1 Evolution

1.1 Introduction

- Universal genetic code is common to all life on Earth
- Extant organisms – species that are still surviving
- Extinct – gone
- Why evolution
    - Dynamic, always changing environment prompts for individuals with the characteristics suitable for the environment to reproduce and pass down their genes
- Theory of natural selection
    - How organisms gradually change and adapt to environment

1.2 History of Evolutionary Thought

- Until 1700-1800's
    - All life has an ideal form – fixed and unchanging since its creation
    - Can be arranged on a "scale of perfection"
- After science and technology progressed
    - Discover new continents and strange plants and animals
    - Led to scientists thinking – can species change?
- Influential thinkers
    - Georges Cuvier (1769-1832)
        - Pioneering palaeontologist
        - Believed that new rocks form above old ones
        - Believed that extinct species and extant species were created at the same time but died due to catastrophic events
    - Jean-Baptiste de Lemarc (1744-1829)
        - Lamarckism – belief where organisms can modify their body parts in accordance with usage (or the lack of) and the changes are inherited by offsprings
            - E.g. necks of giraffes are long as they need to stretch their necks to reach food
    - James Hutton (1726-1797) and Charles Lyell (1797-1875)
        - Theory of "Uniformitarianism" – geological processes occur at the slow and steady state observed today
        - Implies that Earth is much older than 6000 years
- Charles Darwin (1808-1882)
    - Proposed the idea that fossils of extinct animals were related to existing species
    - Unrelated organisms in similar habitats shared similar features across continents
    - Related organisms in different habitats adapt their features to suit the environment
- Alfred Russel Wallace (1823-1913)
    - Professional collector of animal specimens
    - Noticed variations in same species
    - Hypothesized that slight variations may impact survival
- Theory of Natural Selection

    - Proposed jointly by Darwin and Wallace
    - Different characteristics are inherited, some may have a better chance at survival and reproduction
    - Over many generations, favourable traits are accumulated
- Principles of Inheritance
    - Genes are encoded with 2 alleles
    - Genotype (combination of alleles) determines the phenotype (observable characteristic)
    - 2 types: Dominant and Recessive genes
    - Dominant traits need only 1 of the 2 alleles to express
        - e.g. Bb, where B denotes the dominant allele, b denotes the recessive allele
    - Recessive traits need both alleles to express (e.g. bb)
- Population Genetics
    - Evolution – change in allele frequencies within a population from one generation to the next
    - Evolution occurs at the population level
    - Allele frequencies = no. of copies of an allele / total no. of alleles for the same gene in the population
        - e.g. no. of B / no. of B + no. of b

1.3 Forces of Evolutionary Change

- Natural selection
    - Based on environmental pressure (habitats, predators, fighting for limited resources)
    - Results in adaptations of traits that can aid in survival and reproduction
    - Not every trait is an adaptation
        - Neutral traits
        - Maladaptive traits – may jeopardize the organism livelihood
- Artificial selection
    - Human-intervened selection to garner desirable traits
    - E.g. wild mustard plant bred to express different behaviours, resulting in vegetables we know today – broccoli, cabbage, kale, etc.
- Sexual selection
    - Increases reproductive success
        - Thereby increasing genetic diversity
    - Not equivalent to better survivability
    - Evolutionary “fitness” – determined by individual’s contribution to the next generation’s gene pool
- Mutation
    - Random change in DNA sequences
    - Can be neutral, beneficial, or harmful
- Genetic drift
    - Change in allele frequencies that occur by random chance
    - genetic bottleneck – drastic reduction in population size (natural hazards, etc)
    - founder effect – new population formed by few individuals
- Gene flow
    - Introduction or removal of genes due to immigration and emigration

    - May counteract genetic drift

1.4 Evidence for Evolution

- Fossils and fossil records
    - Timeline of events can be created
    - Structural changes of organisms can be observed
    - Will always be incomplete as not all organisms can be fossilized
- Transitional fossils
    - Exhibits traits common to both an ancestral group and its descendant group
- Comparative anatomy
    - Similar anatomical features suggest common ancestors and possible descendants
- Homologous structures
    - Structures where the similarities suggest a common ancestry
    - Often in same position by modified to suit the environment
    - E.g. limbs in vertebrates – made up of "one bone, 2 bones, many bones, fingers"
- Vestigial structures
    - Remnants of inherited structures that are no longer functional
    - E.g. tailbone and appendix
- Analogous structures
    - Similar structures that do not derive from a common ancestor
    - Similar structures developed to adapt to environment
    - E.g. wings of birds and butterflies
- DNA and biochemistry
    - The more closely related species are, the more alike their DNA and proteins
- Experiments on organisms with shorter life cycles
    - >50,000 generations of E. Coli tracked from 1988
    - Found that one strain adapted to use citric acid as a carbon source instead of just glucose in aerobic environments

1.5 Videos/Extra materials

- Birds of paradise courtship dance
    - Male bird of paradise dancing to captivate potential mates
- Manakin male display
    - Male "moonwalking" or tippy tappy dancing, and flap their wings in attempt to captivate potential mates
    - Also shows off their bright yellow legs
- Bowerbird male display
    - Male is bright red and yellow
    - Sets up a stage > alternating pupil enlargement > voice display > dance performance
    - If things go well, male will attempt to headbutt the female's chest
- Anglerfish sexual parasitism (some species)

        - Males are very small (about 1/60 the size of the females)
        - Bites onto the females and become one, sharing everything, including the circulatory system
        - Speculation: This works as immune systems of these species lose the ability to adapt and remember foreign pathogens, so the males are not recognised as invaders and therefore not attacked
- Lizards in hurricane
    - After hurricane, the lizards left on the island had on average
        - larger toepads - more ridges on toes, helping with grip
        - shorter femurs - shorter hind legs don't catch as much wind
    - males also had a smaller body
- Mary Anning – Unsung heroine of fossil discoveries
    - Discovered Ichthyosaurus ("fish lizard") – group of marine vertebrates
    - First to discover Plesiosaurus ("near to reptile") – group of large marine reptile
    - First to discover Pterodactyl – genus of pterosaurs – flying reptiles
    - Pioneered the study of coprolites – fossilised poo
    - Not recognised nor credited for her findings due to her gender (historical social background of 1800s)

1.6 Practice questions

1. Which of the following option is not a homologous structure as the others?
   <u>The wing of a grasshopper</u>

2. Jean-Baptiste Lamarck proposed a theory of evolution that differed from Charles Darwin's primarily in that Lamarck thought that ________
   <u>Evolution was driven by the needs of individual organisms and the inheritance of acquired characters</u>

3. According to Darwin, artificial selection differs from natural selection in that the former __________
   <u>is directed by a human agent</u>

4. Which is/are the main point(s) of Darwin's idea?
   <u>Earth is old</u>
   <u>Evolution is gradual and continuous</u>
   <u>Contemporary species share common ancestors</u>
   <u>Species are formed and adapt by the process of natural selection</u>

5. Why is embryonic development important in Evolution?
   <u>All vertebrate embryos, resemble one another in their early development hence suggesting shared trait</u>

2 Biodiversity

The knowledge learned by evolving species over millions of years about how to survive through the vastly varying environmental conditions Earth has experienced

2.1 Importance of biodiversity

- Protection from natural disasters: Coral reefs and mangroves swamps (cyclones and tsunamis)
- Absorb air pollution in urban areas: trees
- Dispersal of seeds: Tropical tortoises and spider monkeys
- Medicine: a fungi that grows on the fur of sloths and can fight cancer

2.2 Extinction

- 6th mass extinction in geological history: extinction rate of species 1000 times higher than the losses caused by the giant meteorite 65 mya

- humans consume 25%-40% of the planet's entire 'primary production'

- threatened: 25% mammals, 41% amphibians, 13% birds

- marine life: more than half of the ocean is industrially fished

- bugs: 75% of flying insects were lost in 25 years in Germany (likely elsewhere too)

    - function: pollinators, decomposers of waste, predators of waste, base of many wild food chains that support ecosystems

2.3 Factors of biodiversity loss

- increase demand of land: growth of human population leading to deforestation of wild areas (farmland, housing, industrial sites

- poaching and unsustainable hunting: more than 300 species of mammals are being eaten into extinction

- pollution: industrial pollutants (orcas and dolphins seriously harmed)

- global trade: spread of fungal disease due to pet trade (large decline in amphibians), spread of highly damaging invasive species (rats)

- water extraction: pollutions and dams lead to destruction of habitats (81% loss of freshwater animal populations since 1970)

2.4 Benefits of protecting biodiversity

- human food system

    - 75% of food comes from a dozen crop and 5 animal species

    - preserving wild relatives of crops: numerous species are resistant to disease and tolerant to changing environments (durum wheat in Ethiopia, quinoa in South America)

- tackle nutrition problems: The gac, a fiery red fruit from Vietnam, and the orange-fleshed Asupina banana both have extremely high levels of beta-carotene and could help the millions of people suffering vitamin A.

2.5 What to do

- Planetary boundaries: thresholds in Earth systems that define a “safe operating space for humanity”.
- Wildlife reserves: the world currently protects 15% of land and 7% of the oceans
- Sustainable practices: eat less meat (esp. Beef), use products without palm oil
- Natural capital: estimate the financial value of biodiversity
- Technology advancement: identify creatures using machine-learning, real-time DNA sequencing
- Political will: global treaty - Convention on Biological Diversity (CBD) sets targets for protection on land and oceans, sustainable fishing etc

2.6 Video: Sympatric Speciation Examples

- Speciation: process of 1 species splitting into 2
    - Allopatric: a species being split into 2 or more groups by a physical barrier (glaciers during ice age, river carving out canyon, lava flowing from volcanic eruption, construction of highway
        - Split species go in different evolutionary directions:
            - Adapting to specific spots where they ended up
            - Through random genetic drift
        - Becomes different species, unable to interbreed
        - Examples:
            - Kaibab squirrel and Abert’s squirrel on the north and south rim of the Grand Canyon
            - Finches isolated on different islands in the Galapagos
    - Sympatric: a species being split although living in same habitat (no clear physical barrier)
        - To happen: something must make different groups within a population to stop breeding with each other although sharing a habitat
            - Disruptive selection: when natural selection drives a population in 2 different directions at the same time
            - Assortative mating: individuals choose mates that are similar to themselves
        - Example:
            - Apple maggot fly and hawthorn maggot flies of North America
            - Two species of fish are descended from a single ancestral species of cichlid fish in Lake Apoyo, Nicaragua
        - Controversial: clear-cut examples of sympatric speciation in nature are rare due to specific conditions

2.7 Video: Where do species come from

- Species: network of streams, branching off a big river

- Difficult to draw clear line between species but important because it impacts how the species are protected and whether they survive
- Speciation: evolution of species
    - Microevolution: changes in specific populations (mosquitoes living at same area breed with each other and develop pesticide resistance over time)
    - Macroevolution: changes in broad groups of living things
- Biological species concept: groups of organisms that can potentially interbreed with others of the same group and produce fertile offspring
    - Hybrid: cross between 2 species
        - Sometimes do not survive
        - Sometimes do not reproduce due to different numbers of chromosomes (zorse)
        - Sometimes reproduce (plumcot, some lizard females)
- Phylogenetic species concept: focuses less on who can breed with whom and more on ancestry and evolutionary history
- Ecological species concept: parses species based on differing environmental conditions
- Distinction of species: (for most species) reproductive isolation/inability to interbreed
    - Prezygotic: stops mating or fertilisation from occurring at all
    - Postzygotic: fertilisation happens but ends with hybrid

2.8 Scientific name

2.9 Names of places:

2.10 add -ensis behind the country, Eg. Singapore > singaporensis, malaysia > malayanensis

2.11 add -a behind the name, johor > johora

2.12 Names of people

2.13 Add -i behind male name: leonardi

2.14 Add -ae behind female name: beyonceae

2.15 Practice questions

1. According to the Linnaean classification system, onion (*Allium cepa*), garlic (*Allium sativum*) and leek (*Allium ampleloprasum*) all belong to the same
kingdom, phylum, class, order, family, genus

2. Which of the following may, over time, promote speciation?
Formation of a new mountain, available but different food supply, formation of a new river tributary

3. All living organisms obey the Biological Species Concept.
False

4. Historically, extinction occurred at a steady, consistent rate until the current time (human-driven extinctions).
False

5. All living organisms are classified into 3 domain(s) and 6 kingdom(s)

3 Plant Form Function

3.1 Introduction to Plants

- Major plant groups
    - Bryophytes
        - No vascular tissues – unable to move water around within them
        - Need moist environment
        - Reproduce by spores
    - Seedless vascular plants
        - Have vascular tissues – xylem and phloem
        - Leaves, stems, and roots
        - Reproduce by spores
    - Gymnosperms (non-flowering plants)
        - Complex vascular systems
        - Cones – reproductive structure
        - “naked” seed – seed not enclosed within fruits
    - Angiosperms (flowering plants)
        - Complex vascular system
        - Flowers – reproductive structure
        - Seeds enclosed within fruits
        - Monocots
            - 1 embryonic seed leaf (cotyledon) (e.g. corns)
            - Root xylem and phloem in a ring
            - Vascular bundles scattered in stem
            - Leaf veins form a parallel pattern
            - Flower parts in multiples of threes
        - Eudicots
            - 2 embryonic seed leaves (cotyledon) (e.g. peanuts)
            - Root phloem between arms of xylem, forming a star shape
            - Vascular bundles in a distinct ring in stem
            - Leaf veins form a net pattern
            - Flower parts in multiples of fours or fives
- Plant evolution
    - Common ancestor of land plants – similar to freshwater algae
    - Advantage of land
        - Increased levels of light and CO_2 for photosynthesis (food)
    - Disadvantage of land
        - Gravity – no more water to buoy to the surface for sunlight
            - Stem and leaves become rigid to receive optimal sunlight
        - threat of drying out – not in wet/moist environment anymore
        - reproduction - lost water as a medium to transport pollens/spores

3.2 Flowering Plant Anatomy (phytotomy)

- Internal anatomy
    - Cells specialized according to function
    - Cells, tissues, organs, and organ systems
- External anatomy
    - Plant organs – leaves, stems, roots, flowers, fruits, seeds

- Shoot and root system
- Plant tissues

Tissues	Function	Types
Ground tissues	Respiration, photosynthesis, storage, support	Parenchyma - Cell wall of equal thickness - Thin cell walls Collenchyma - Uneven cell walls - Stretches as the plant grows Schlerenchyma - Dead at maturity - Cell walls contain lignin (hard) - Provides rigid support
Dermal tissues	Protection, gas exchange	Epidermal cells - Flat, transparent, tightly packed Cuticle - Waxy waterproof coating - Prevents water loss - Impermeable to CO_2 and O_2 Specialized cells - Guard cells and trichomes in leaves - Root hairs in roots o Helps with diffusion of water
Vascular tissues	Transporting materials	Xylem - Transport water and dissolved minerals - Schlerenchyma cells with perforations (tiny holes) for easy movement of materials o Tracheid – thin and tapered o Vessel element – large diameter Phloem - Transport dissolved organic compounds (sugars and starch) - Sieve tube element o Stacked end to end o Move materials up/down through sieve plates - Companion cells o Transfer materials in and out of sieve tube elements

- Plant organs

<table>
<tr><th>Parts</th><th>Anatomy</th><th>Description</th></tr>
<tr><td rowspan="2">Leaves</td><td>External</td><td>- For photosynthesis and gas exchange
- Blade – flattened portion
- Petiole – stalk-like structure that attaches to stem</td></tr>
<tr><td>Internal</td><td>- Epidermis – dermal tissue covering the outside
- Mesophyll – parenchyma cells with abundant chloroplast
- Vascular tissue – xylem and phloem seen as ‘veins’
o Eudicots – network patten
o Monocots – parallel pattern</td></tr>
<tr><td rowspan="2">Stem</td><td>External</td><td>- For support – elongation and growth
- Terminal bud – growth at stem tips
- Node – point at which leaves attach
- Axillary bud – other buds found at the nodes
- Internode – the stem between nodes</td></tr>
<tr><td>Internal</td><td>- Young stem
o Primary xylem and phloem
o Ground tissue
o Epidermis
o Monocots and eudicots have different arrangements of vascular and ground tissues
- Old eudicot stem
o Secondary woody tissues provide support</td></tr>
<tr><td rowspan="2">Root</td><td>External</td><td>- To anchor and absorption of water and nutrients
- Taproot system
o Eudicots
o One large central root with few other small branches
- Fibrous root system
o Monocots
o Many branches of slender and shallow roots</td></tr>
<tr><td>Internal</td><td>- Central vascular cylinder and surrounding ground tissue
- Root hairs
o Extension of epidermal cells
o Increased surface area for increased absorption
- Endodermis
o Ensures all absorbed material passes through cells
o Helps regulate flow of water in and out of plant
- Monocots and eudicots have different arrangements of vascular and ground tissues</td></tr>
</table>

- Modified plant organs

Organ	Name	Description
Stem	Stolon	- Aboveground stems - Asexually forming new plants at nodes
	Rhizome	- Horizontal underground stems - E.g. ginger
	Tubers	- Swollen underground stems for storage - E.g. yam
	Thorns	- Modified branches for protection
	Phylloclade	- Green stem that can photosynthesis
Leaves	Bulbs	- Enlarged leaves for storage
	Spines	- Defence and water conservation - Reduced surface area to hold onto water
	Bracts	- Colourful leaves surrounding flowers
	Carnivorous plant leaves	- Attract, capture and digest prey - E.g. pitcher plants, venus fly traps

3.3 Flowering Plant Functions

- Photosynthesis
  - Make glucose from carbon dioxide using water and sunlight in chloroplast, releasing oxygen
  - Light dependent stage
    - Occur in thylakoid membranes in chloroplast
    - Make ATP (stores energy) and NADPH (carries electrons)
  - Light independent stage
    - Occurs in stroma in chloroplast
    - ATP and NADPH used to reduce CO2 to glucose (carbon fixation or Calvin cycle)
  - Guard cells regulate the stomata openings in response to need for water
    - Open when water evaporates from the leaves (transpiration)
      - Capillary action pulls water up to stomata
    - Close when plant needs to conserve water
- Growth
  - Occurs at meristems – regions of active cell division (mitosis)
  - Primary growth (vertical growth)
    - Occurs at apical meristems
  - Secondary growth (horizontal growth)
    - Occurs at lateral meristems
  - Apical meristem
    - New cells become primary tissues at tips of stems and roots
  - Lateral meristem
    - Found in woody eudicots
    - New cells replace primary tissues as plant grows larger
    - Vascular cambium – produces secondary xylem and phloem
    - Cork cambium – produces parenchyma and cork (waxy cells)

- Secondary tissues
  - Wood – core of secondary xylem
  - Bark – produced by cork cambium
- Reproduction
  - Parts of a flower
    - Sepals
    - Petals
    - Stamens
      - Male reproductive parts
      - Anther and filament
    - Carpels
      - Female reproductive parts
      - Stigma, style and ovary
  - Pollination
    - Process of fertilization
    - Pollination by wind or animals (pollinators)
    - Pollen tube extends down style when pollen lands on stigma
    - Nucleus in pollen divides to produce sperm
    - Double fertilization produces zygote and endosperm
    - Zygote – plant embryo
    - Endosperm – stored food
    - Ovary wall or other floral parts – fruit flesh or skin
    - Fruits help disperse seeds through wind, water or animals
  - Seeds consist of
    - Dormant plant embryo
    - Endosperm
    - Seed coat
  - Monocots and eudicots have different development patterns

3.4 Video – Photosynthesis

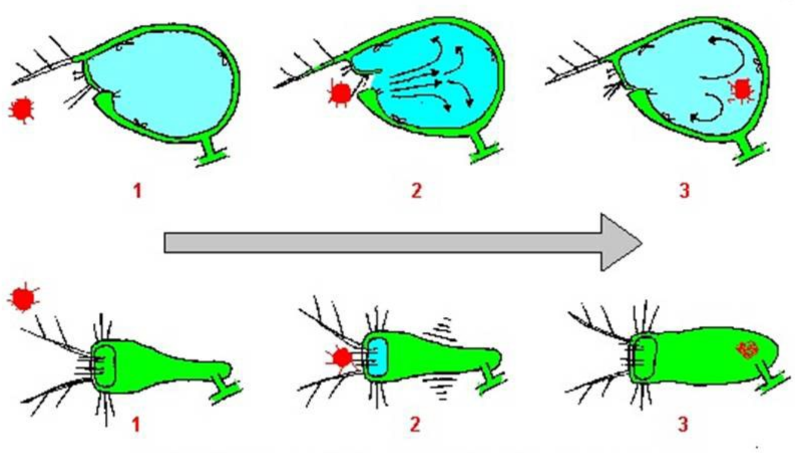
refer to CA1 – Energy of life

3.5 Video – transport in plants

- Absorbing water and minerals through the roots
  - Apoplastic pathway
    - Water and minerals move into the plant through spaces in between the cell walls
  - Symplastic pathway
    - Water and mineral move across the cytoplasm and finally reach the xylem
- ~95% of water absorbed is lost through transpiration, through the stomata on leaves
- More stomata on the underside of the leaves – away from the sun
- Stomata opening and closing guarded by guard cells
  - Opening – water and potassium ions enter guard cells, increasing turgidity and hence opens the stomata
  - Closing – water and potassium ions leave guard cells, reducing turgidity and hence closes the stomata

3.6 Video – evolution of carnivorous plants

- What constitutes a carnivorous plant
  - It can take nutrients from dead prey
  - Have at least one adaption that actively lures in or captures its prey
- Types of carnivorous plants/traps
  - Passive
    - Pitfall traps
      - pitcher plants
    - Flypaper traps
      - Sticky residue to trap prey
    - Eel-traps/lobster-pot traps
  - Active
    - Flypaper traps
      - Sticky residue that traps prey
      - Moves to capture its prey
    - Snap traps
      - Venus fly traps
    - Bladder-suction traps
      - Contains a vacuum that sucks the prey when triggered



Bladderwort Prey Trapping Sequence

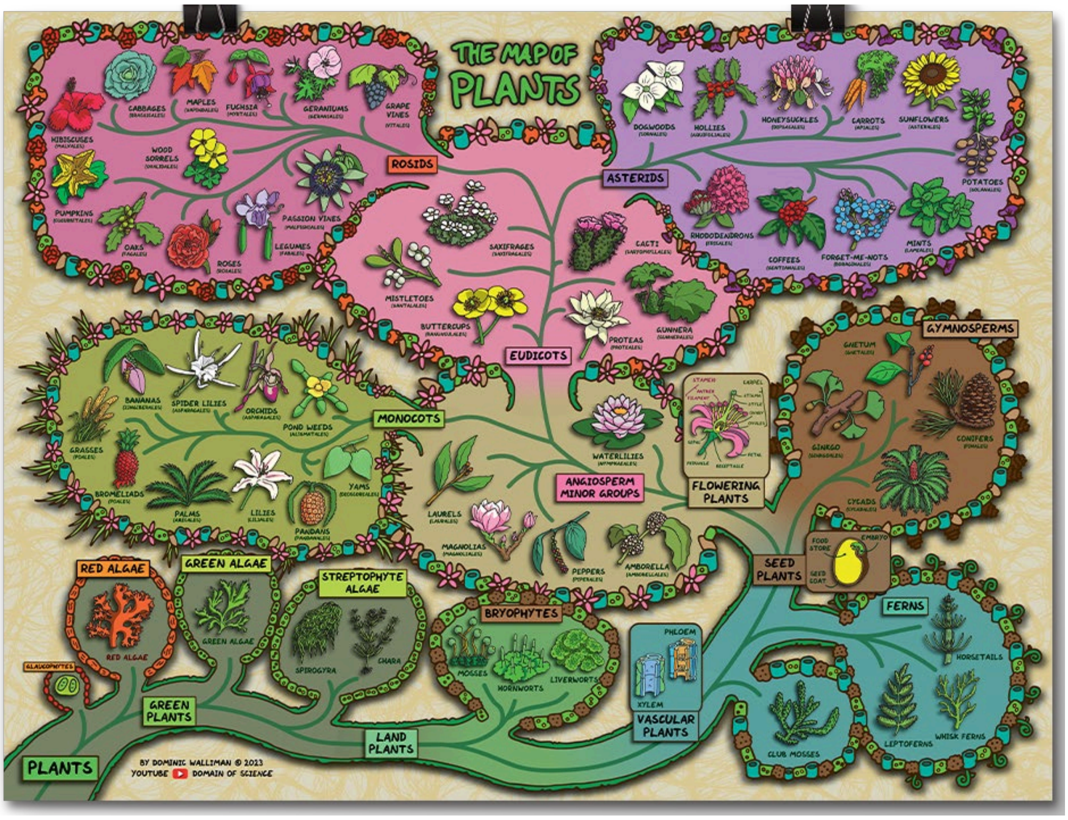
- Evolved independently at least 9 times in plants
  - Botany carnivory - example of convergent evolution where organisms that are not closely related develop similar adaptations independently in response to similar environmental pressures
- Reasons
  - Plants need sunlight, water and nutrients to survive
  - Some species grow in moist but nutrient-poor conditions – they do not get enough nitrogen and phosphorus
  - Become carnivorous to get the necessary nutrients from animals

3.7 Video – pitcher plants

- Tip of the midrib (central vein of a leave that runs from base to tip) of the leave continues to grow, eventually inflate to form the pitcher
- Lid opens when the pitcher matures

- Attract their prey with nectar
- Slippery internals
- Contain juices that active dissolve

3.8 Video – surprising map of plants



3.9 Practice questions

1. Which of the following you would expect to have when examining the end of an onion root under the microscope?
   <u>Apical meristem</u>
   <u>Epidermal hairs</u>
   <u>Vascular tissue</u>
   <u>Ground tissue</u>

2. Which of the following plants use seeds to reproduce?
   <u>Maize</u>
   <u>Sunflower</u>

3. Leaves are the only sites of photosynthesis.
   <u>False</u>

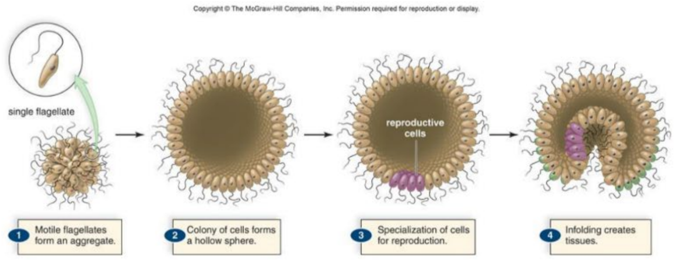
4. The trapping structure on the Venus flytrap is a modification of the ________
   <u>Leaves</u>

4 Animal Form Function

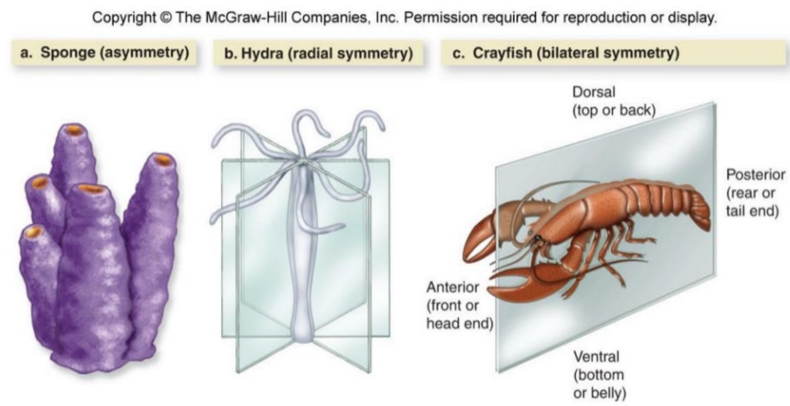
4.1 Introduction to animals

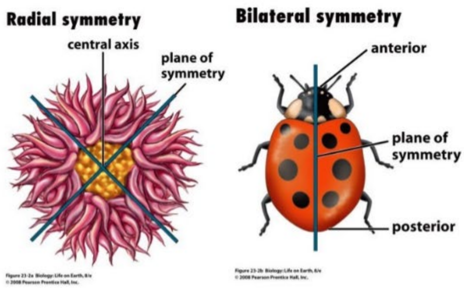
- Key features
    - Multicellular eukaryotes
    - Cells w/o cell walls
    - Heterotrophs: ingest food and digest internally
    - Generally mobile, able to respond rapidly to stimuli
        - Immobile: corals, barnacles
    - Most reproduce sexually
- Animal evolution
    - Descended from a flagellated protist (likely)
        - Evolution of multicellularity through colonial flagellate hypothesis: infolding of cells into the center of the spherical colonies formed tissue layers

Choanoflagellates are protists most closely related to animals



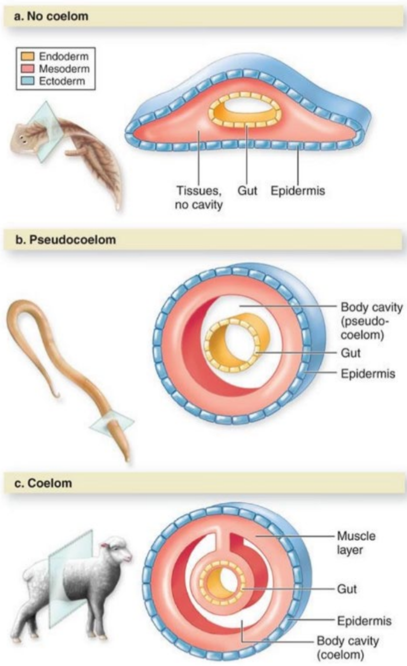
-
    - Different animal groups characterised by:
        - Number of tissue layers
            - Tissue: group of cells that specialise (interact and perform specific functions)
            - Simplest animals do not have true specialised tissues
            - Diploblastic have 2 layers of tissues (endoderm, ectoderm) but no specialised organs (sponges, coelenterates: jellyfish, corals sea anemones)
            - Triploblastic animals have 3 embryonic tissue layers
                - Endoderm: skin and nervous system
                - Ectoderm: digestive tract and derived organs
                - Mesoderm (allows the development of true organs): muscles, reproductive system
        - Body symmetry (external)
            - Asymmetrical: no symmetry=no pattern to body plan
            - Radical symmetry:
                - Several planes divide into mirror images
                - Allows organism to extend in all directions from one central point
            - Bilateral symmetry: has head
                - Only 1 plane produces mirror image
                - Accompanied by cephalisation



- 

Animals with radial symmetry lack a well-defined head. Any plane that passes through the central axis divides the body into mirror-image halves.

Animals with bilateral symmetry have an anterior head end and a posterior tail end. The body can be split into two mirror-image halves only along a particular plane that runs down the midline.

▪ Presence of body cavity
  - Coelom: fluid-filled cavity completely within the mesoderm that provides organs with flexibility and absorbs shock
  - A bilaterally symmetrical animal may be:
    - Acoelomate: no body cavity
    - Pseudocoelomate: body cavity lined partly by mesoderm and endoderm
    - Coelomate: completely lined by mesoderm
  - 

▪ Presence of segmentation

            - Division of animal body into repeated sections, externally or internally
            - Adds flexibility and potential for specialisation
                - Segments may be fused and modified for special functions
        - Developmental paths
- Animal anatomy and physiology
    - Anatomy: study of an organism's structure > parts that compose it and their location in the body
    - Physiology: describes how those parts work
    - Organisational hierarchy in the body
        - Cells: basic building blocks of the body
        - Tissues: cells that interact and provide specific functions
        - Organs: 2 or more interacting tissues
        - Organ systems: 2 or more organs joined physically or functionally
    - Animal tissue:
        - Epithelial tissue:
            - Cover body's internal and external surfaces with 1 or more layers of tightly packed cells
            - One surface exposed either to outside to a space within the body
            - Opposite surface anchored to other tissues by a basement membrane
            - Functions: protection, nutrient absorption, gas diffusion, secretion
            - Example: forms glands that secrete substances such as milk or sweat
            - Types of tissue based on combination
                - Shape
                    - Squamous
                    - Cuboidal
                    - Columnar
                - Layers
                    - Simple
                    - Stratified
                    - Pseudostratified
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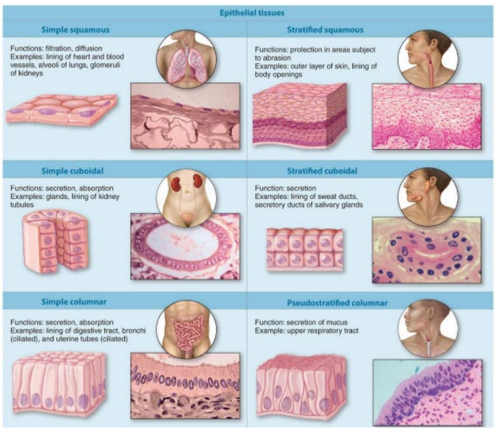
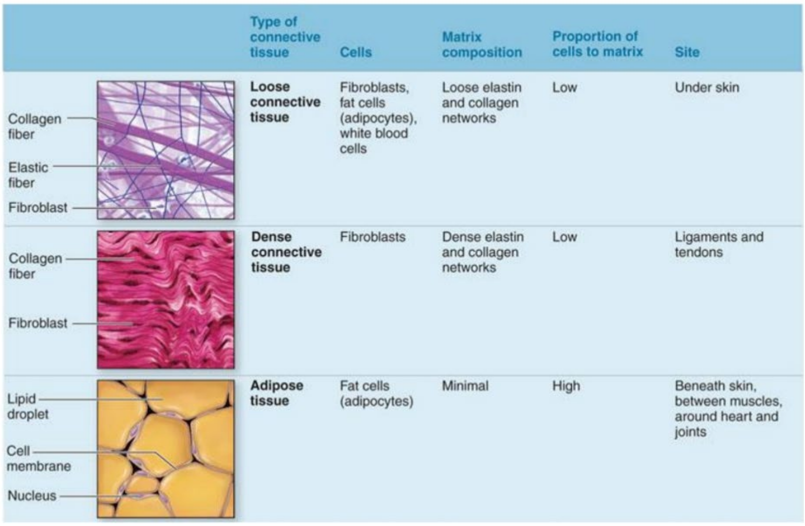
                - 

- Connective tissues
  - Most variable tissue type
  - Cells embedded in extracellular matrix of non-living substances
    - Ground substance:
      - Solid > bone
      - Liquid > blood
      - Semisolid > cartilage
    - Protein fibers: collagen and elastin
    - Fibroblasts: most common cells that secrete materials in the extracellular matrix
  - Functions: fill spaces, attach epithelium to other tissues, protect and cushion organs, provide mechanical support
  - Types of connective tissues



Type of connective tissue	Cells	Matrix composition	Proportion of cells to matrix	Site
Loose connective tissue	Fibroblasts, fat cells (adipocytes), white blood cells	Loose elastin and collagen networks	Low	Under skin
Dense connective tissue	Fibroblasts	Dense elastin and collagen networks	Low	Ligaments and tendons
Adipose tissue	Fat cells (adipocytes)	Minimal	High	Beneath skin, between muscles, around heart and joints

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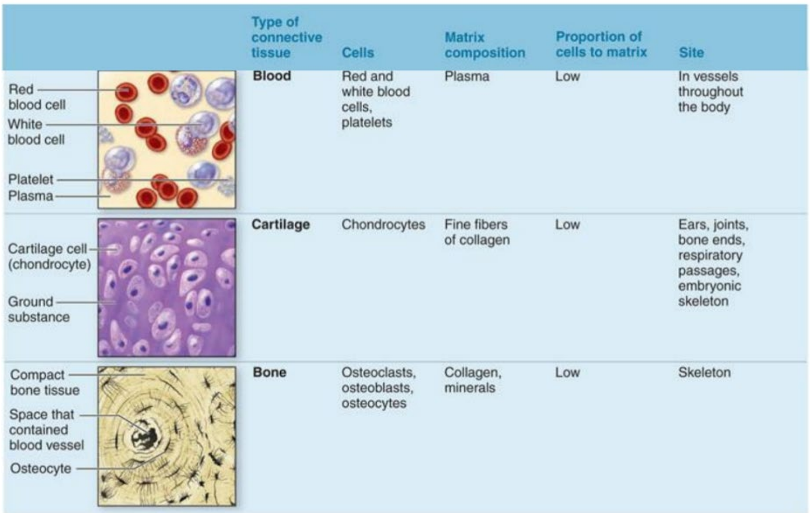
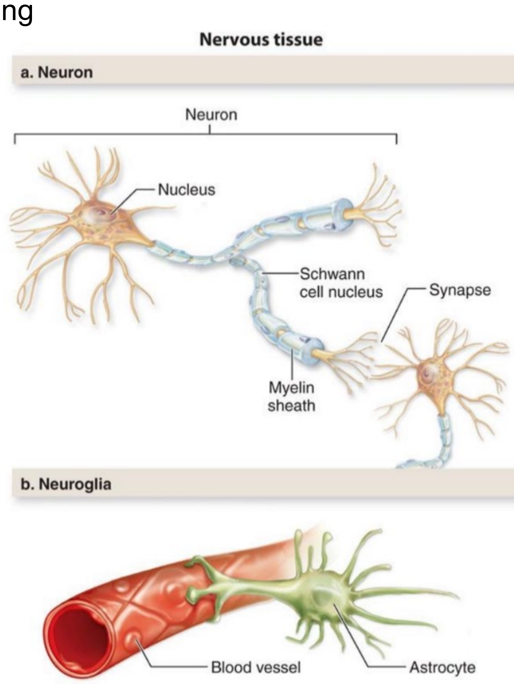


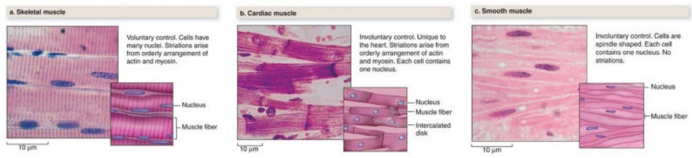
Type of connective tissue	Cells	Matrix composition	Proportion of cells to matrix	Site
Blood	Red and white blood cells, platelets	Plasma	Low	In vessels throughout the body
Cartilage	Chondrocytes	Fine fibers of collagen	Low	Ears, joints, bone ends, respiratory passages, embryonic skeleton
Bone	Osteoclasts, osteoblasts, osteocytes	Collagen, minerals	Low	Skeleton

- Nervous tissue
  - Transmit information rapidly within an animal's body by electrical and chemical signals
  - 2 cell types
    - Neurons: form communication networks that receive, process, and transmit information

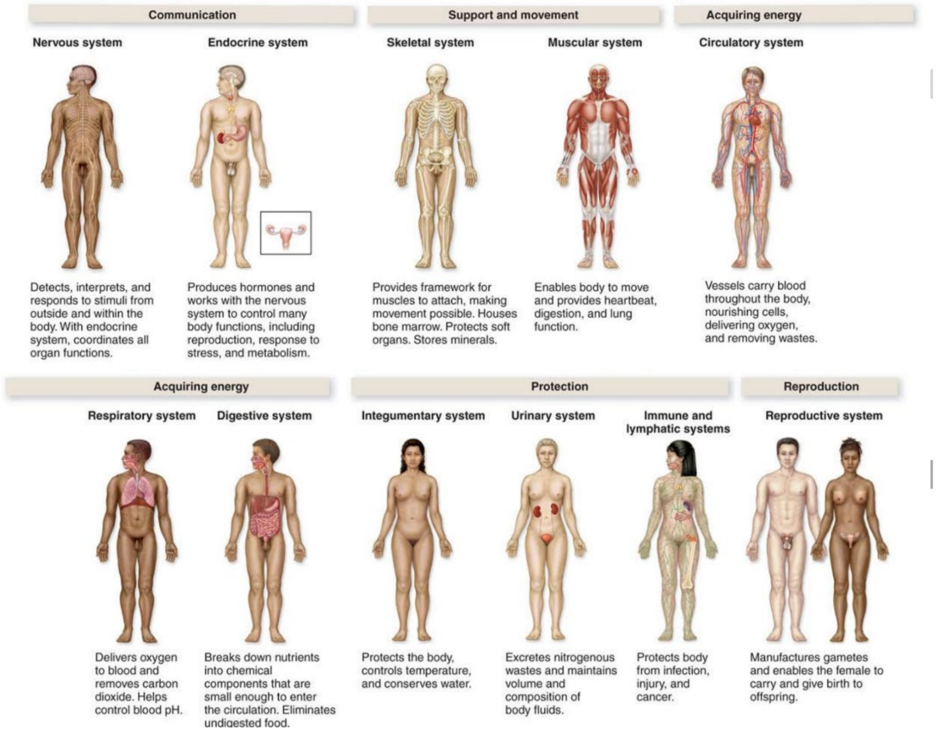
- Neuroglia: support cells that assist neurons in functioning

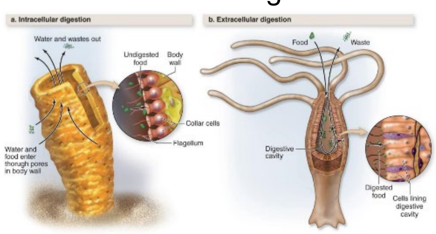


- Muscle tissue
  - Cells with abundant mitochondria that contract when protein filaments slide past one another
  - 3 types
    - Skeletal: striated, attaches to bone, voluntary control
    - Cardiac: striated, only in heart, involuntary control
    - Smooth: not striated, involuntary control



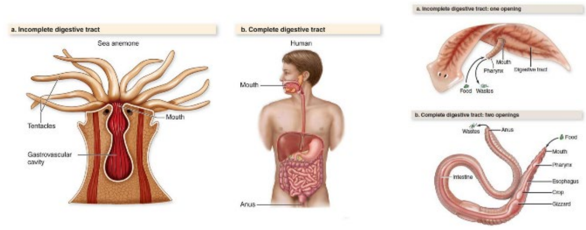
- Organ systems by function
  - Acquiring energy
    - Digestive system
    - Circulatory system
    - Respiratory system
  - Protection
    - Integumentary system
    - Urinary system
    - Immune system
    - Lymphatic system
  - Communication
    - Nervous system
    - Endocrine system
  - Support and movement
    - Skeletal system
    - Muscle system

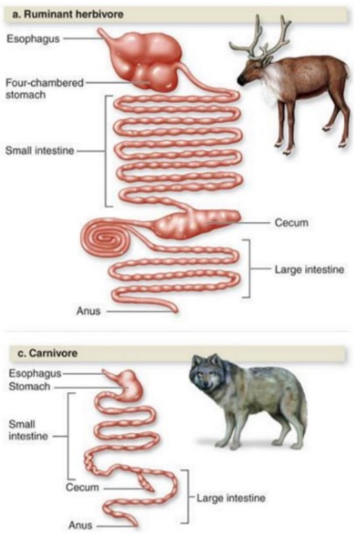
- Reproduction
    - Reproductive system
- 

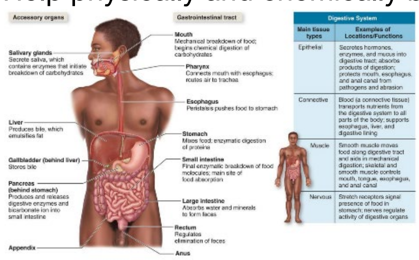
- Digestive system
    - Animals are heterotrophs, need to consume food to obtain carbon and energy
    - Different animal digestive tracts > different diet
    - 4-step process of obtaining and using food
        - Ingestion: assimilation of food into the digestive tract
        - Digestion: physical and chemical breakdown of food
        - Absorption: nutrient cross cels lining the digestive system and enter the blood
        - Elimination: undigested food egested
    - Intracellular digestion
        - No special compartment for digestion: particles captured by collar cells which utilise intracellular digestion (sponges)
    - Extracellular digestion
        - Most animals use this within a digestive tract
        - 

    - Types of digestive tracts:
        - Incomplete digestive tracts: 1 opening for ingestion and elimination

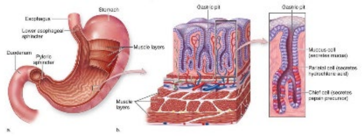
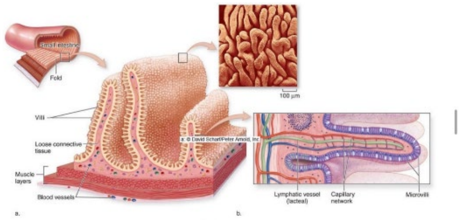
- Complete digestive tracts: 2 openings (mouth and anus

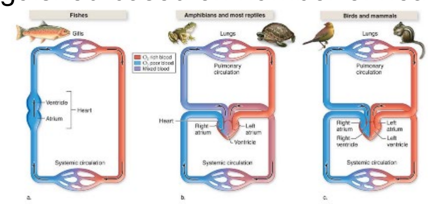
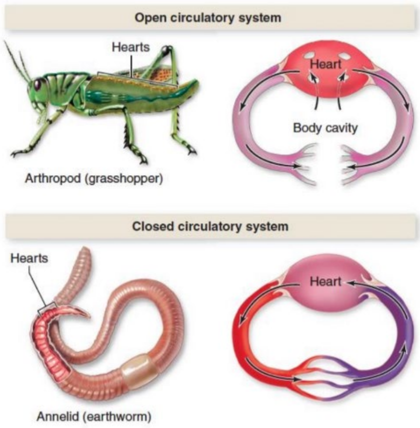


- Structure depends on diet
    - Herbivorous have longer digestive tracts
        - Hard-to-digest cellulose needs more time to digest
        - Specialised organs: stomach has 4 chambers
    - Carnivorous have short intestines and small or absent cecum
    - 

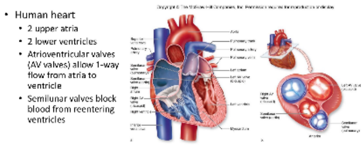
- Human
    - Complete digestive tract
        - 2 openings
        - 1 way travel
    - Extracellular digestion
        - Secrete hydrolytic enzymes to digest food
        - Food remains outside body cells until absorbed
    - Accessory structures
        - Salivary glands, teeth, tongue, pancreas, liver, gall bladder
        - Help physically and chemically break down food
    - 

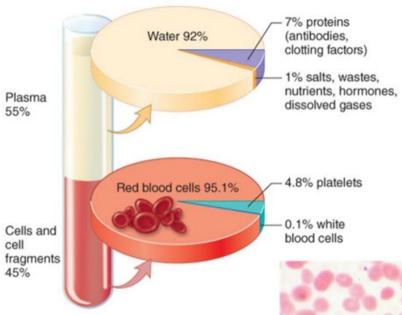
    - Stomach
        - Can expand to 3-4L

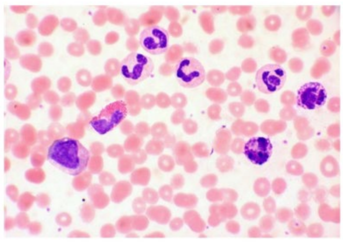
            - Mechanical and chemical digestion (hydrochloric acid and enzymes)
            - 
        - Small intestine
            - Completes digestion and absorbs nutrients
            - Villi increase surface area and has blood vessels
            - Receive enzymes from liver and pancreas
            - 
        - Large intestine
            - Receive indigestible components, absorb water and salts, eliminate feces
            - 500 different species of bacteria
            - Produce odours of feces and gas
- Circulatory system
    - Heart
        - Atria: collect blood
        - Ventricles: pump blood out
        - Valves: prevent backflow of blood
        - muscular septum: divides two sections of the heart
            - Left: oxygenated blood
            - Right: deoxygenated blood
        - Cardiac output: amount of blood pumped out of heart (L/min)
            - Male: 5.6L
            - Female: 4.9
            - Calculate: multiplying heart rate by stroke volume
    - Blood vessels (categorised according to histological structure)
        - Arteries: transport blood towards tissues and away from heart
            - Thick muscular walls and small internal lumina that can withstand blood under high pressure
        - Veins: transport blood away from tissues and towards heart
            - Thin walls
            - Larger internal lumen compared to arteries due to low pressure blood
            - Have valves that prevent blood from backflowing
        - Capillaries: exchange of gas, water, nutrients, waste products
            - Found in muscles and lungs
            - One cell layer thick endothelial lining (width: one single epithelial cell)
            - Can only tolerate low pressure as it moves slower to allow gas exchange

- Transport gases, nutrients, hormones to and from cells in the body via blood through a system of blood vessels
- Vertebrates > functions to fight diseases, stabilise temperature and carry nitrogenous waste to excretory system
- Contractions of the heart create pressure and continuous flow of blood through vessels
- Features
    - Cells require oxygen (aerobic respiration) to generate ATP
    - Works with respiratory system to acquire oxygen/eliminate CO_2
    - Respiratory surfaces are varied but
        - All must be moist for gas diffusion
        - All must have sufficient surface area
- Types
    - Open circulatory system
        - Has short, open-ended vessels
        - No distinction between blood and interstitial fluid
        - Combined fluid: hemolymph
    - Closed circulatory system
        - Blood remains in vessels
        - Distinguished based on number of heart chambers
        - 
        - Vertebrates, annelids and cephalopods
        - 

            - Vertebrates: 2 circulatory circuits
                - Pulmonary circuit: vessels lead to respiratory surfaces, blood exchanges gases with the environment
                - Systemic circuit: vessels lead to body tissues, blood exchanges gases and nutrients with tissues
            - Fish
                - 1 circuit

- 2 chambered heart: 1 atrium, 1 ventricle
    - Amphibians and most reptiles
        - 2 circuits, not completely separated
        - 3 chambered heart: 2 atria, 1 ventricle
        - Some mixing of oxygenate and deoxygenated blood
    - Crocs, birds, mammals
        - 2 circuits: systemic (to body), pulmonary (to lungs) completely separated
        - 4 chambered heart: 2 atria, 2 ventricles
        - Maximises amount of oxygen reaching tissues
    - Human
        - 

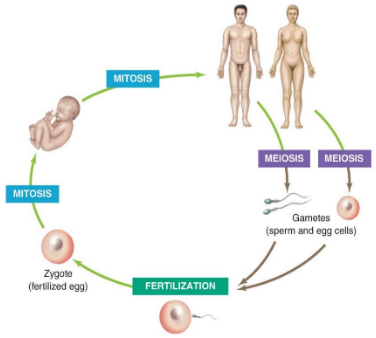
    - Diffusion occurs in smallest vessels: capillaries
  - Blood
    - Fluid of vertebrate circulatory system
    - Plasma is the medium of exchange of many substances in the body
    - Red blood cells have hemoglobin for oxygen transport
    - White blood cells fight infection (antibodies and bone marrow)
    - Platelets initiate clotting
    - 



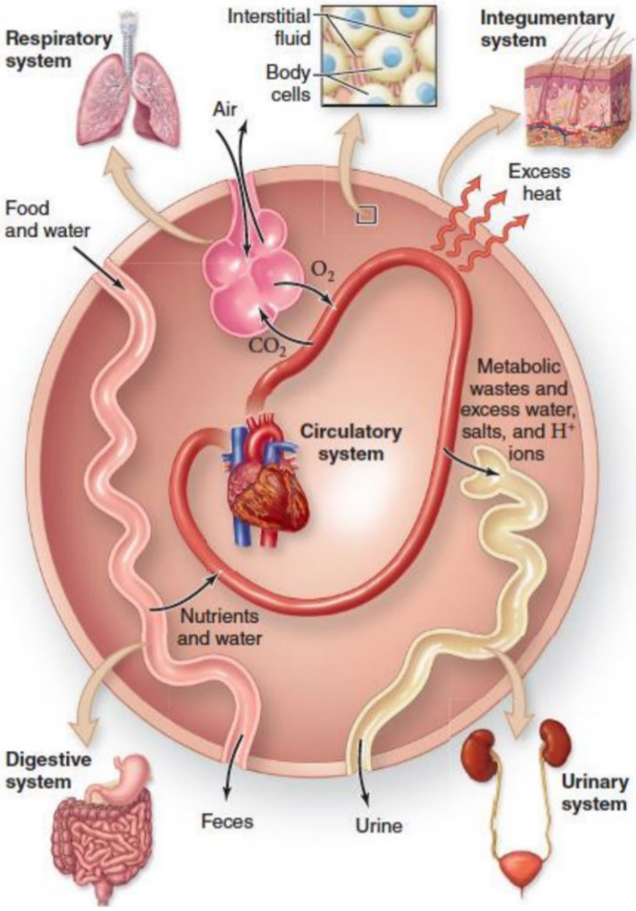
- Homeostasis: organ systems work together to maintain homeostasis
  - Maintain a stable internal environment in the face of external changes
  - Many systems in the body use negative feedback to maintain homeostasis
    - Example: body temperature, blood pressure, fluid composition in the body
  - Positive feedback to amplify
    - Example: breastfeeding, clotting
  - Detect a change from optimal internal conditions > respond by counteracting the change

- Animal reproduction
    - Reproduce sexually and asexually
    - Complex behaviours
        - Courtship
            - Species identification
            - Stimulation of hormonal changes in participants
            - Mate quality assessments

        - The gonads of sexually reproducing individuals produce haploid gametes by meiosis
            - Human male and female gametogenesis occur at different life stages
        - Gametes unite at fertilization, forming a diploid zygote



    - Embryogenesis
        - Zygote divides soon after fertilisation is complete
        - Cells differentiate/acquire specialised functions
        - Genes determine overall shape and structure of animal’s body
    - Parental care
        - Monogamous species: male and female both provide care
        - Polygamous mating systems: males do not care for young (dk which young are theirs)
- Animal development
    - Indirect: immature stage looks different from adult
    - Direct: immature stage looks like small adult



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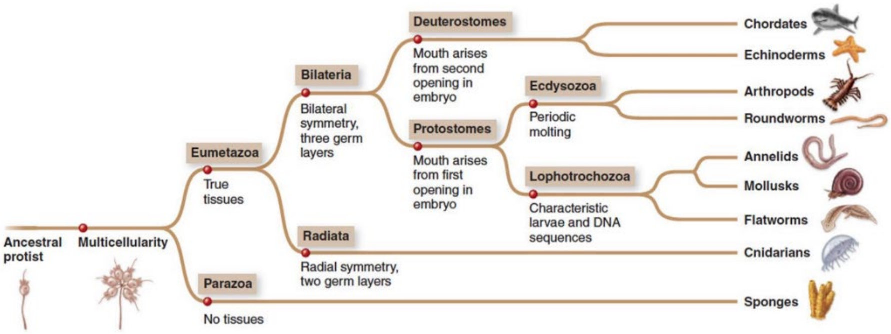
- Major animal groups
-



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animals	habitat	Body symmetry	features	mobility	Food and digestive system
sponges	aquatic	Asymmetrical/radial symmetrical	- Simple: no tissues/organs - Stiffened by mineral spines	Adults are sessile (fixed in one place)	Filter feeders: depend on water flow, cells digest food intracellular
Cnidarians (jellies, corals,	aquatic	Radially symmetric	- two tissue layers enclose noncellular jelly substance	Adults: - polyp: sessile with tentacles	- Predators: stinging cnidocytes help catch prey

anemones)				- medusa: free swimming	- incomplete digestive tract with tentacles around the mouth
Mollusks (snails, clams, squid)	Aquatic, terrestrial	Bilaterally symmetrical and asymmetrical	- soft, unsegmented - hydrostatic skeleton, supporting ext/int shell secreted by mantle tissue	Muscular foot provides movement	- Filter-feeders, herbivores, predators - complete digestive tract, coelom
Annelids (earthworms, leeches)	Terrestrial, aquatic	Bilateral symmetry	- have repeated body segments - closed circulatory system, simple nervous and excretory system		- Detritivores (feed on dead, decaying organic materials), bloodsuckers, filter-feeders, predators - complete digestive tract, coelom
Arthropods (insects, spiders, crabs, prawns)	Terrestrial, freshwater, marine	Bilateral symmetry	- segmented body plan: major body regions (head, thorax, abdomen), jointed appendages - exoskeleton of chitin and protein: must molt to grow - open circulatory system, extensive respiratory system of tubes open to outside - Simple brain, well developed nerves		- complete digestive tract, coelom
Echinodermata	marine	Five-part radial	- water vascular		- predators, detritivores

(starfish, sea cucumbers, sea urchins)		symmetry with bilaterally symmetrical larvae	system with tube feet act as gills, sense organs, perform circulatory and excretory functions		- complete digestive tract
Chordates (lancelets, tunicates, hagfish, vertebrates), vertebrates share this clade with some invertebrates			4 features at some point of developments - notochord - Dorsal, hollow nerve cord - pharyngeal pouches or slits - postanal tail		

- Vertebrate characteristics

Feature	Advantage
Internal skeleton	Support, movement, protect internal organs
Jaws	Efficiency in capturing prey
Four limbs with skeleton	Promote locomotion
Lungs	Exchange of gases with air instead of water
Amniotic egg and internal fertilization	Reproduction away from water
Body coverings	Better insulation

-

4.2 How do caterpillars acquire chubby legs

- Caterpillars use their prolegs to grab on to twigs and leaves, while using their thoracic or 'true' legs to hold on to other plant parts for feeding.
- Three theories:
    - modified thoracic legs
    - completely novel traits
    - modified lobes (endites) of primitive thoracic legs
- Our study proposes that prolegs are indeed novel traits unrelated to thoracic legs. However, they are derived from a genetic program that specifies lobes that were originally found in the proximal region of crustacean limbs, but had remained inactive in this limb region for millions of years.

4.3 Practice questions

2. Which of the following feature(s) is/are shared by annelids and molluscs?
   True coelom, three tissue layers, bilateral symmetry
   Incorrect: segmentation, radial symmetry

3. Which of the following is/are primary characteristic(s) of epithelial tissue in animals?
   One free surface, little extracellular material, lines all internal surfaces of body
   Incorrect: loosely packed cells, provide mechanical support to internal organs

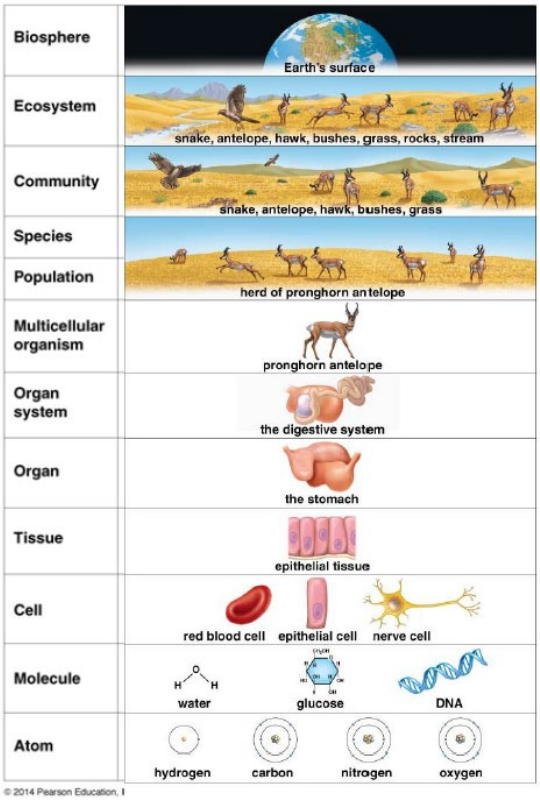
4. If red blood cells are without a nucleus, that means they also do not possess DNA.
   True

5. Cnidarians are the only animals with radial symmetry.
   False

6. What is an organ system?
   Two or more organs that are joined functionally

5 Ecology

5.1 Introduction

- What is ecology
  - Study of relationships between living things and their environment
  - Where are they found, and why
  - Study of how human impact the relationship between living things and their environment
- Ecological hierarchy
  - Individuals > populations > communities > ecosystems > biosphere
  - 

- Environmental heterogeneity
  - Earth is round and axis is tilted
  - Different parts of the earth will have unequal amounts of resources – sunlight, waterfall, nutrients
  - Areas near equator will receive more sunlight throughout the year
  - Amount of solar energy changes seasonally due to the earth orbiting the sun
- Biomes
  - Regions of the earth with similar environmental conditions
  - Plants and animals in that biome are adapted to that environment

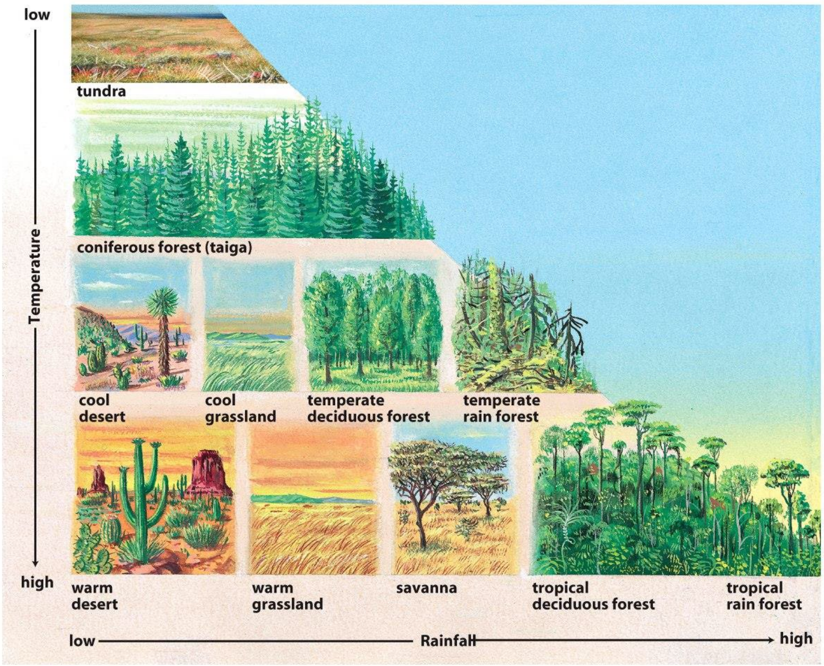
- 

Figure 29-8 Biology: Life on Earth, 8/e

- Reclamation of land on shallow shores
  - Destructive to the biome there
  - E.g. mangroves, corals

Biome Summary Chart

Biome	Location	Climate	Soil	Plants	Animals
Desert	midlatitudes	generally very hot days, cool nights; precipitation less than 10 inches a year	poor in animal and plant decay products but often rich in minerals	none to cacti, yuccas, bunch grasses, shrubs, and a few trees	rodents, snakes, lizards, tortoises, insects, and some birds. The Sahara in Africa is home to camels, gazelles, antelopes, small foxes, snakes, lizards, and gerbils
Tundra	high northern latitudes	very cold, harsh, and long winters; short and cool summers; 10-25 centimeters (4-10 inches) of precipitation a year	nutrient-poor, permafrost layer a few inches down	grasses, wildflowers, mosses, small shrubs	musk oxen, migrating caribuou, arctic foxes, weasels, snowshoe hares, owls, hawks, various rodents, occasional polar bears
Grassland	midlatitudes, interiors of continents	cool in winter, hot in summer; 25-75 centimeters of precipitation a year	rich topsoil	mostly grasses and small shrubs, some trees near sources of water	american grasslands include prairie dogs, foxes, small mammals, snakes, insects, varous birds. African grasslands includeelephants, lions, zebras, giraffes.
Deciduous Forest	midlatitudes	relatively mild summers and cold winters, 76-127 centimeters (30-50 inches) of precipitation a year	rich topsoil over clay	hardwoods such as oaks, beeches, hickories, maples	wolves, deer, bears, and a wide variety of small mammals, birds, amphibians, reptiles, and insects.
Taiga	mid- to high latitudes	very cold winters, cool summers,; about 50 centimeters (20 inches) of precipitation a year	acidic, mineral-poor, decayed pine and spruce needles on surface	mostly spruce, fir, and other evergreens	rodents, snowshoe hares, lynx, sables, ermine, caribout, bears, wolves, birds in summer
Tropical Rainforest	near the equator	hot all year round, 200-400 centuimeters (80-100 inches) of rain a year	nutrient-poor	greatest diversity of any biome; vines, orchids, ferns, and a wide variety of trees	more species of insects, reptiles, and amphibians than anyplace else; monkeys, other small and large mammals, including in some places elephants, all sorts of colorful birds

-

5.2 Ecology of Individuals

- Organisms have features and structures adapted to their native environment
- May not do well if shifted to another environment
- Environmental factors affecting organisms

Abiotic (non-living)	Biotic (living)
Light intensity Precipitation Temperature Humidity pH salinity	Food plants Prey Competitors Predators Parasites Mutualists

- Temperature regulation

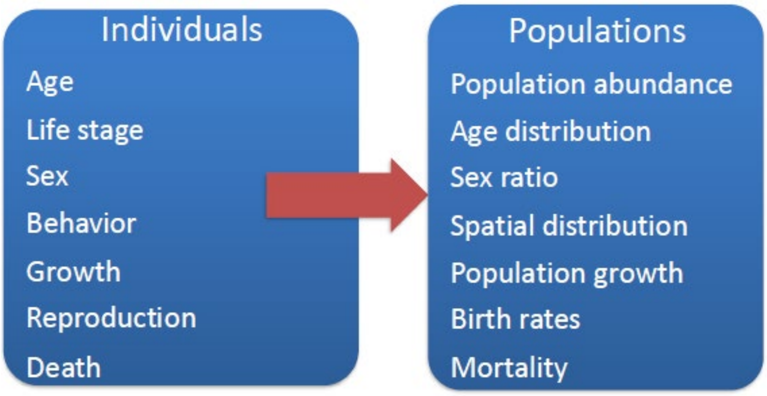
Regulation	Description
Ectotherms (cold-blooded)	- Acquire heat from external sources - Variable body temperature - Active only when warm enough - Low metabolic rate, don't need to eat often - Poor oxygen supply, restricted to short bursts of activity - Poorly insulated, limited optimal range of temperatures
Endotherms (warm-blooded)	- Acquire heat from internal sources - Constant body temperature through metabolic heat - High metabolic rate, need to eat more - Insulated, can survive at wider temperature ranges

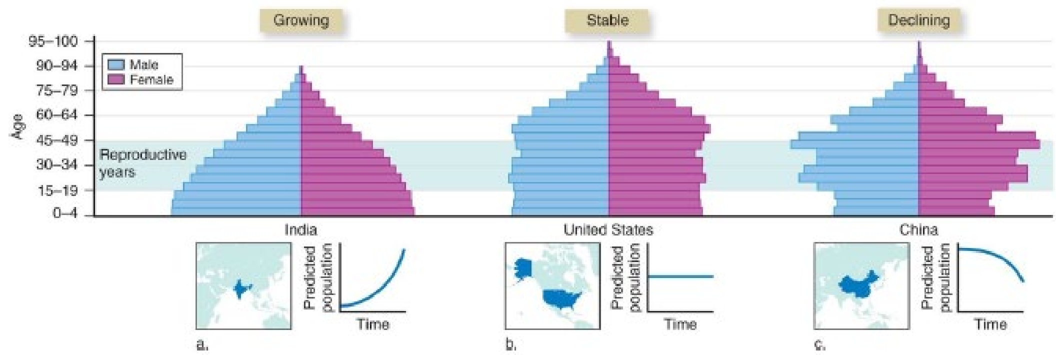
- Life history strategies
    - Reproduction takes up a lot of energy (high energy investment)
    - Need to balance reproduction with other requirements

Life history	Description
Opportunistic (r-selected)	- Quantity - maximizes number of offsprings - Short-lived adults - Reproduce at early age with many offsprings - Receive little parental care - Inhabit unstable/unpredictable environments - Resources are not limiting
Equilibrium (K-selected)	- Quality – focuses on offspring quality - Long-lived adults - Reproduce later in life with few offsprings - Receive extended parental care - In stable environments with high competition

    - Most organisms have characteristics from both life history strategies

5.3 Population Ecology

- Population – group of individuals of the same species inhabiting a given area with potential to interbred
- Population properties – derived from characteristics of individual organisms
    - 

- Population growth
    - Influenced by fecundity rates (no of births), immigration, mortality rates (no of deaths) and emigration
    - 

    - Potential to increase exponentially provided sufficient resources
    - Will not happen in natural environments due to
        - Density-dependent factors
            - Competition for resources
                - May lead to increased mortality rate due to some not getting enough resources for survival
            - Stress of crowded conditions reduces birth rates due to lack of resources
            - Diseases spreads faster in larger population
        - Density-independent factors
            - Natural hazards etc

5.4 Community and Ecosystem Ecology

- Community
    - Group of interacting populations in the same place
    - Coevolution – mutual evolutionary influence between 2 interdependent species
        - E.g. some species of orchids morph their flowers to look like the females of pollinators

  - Ecological niches – resources where a species exploits/relies on for its survival, growth, and reproduction
    - “way of life”
- Species interactions

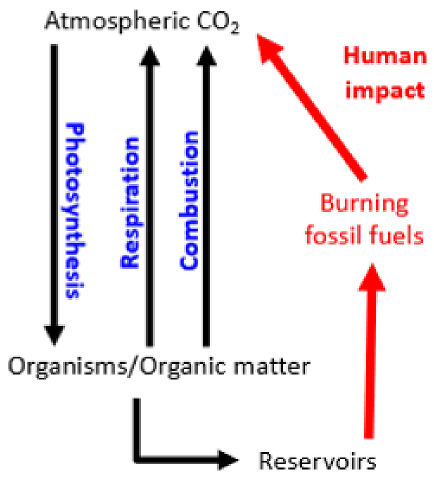
Interactions	Description

Competition	- Competition for limited resources
	- Usually results in both parties paying a hefty price
	- Competitive exclusion principle
	  ○ Two species with the same niche cannot coexist as they compete for the same resources
	- Partitioning – multiple species using the same resource in different ways or different time
	  ○ Spatial partitioning – split resource into different parts
	  ○ Temporal partitioning – use the same resource at different time
	  ○ Resource partitioning – use of different resources in same habitat

Predator-prey	- Predation exerts strong selective pressure on prey to avoid being eaten
	  ○ Camouflage (physical mimicry)
	  ○ Warning colours
	  ○ Weapons and structural defences
	  ○ Behavioural mimicry (e.g. mimic octopus)
	- Predators will have to defeat these defences

Herbivory	- Herbivores eat parts of the plant but don’t kill the plant
Parasitism	- Parasites consume part of the host but don’t kill the host - Harmful to the host - Internally or externally located - Usually attacks 1 or a selected set of species
Commensalism	- Dependent relationship where one benefits where the other is not affected (not benefitting or losing)
Mutualism	- Beneficial to both species - Leads to coevolution - E.g. corals and zooxanthellae, anemone and clown fishes

- Energy flow
  - Food chains show the transfer of energy and nutrients between organisms
  - Food web shows several interconnected food chains
  - Ecosystems that receive more energy can support higher diversity and biomass of organisms
  - Transfer of energy is never 100%
    - Only about 10% of the energy is transferred from 1 chain to the other
- Biogeochemical cycles
  - The earth is a closed system with no new supply of materials
  - Cycling and recycling of materials within ecosystems are through
    - Water, carbon, nitrogen and phosphorus cycles
  - Healthy ecosystems – self-regulating and self-maintaining

- Cycle matters internally
  - Intact biodiversity is key to healthy ecosystems
  - 

5.5 Video – Mimic octopus

- Mimic octopus changing colour, shape, and behaviour in response to different predators
- Able to mimic different animals
  - Lionfish (known poisonous)
  - Sea snakes (known poisonous)
  - etc

5.6 Video – Cordyceps

- Cordyceps infiltrate the bodies and minds of ants
- Forces ants upwards and grip onto stems with their mandibles (lower part of the jaw)
- Fruiting body erupts from the ant's head
- Bursts when matured, in about 3 weeks, dispersing spores
- Infected ants are discarded far away from the ant colony if discovered
- Different types of cordyceps fungi attack different species of insects

5.7 Practice questions

1. If you were studying the niche of a species of fish, what would you study
   <u>The food it eats</u>
   <u>The temperature it needs to survive</u>
   <u>The place where it nests</u>

2. What are the two environmental drivers that govern the formation of different biomes?
   <u>Temperature</u>
   <u>Precipitation</u>

3. The amount of solar energy received along the equator does not change seasonally.
   <u>False</u>

4. Why are ectothermic animals typically referred to as 'cold blooded'?
   <u>They acquire heat from external sources</u>

5. Which of the following biome(s) are present in Singapore?
   Lowland tropical rainforest

5.8 Tutorial – Climate literacy quiz

1. **What is the greenhouse effect?**
   Certain gases in the atmosphere trap heat and warm the Earth
   The greenhouse effect is a natural phenomenon. Certain gases in the atmosphere have the ability to absorb radiation that would otherwise escape into space. The greenhouse effect is somewhat like a blanket that retains your body heat and keeps you warm.

   Gases that trap heat are called greenhouse gases and they include water vapor, carbon dioxide, methane, and nitrogen oxides. These gases can have potent effects even in small quantities.

   Without this natural greenhouse effect, the Earth's average temperature would be below freezing!

   Note that answer c, 'The tilt of the Earth changes the amount of solar energy the Earth receives,' is also true, but is not related to the greenhouse effect. Variations in the tilt and orbit of Earth do affect how much solar radiation reaches the Earth, and this is one of many natural variations in our climate system.

   Note also that answer b, 'Life exhales gas that warms up the atmosphere,' is partly true. Some life forms, like humans and mammals exhale CO2, but this CO2 only recently came out of the atmosphere. Plants use up CO2 to make carbohydrates/sugar/which?, animals eat the plants and return the CO2 to the atmosphere. This is an example of a short-term process within the carbon cycle, and it balances out from year to year. By contrast burning fossil fuels rapidly releases carbon that has been stored in Earth's crust for millions of years.

2. **If the greenhouse effect is natural, then why is today's climate change a bad thing?**
   A small increase in greenhouse gas concentration can have a large effect of increased warming.
   Humans have altered a natural process and exaggerated changes that might normally occur over millions of years.
   Once released into the atmosphere, greenhouse gases remain potent for many years, making it difficult to reverse the process.
   Abrupt changes to the climate system may have unintended outcomes that may pose challenges for societies, like more extreme weather, spread of diseases, a decline in marine life, or an alteration of ocean circulation patterns.
   While the greenhouse effect is natural and in fact, helps maintain a climate suitable for life as we know it, humans have altered a natural process. A small change in the amount of greenhouse gases in the atmosphere has a large and long-lasting effect. Furthermore, humans have changed the composition of the atmosphere over a short time span, and the resulting warming us many times faster than natural changes. We

are already seeing consequences like heat waves, melting sea ice, rising sea level, increased wildfires, and increases in extreme weather.

3. **Which activities are the largest contributors of greenhouse gases?**
   <u>Electricity generation and Transportation</u>
   Although all of the activities on the list cause greenhouse gas emissions, transportation and electricity generation are the biggest causes.
   In the USA, greenhouse gas emissions from electricity are falling as coal burning is slowly declining. Thus, the proportion of emissions from transportation has grown, and it accounted for 29% of total USA emissions in 2019, according to EPA data.

4. **How much has CO2 in the atmosphere increased since the Industrial Revolution? In the 10,000 years before the Industrial Revolution in 1751, carbon dioxide levels rose less than 1 percent. Since then, they've risen by:**
   <u>CO2 in the atmosphere has risen 49 percent since 1751.</u>
   From 1751-2018, humans added 1,611 billion tons of carbon to the atmosphere in the form of carbon dioxide. Around 80% of all human-produced carbon dioxide comes from burning coal, natural gas, oil and gasoline.

   When today's CO2 trend is viewed in the context of 400,000 years of climate data, the result is even more stark. Humans have profoundly changed the composition of Earth's atmosphere, and along with that, the energy balance of the planet.

   This question is from the NASA quiz, It's a Gas. When the climate literacy quiz was originally written in 2018, the answer was 43%. NASA's original quiz was updated to reflect the continued addition of CO2 to the atmosphere, which raised the percentage to 46%. This quiz was updated in 2021 to reflect yet another increase to 49%.

   To keep up with the changing composition of the atmosphere, compare the current CO2 concentration with the pre-industrial average of 278 ppm in 1750.

5. **How has the global average temperature changed since the Industrial Revolution?**
   <u>Warmer by more than 1 degree C (2.07 degrees F)</u>
   As of mid 2021, the Earth's average temperature (considering both land and water) has risen 1.19 degrees Celsius (2.14 degrees F) over the pre-industrial average (1880-1900).

   Furthermore, the rate of temperature change is increasing: "The global annual temperature has increased at an average rate of 0.07°C (0.13°F) per decade since 1880 and over twice that rate (+0.18°C / +0.32°F) since 1981." (Quote from the NOAA page linked below).

   NOAA's page about global temperature provides a summary of changing temperatures; this page is updated regularly.

6. **How does the rate of today's warming compare to previous episodes of rapid climate change on Earth?**

Today, the Earth's climate is changing much faster than it has changed in the past.
We know that the Earth's temperature made big swings as we moved in and out of ice ages. And as rapid as those changes were, today we are warming the climate 10 times faster.

"As the Earth moved out of ice ages over the past million years, the global temperature rose a total of 4 to 7 degrees Celsius over about 5,000 years. In the past century alone, the temperature has climbed 0.7 degrees Celsius, roughly ten times faster than the average rate of ice-age-recovery warming."

"Models predict that Earth will warm between 2 and 6 degrees Celsius in the next century. When global warming has happened at various times in the past two million years, it has taken the planet about 5,000 years to warm 5 degrees. The predicted rate of warming for the next century is at least 20 times faster. This rate of change is extremely unusual." (From How is Today's Warming Different from the Past?)

"We know from past changes that ecosystems have responded to a few degrees of global temperature change over thousands of years," said Diffenbaugh. "But the unprecedented trajectory that we're on now is forcing that change to occur over decades. That's orders of magnitude faster, and we're already seeing that some species are challenged by that rate of change." (From Climate change on pace to occur 10 times faster than any change recorded in past 65 million years)

It's even more interesting to note past spikes in temperature in the paleoclimate record (such as the Paleocene-Eocene Thermal Maximum ~55 million years ago) have been associated with other extreme changes such as rapid ocean acidification which was detrimental to marine life on Earth. Also, the Permian Mass Extinction was thought to have been initiated by rapid ocean warming leading to reduction in circulation, oceans going anoxic and emission of poisonous hydrogen sulfide into the atmosphere. Earth's geologic history gives us plenty of evidence that rapid swings in climate cause difficult conditions for life.

7. **We know that variations in Earth's orbit, solar output, and other factors cause changes in the climate. If we removed the human impacts of greenhouse gas emissions, what might the climate be doing today, on its own?**
   Slight cooling
   Left to its own devices, the Earth would be in a minor cooling phase today. But human emissions of greenhouse gases have over-ridden natural effects and tipped the balance toward rapid warming.

8. **When was the last time in Earth's history that CO2 was as high as it is now?**
   The last time CO2 was this high was 3 million years ago.
   As of 2020, the atmosphere contained 409 to 416 parts per million of carbon dioxide. This number goes out of date quickly, as CO2 levels continue to rise; check the latest data from Scripps.
   Throughout all of the cool-downs and warm-ups of the last ice ages, CO2 never topped 300 ppm. So we're way above anything that happened during the ice ages. To

look for the last time Earth's atmosphere had more than 400 ppm of CO2 we have to go farther back. Way farther back, to the Pliocene, 3 to 5 million years ago.

How was the climate back then? The temperature was 2 to 4 degrees Celsius (3.6 to 7.2 degrees Fahrenheit) warmer than today, and sea level was 50 to 80 feet higher!

On the other hand, there were giant camels, so that part sounds pretty good.

9. **Modern instruments have only been around for a little over 100 years. So how do we know what greenhouse gas concentrations (and temperature) were in Earth's past? (select all that apply)**
   <u>Air bubbles trapped in ice cores provide detailed records of what the atmosphere was like in the past.</u>
   <u>Examining organisms in marine sediments can tell us what the temperature was like in the past.</u>
   <u>Pollen in lake beds shows what plant species have lived there during different times. Different plant populations are associated with different types of climates.</u>
   <u>Glacial moraines show when and where previous episodes of glaciation occurred.</u>
   <u>Tree rings show the history of drought, fire, and other environmental variations.</u>
   The science of paleoclimatology uses geologic evidence to determine what the climate was like throughout Earth's history. Learn more in the video, Our Shared Climate Future, by scientists at the University of Colorado, CIRES. This specific question is addressed at 2:40 in the 5-minute video.

10. **What proportion of climate scientists has concluded that humans are the primary driver of today's climate warming?**
    <u>97% (or even more!)</u>
    The vast majority of climate scientists agree with the overwhelming evidence that humans are causing global warming. The reason there is a consensus of scientists is that there is a consensus of evidence.

    The scientific consensus was measured by reading the abstracts of nearly 12,000 scientific papers. This exercise is easy for anyone to repeat: simply look at published papers in legitimate climate science journals, and tally up how many agree with the idea that humans are changing the climate. Or, if reading is not your thing, attend any earth science conference and listen to what scientists are saying. They are in resounding agreement – because the evidence is overwhelming.

    If this is true, then why do we hear so much dissenting information? The answer is simple. Most of the claims that dismiss climate science are not based on legitimate science and are not found in peer-reviewed journals. When a paper has been peer-reviewed, that means it has been evaluated by a number of qualified scientists and found to have followed legitimate scientific methods

11. **The most common misunderstanding about climate change is that the Earth's climate has changed naturally in the past, therefore humans are not the cause of global warming. That is not correct. What are some analogies or rebuttals that help debunk this myth?**

At the heart of this misconception is the idea that if something happens naturally, then it can only happen naturally. But of course that's not true. Here are some examples.

> *Forest fires occur naturally. Does that mean that arson is a hoax?*
>
> *People die of natural causes. But sadly, people are sometimes murdered. But if people can die on their own does that mean that murder does not happen?*
>
> *It rains, which makes my lawn wet. But sometimes, a sprinkler is used to make the lawn wet. So the lawn can become wet for either natural or human-caused reasons.*
>
> *Rivers have always flooded. But some floods are either caused by, or made worse by human actions. If a dam ruptures, the resulting flood is because of humans – not because floods happen on their own.*

Many processes on Earth have more than one cause. The presence of a natural cause does not negate the reality of a human trigger.

Furthermore, the fact that climate has changed on its own gives us some very helpful information. Throughout geologic history, we know that more greenhouse gases in the atmosphere equates to a warmer climate, regardless of the source of the greenhouse gases (from the ocean, from wildfires, from volcanoes, from melting permafrost, etc.). So as humans add CO2 and other greenhouse gases to the atmosphere, we know that it also has the same warming effect. The physical process is the same either way.

Lastly, a key difference between past climate changes and today's climate change is the rate of change. Today's warming is much more rapid that past shifts in climate. This makes it harder for ecosystems to adapt.

In past geological ages the drivers of climate have been natural (volcanoes, plate tectonics, meteorites, cyanobacteria evolving and putting oxygen into our atmosphere, etc.), but now we as humans are the drivers of climate. This is why some scientists refer to today's geological era as the 'Anthropocene.' While it is scary to think that we as a species are responsible for altering the climate, it also highlights the fact that we humans are the first 'self-aware' climate driver and so could potentially do something about our actions.

12. **Which country has emitted the most CO2 over time? In other words, which nation has the most responsibility for the greenhouse gases that are currently residing in the atmosphere?**
    <u>USA</u>
    While China is currently the largest emitter of greenhouse gases, cumulative emissions are an important way to look at our overall contribution to global warming.

China's greenhouse gas emissions per year have only recently surpassed the US. Over time, the USA has been the largest emitter of greenhouse gases to the atmosphere. In fact, we've emitted twice as much CO2 as China.

This matters because greenhouse gases have a long life span in the atmosphere. CO2 in the atmosphere lasts for 50 to 100 years or more (as explained in this article in Yale Climate Connections). The reason why it's so important to curb emissions quickly is because greenhouse gases have a long-lasting effect. It's also why we can't sit back and blame China for their high emissions. All nations need to work together to address climate change.

13. **How long does CO2 remain in the atmosphere?**
    <u>CO2 remains in the atmosphere for up to 200 years, or more.</u>
    As you know from the carbon cycle, some processes, like photosynthesis, use up carbon dioxide quickly, while others, like carbon dioxide captured by weathering of rocks, operate over many thousands of years. Thus, you can't put your finger on the exact life span of a given molecule of CO2 in the atmosphere.

    The bottom line is that once emitted, CO2 continues to affect the climate for decades to millennia. That's why reducing emissions quickly is important. Because of the existing CO2 in the atmosphere, the Earth will continue to warm even after we stop burning fossil fuels.

    The complexity of CO2 residence time is summed by Zeke Hausfather in Yale Climate Connections:

    > *"Using a combination of various methods, researchers have estimated that about 50 percent of the net anthropogenic pulse would be absorbed in the first 50 years, and about 70 percent in the first 100 years. Absorption by sinks slows dramatically after that, with an additional 10 percent or so being removed after 300 years and the remaining 20 percent lasting tens if not hundreds of thousands of years before being removed."*

    IPCC uses an estimate of 5 to 200 years, noting, "No single lifetime can be defined for CO2 because of the different rates of uptake by different removal processes."

14. **If we stopped burning fossil fuels today, what would happen to the climate?**
    <u>Temperatures would stop increasing once greenhouse gas concentrations stopped increasing.</u>
    The science is evolving on this question, and this quiz was updated in 2021 to reflect those changes. Among all the bad news on climate change, this is a bit of good news. There is general agreement among scientists that when emissions fall to net zero, then the amount of greenhouse gases in the atmosphere will stop increasing. At that point, the global increase in temperature will slow or stop.

    Carbon Brief has an excellent, well-referenced article that explains why the science - and the messaging - around this topic has changed.

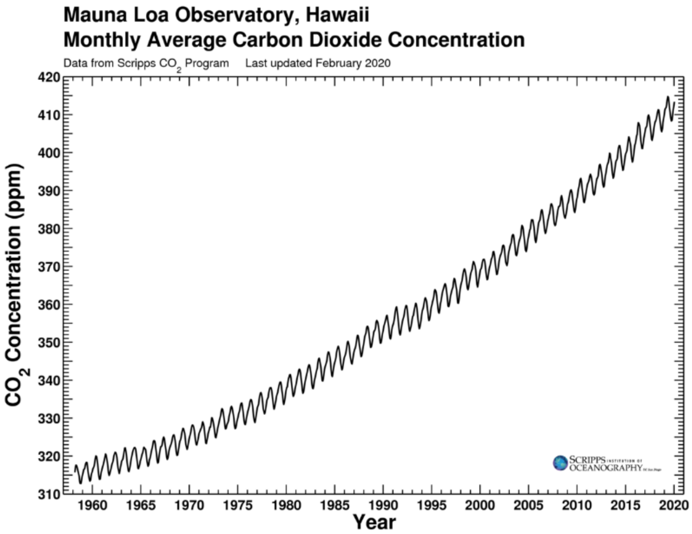
There are a few factors to keep in mind:

Air pollution - caused largely by burning fossil fuels - actually cools the planet by reflecting some incoming solar radiation. It's likely that there would be a temporary increase in temperature if airborne pollution were stopped. Overall, reducing air pollution would save millions of lives and trillions of dollars, so the benefit is still very worthwhile.

Often, the differing messaging on this topic is due to different questions being posed. For example, Earth's temperatures should stop increasing when greenhouse gases stop increasing, but an actual cool-down could take longer because of the long residence time of greenhouse gases in the atmosphere.

This remains an active area of climate research.

15. This is a graph of carbon dioxide in Earth's atmosphere, measured since 1958. There are two patterns in this data, what are they?



- *There is an annual 'wiggle' in the amount of CO2 in the atmosphere.*
- *There is also an overall trend of increasing CO2 in the atmosphere.*

16. Based on the graph in question 15, What causes the annual up-and-down fluctuation in CO2 in the atmosphere?

Plants take up more CO2 during the Northern Hemisphere summer

The 'seesaw' of carbon dioxide in the atmosphere is caused by the changing seasons. During the summer in the Northern Hemisphere, plants and marine algae take up CO2 through photosynthesis. As plants use up CO2, it's temporarily drawn down from the CO2 in the atmosphere. In the fall, plants slow down their uptake of CO2, and CO2 is released from soils. This process is dominated by the Northern Hemisphere because there is more land mass in the Northern Hemisphere.

17. What is the primary cause of the overall rising trend in CO2 in the atmosphere?

The increase in CO2 is caused by burning of fossil fuels.

The evidence is absolutely clear on this one. Humans have burned ever-increasing amounts of fossil fuels since the industrial revolution. Over this same time scale, CO2 *concentrations in the atmosphere have risen similarly. Isotope studies show the excess carbon in the atmosphere is plant-based carbon that had been locked away in Earth's crust until recently. If the increase in CO_2 were coming from the oceans or melting permafrost, it would have a different isotopic signature.*

That said, warming oceans and melting permafrost also release CO_2. These are examples of self-reinforcing cycles, also known as positive feedback cycles. But the oceans are warming, and permafrost is thawing because of human emissions of greenhouse gases. They are not driving the cycle; they are responding to changes caused by humans.

18. **What are the major causes of sea level rise? (there is more than one correct answer)**
    <u>Melting glaciers and ice sheets and seawater expanding as it gets warmer (also known as thermal expansion).</u>
    "Sea level is rising for two main reasons: glaciers and ice sheets are melting and adding water to the ocean and the volume of the ocean is expanding as the water warms. A third, much smaller contributor to sea level rise is a decline in water storage on land—aquifers, lakes and reservoirs, rivers, soil moisture—mostly as a result of groundwater pumping, which has shifted water from aquifers to the ocean.

    "From the 1970s up through the last decade, melting and thermal expansion were contributing roughly equally to the observed sea level rise. But the melting of glaciers and ice sheets has accelerated, and over the past decade, the amount of sea level rise due to melting—with a small addition from groundwater transfer and other water storage shifts—has been nearly twice the amount of sea level rise due to thermal expansion."

19. **What causes ocean acidification?**
    <u>CO_2 dissolved in ocean water.</u>
    Ocean acidification is sometimes called "the other carbon dioxide problem." The oceans have absorbed 25 to 30 percent of the CO_2 released into the atmosphere.

    The increase in dissolved CO_2 makes the ocean water more acidic (lowering the pH). This matters because many organisms in the ocean – from coral reefs to clam shells to plankton – build shells from calcium carbonate that is dissolved in ocean water. More acidic water makes it harder for these animals to build and maintain their shells.

    Since the industrial revolution, the pH of seawater has fallen from 8.2 to 8.1 – a decrease of 0.1 pH units. While that may not sound like much, it's a 30% increase in acidity. It's also important to note that the oceans are not acidic overall. The pH of ocean water is above 7, which is means it's basic, not acidic. But ocean acidification is making the water less basic – - or more acidic. For many organisms, this is a dramatic change in the conditions they are adapted for. The current drop in pH is the fastest known change in ocean chemistry in the past 50 million years. (Reference)

    Why does this matter? From NOAA's ocean acidification education page:

"Ocean acidification is currently affecting the entire world's oceans, including coastal estuaries and waterways. Today, more than a billion people worldwide rely on food from the ocean as their primary source of protein. Approximately 20% of the world's population derives at least 1/5 of its animal protein intake from fish. Many jobs and economies in the U.S. and around the world depend on the fish and shellfish that live in the ocean."

20. **What is the leading cause of coral bleaching?**
    warm water
    From NOAA's National Ocean Service page: "Warmer water temperatures can result in coral bleaching. When water is too warm, corals will expel the algae (zooxanthellae) living in their tissues causing the coral to turn completely white. This is called coral bleaching. When a coral bleaches, it is not dead. Corals can survive a bleaching event, but they are under more stress and are subject to mortality."

    "A healthy, resilient reef can either resist a stressful event, like bleaching, or recover from it. When a coral bleaches, it is not dead. Corals can survive if water temperatures return to normal quickly."

21. **Many of us are already familiar with solutions to climate change. While there are many actions we can take every day, it's important to focus on the solutions with the biggest result. Most of the actions show below will reduce emissions, but which will have the biggest effect? There are several correct answers.**
    Adopting a plant-based diet, wasting less food, large-scale solar farms, restoring tropical forests, onshore wind turbines
    Switching energy sources away from fossil fuels, wasting lass food, and adopting a plant-based diet, and restoring tropical forests are all key solutions for limiting climate change. Educating girls and family planning are/is another solution that can reduce greenhouse gas emissions.

    See the full list of solutions from Project Drawdown. This list is continuously updated, and this quiz question was updated in 2021 and is subject to change as we learn more.

    Large-scale, systemic change is needed to address climate change, and changes made on a personal level are not enough to solve the problem. Nonetheless, adopting a cleaner lifestyle offers the simultaneous benefits of emitting fewer greenhouse gases while also illustrating the scale and effectiveness of various solutions

22. **How fast to we need to stop burning fossil fuels to limit global temperature rise to 2 degrees C? (3.6 degrees F)**
    We need to stop burning fossil fuels by 2040.
    Emissions paths
    Climate scientists Stefan Rahmstorf and Anders Levermann estimated that we need to dramatically decrease emissions starting by 2020 and drop off quickly to near zero by around 2040.
    This quiz question was written in 2018. The 'deadline' of 2020 has come and gone, so we can observe our progress on reducing emissions. The world consumed less fossil

fuels in 2020, and less energy overall, largely due to the Covid-19 pandemic. So far in 2021, it appears that consumption is rebounding past 2020 levels. If we intend to minimize dramatic effects on Earth's climate system, we face a monumental challenge to overhaul the world's energy use within just a few years.

Note that there are other factors that can influence this estimate, such as CO2 removal from the atmosphere. The degree to which direct carbon capture could reduce the buildup of atmospheric greenhouse gases remains speculative at this point.

In 2017 Rahmstorf and Levermann concluded, "It is still possible therefore to meet the Paris temperature goals if emissions peak by 2020 at the latest.... We will need an enormous amount of action and scaled up ambition to harness the current momentum in order to travel down the decarbonisation curve at the necessary pace; the window to do that is still open."

Since the statement above was made, emissions have risen, fallen, then risen again.