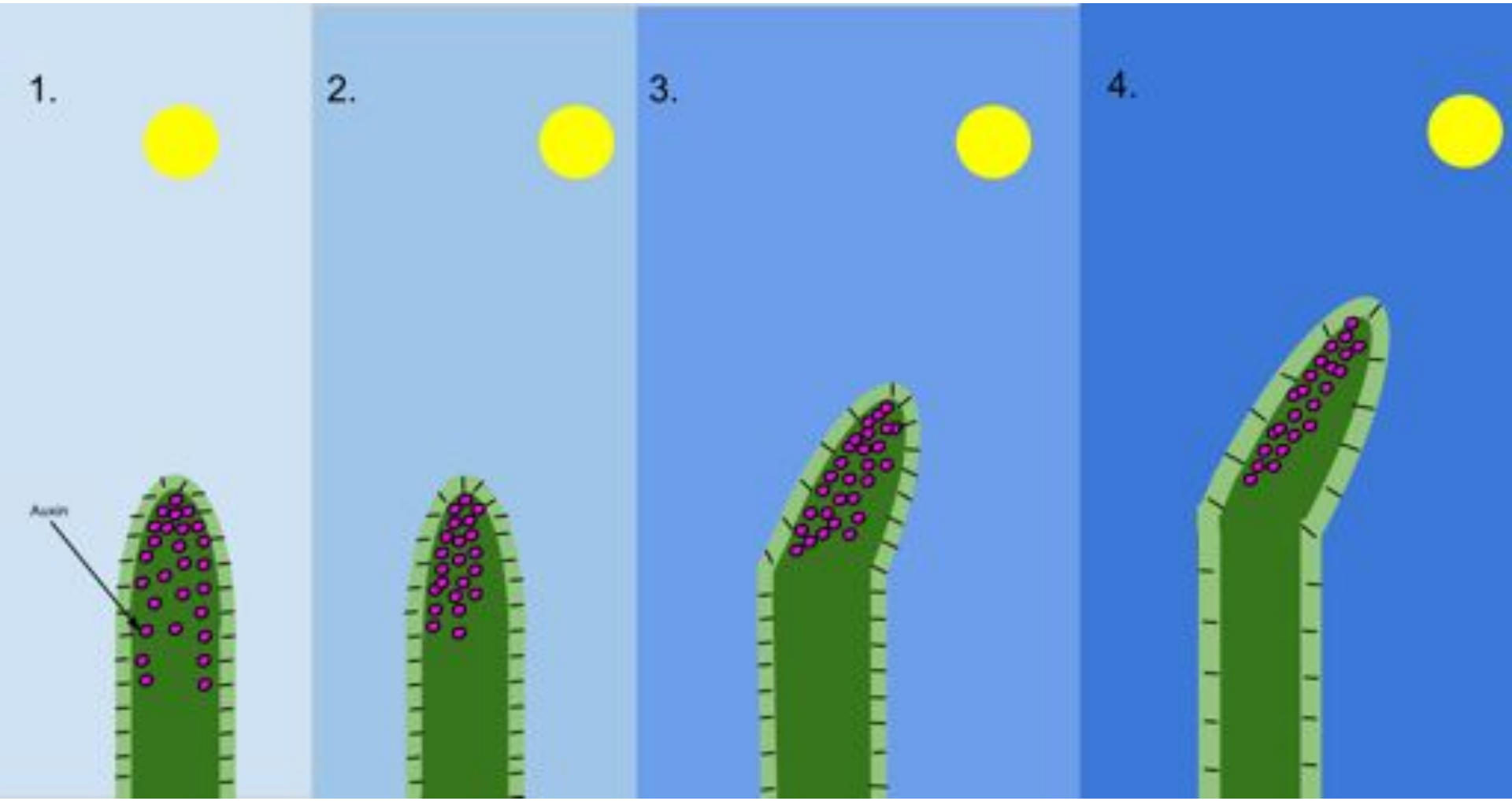
1. REGULATION OF BEHAVIOR

Behavior

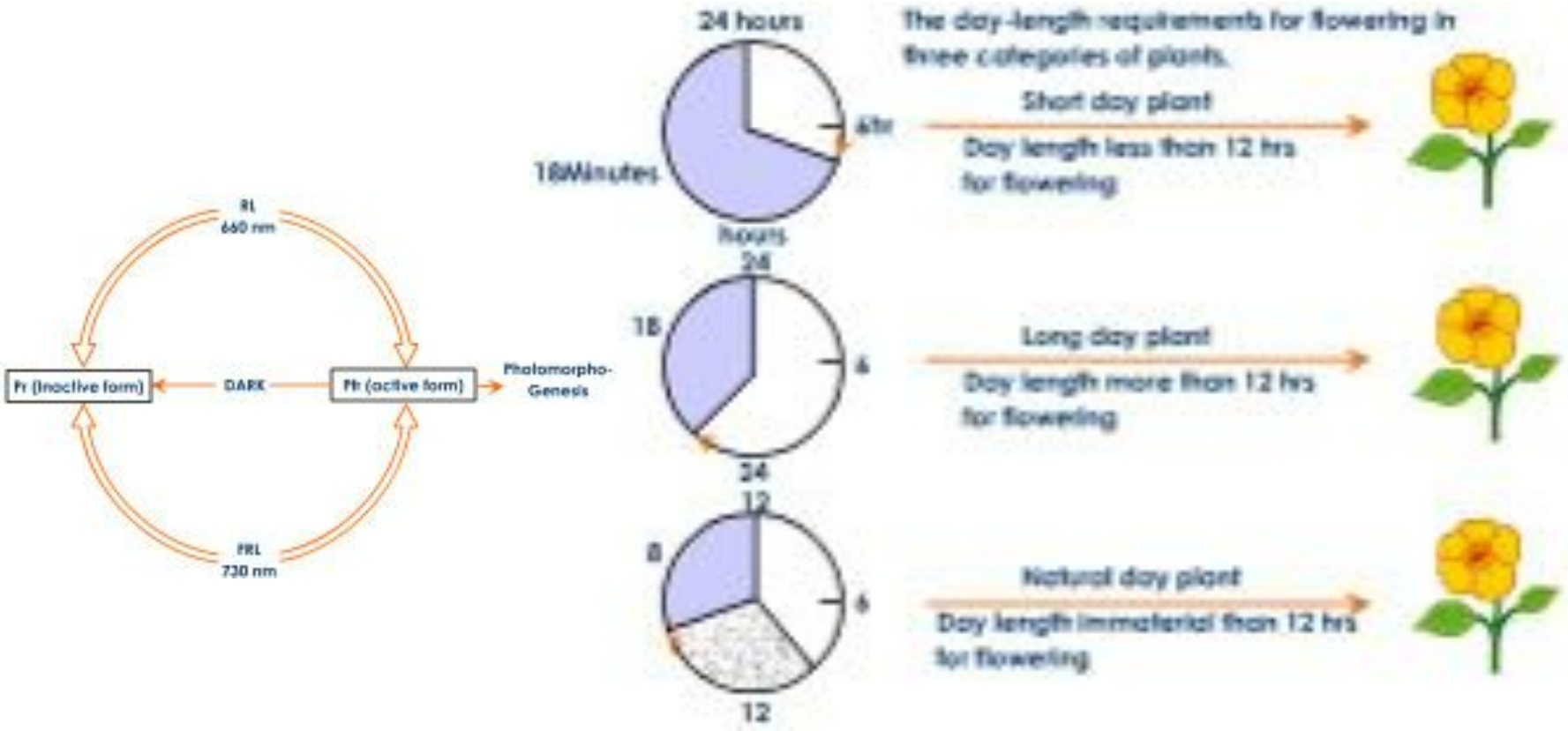
Behavior: Anything an organism does, and how it does it.

All Organisms are able to respond to changes in the environment by changing their behavior.

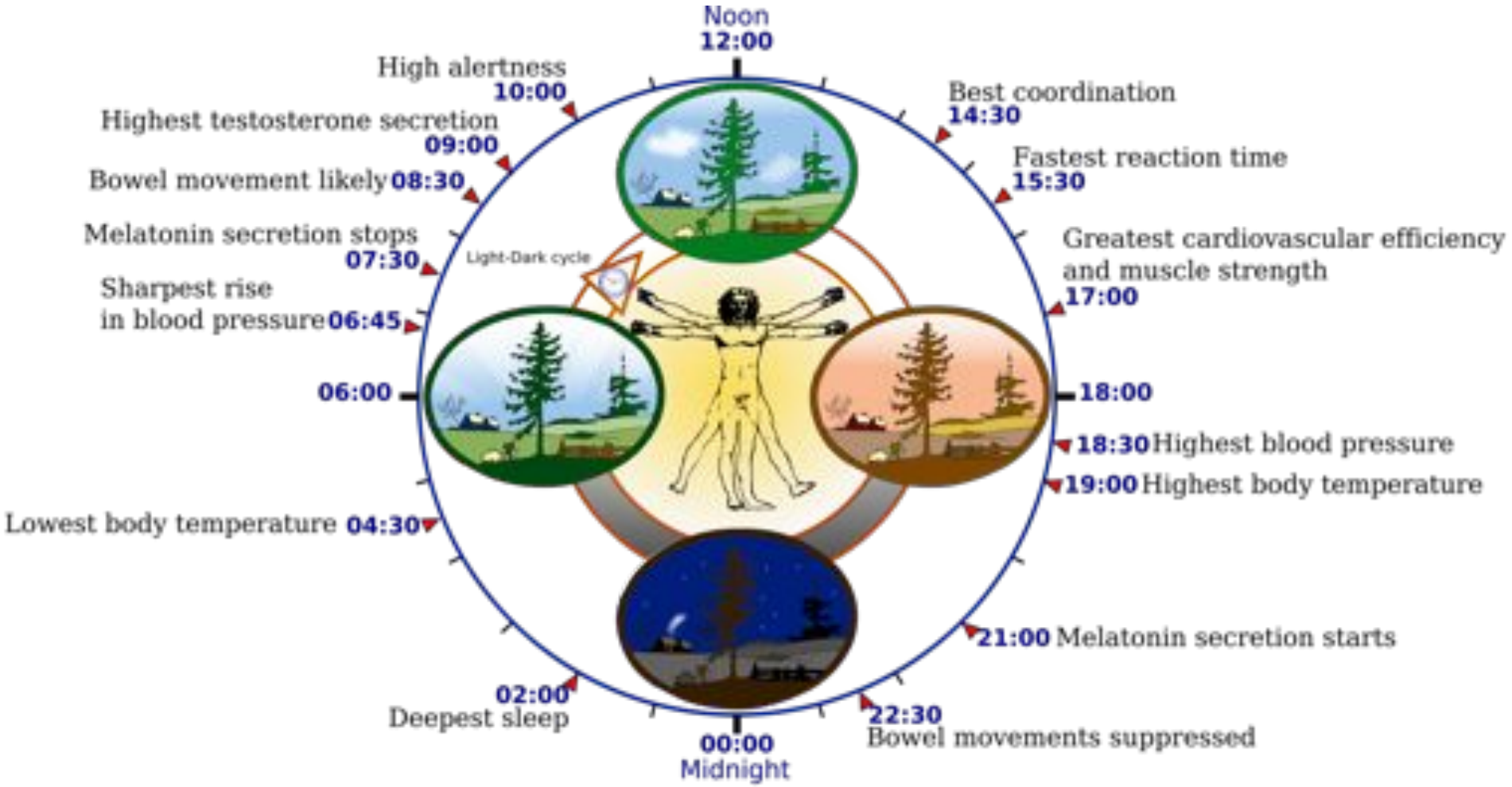
Ex. Auxin and the phototropic response.



Ex. Phytochromes and the Flowering Response

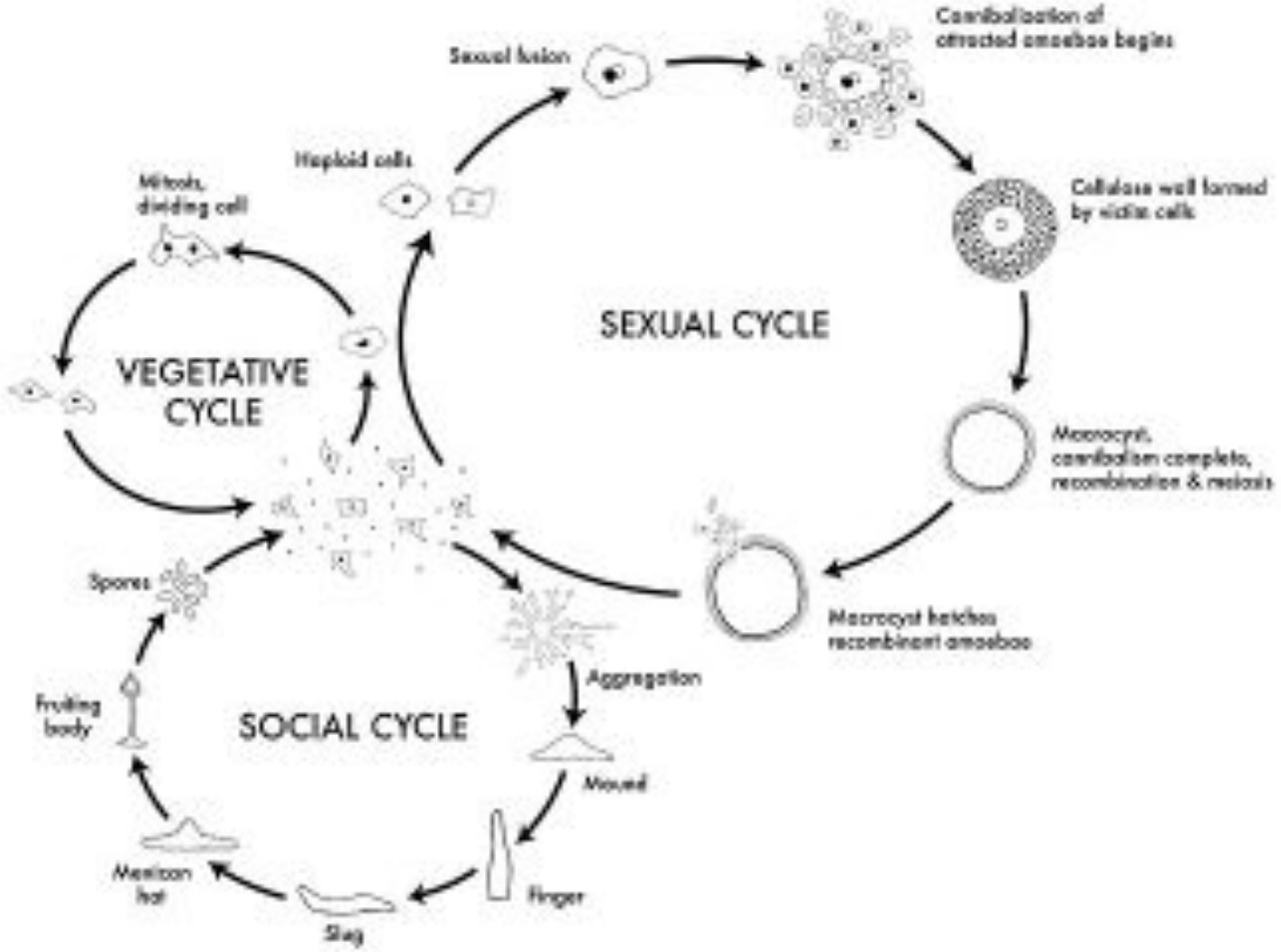


Ex. Circadian Rhythms in Animals

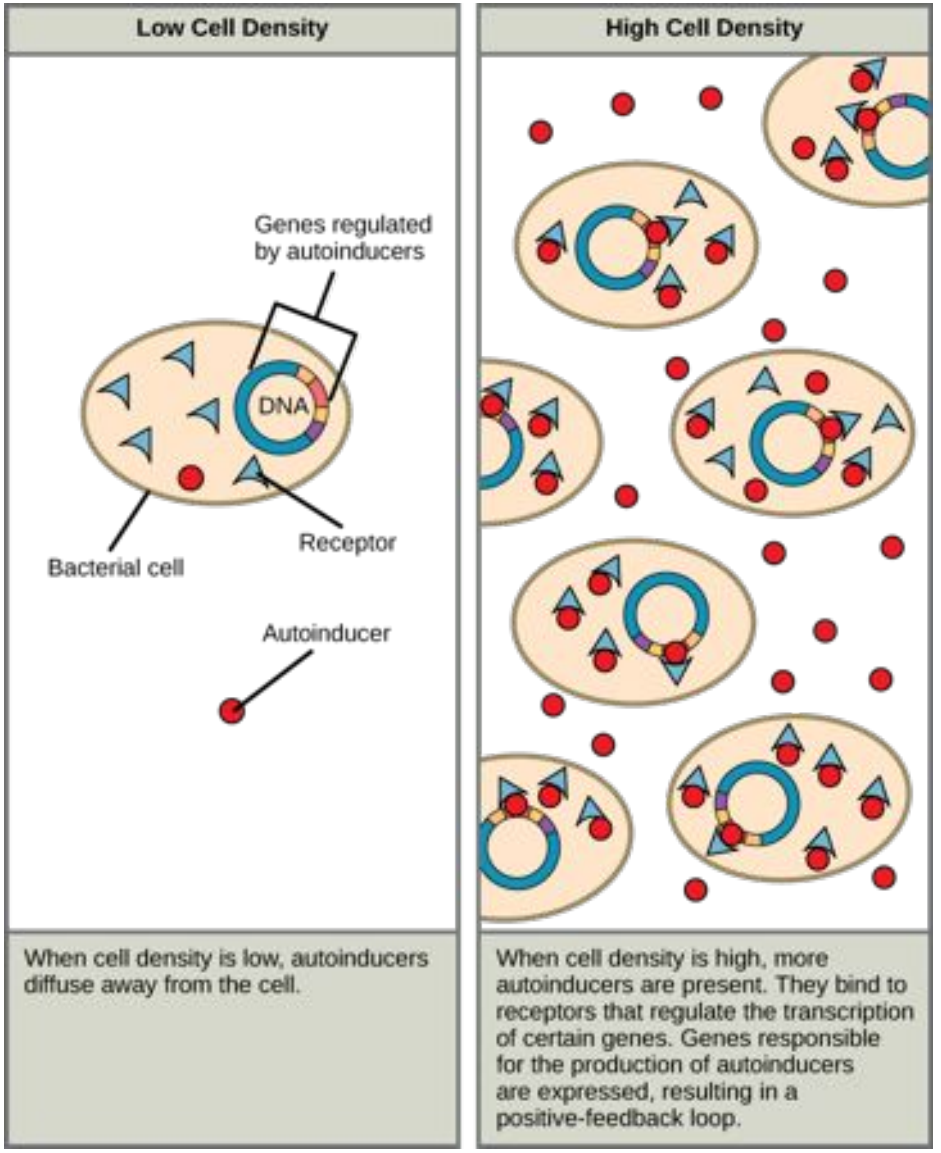


Ex. Hibernation Responses

Ex. Fruiting Body Formation



Ex. Quorum Sensing



In All Cases

Behavior is a result of interactions between the environment and the organism.

Behavior is regulatory in nature.

Any behavior with a genetic component can be adapted by natural selection.

Image Credits

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Exceptions:

Slide 9, 21: Kimball's Biology Pages

Slide 45: From pdb.org