Photosynthesis affects Earth's atmosphere

Photosynthesis also affects the composition of Earth's atmosphere. Photoautotrophs produce oxygen, an important atmospheric gas. Oxygen is essential for nearly all organisms and helps to break down food for energy.

Much of the world's atmospheric oxygen comes from terrestrial plants. However, about half of all oxygen comes from photoautotrophs in the ocean, known as phytoplankton. Phytoplankton (such as green algae and diatoms) are microscopic organisms found near the ocean's surface.

Photosynthesis also removes carbon dioxide from the atmosphere. During photosynthesis, photoautotrophs take inorganic carbon (carbon dioxide) and incorporate it into organic molecules. This process is called carbon fixation, and the carbon in organic molecules is known as fixed carbon. In other words, carbon is fixed and incorporated into carbohydrates that can be used by cells. If there were no photoautotrophs, the amount of carbon dioxide in the atmosphere would increase over time.

Human activities (such as burning fossil fuels for energy) are producing more carbon dioxide than photosynthetic organisms can absorb. Increased levels of carbon dioxide in the atmosphere are raising global temperatures and disrupting regional climates. Protecting natural systems that fix carbon—such as forests, grasslands, coastal wetlands, and mangrove forests—is an important strategy to help remove excess carbon dioxide from the atmosphere.

Light, temperature, and water affect photosynthesis

The reactions involved in photosynthesis depend on many different enzymes in a photoautotroph's cells. If abiotic factors change—such as light intensity, temperature, or water availability—the rate of photosynthesis may slow or even stop. In particular, photoautotrophs are sensitive to high levels of light, high temperatures, and dry conditions. For example, terrestrial plants that occur in dry conditions often have waxy coatings on their leaves to reduce water loss.

In different climates, different types of photosynthesis occur in plants

In warm, arid conditions, plants must close their stomata to avoid water loss. Although this helps plants to retain water, it effectively stops any exchange of carbon dioxide and oxygen between leaves and the atmosphere.

When stomata close, oxygen begins to build up inside leaves, resulting in a phenomenon called photorespiration. During photorespiration, plants use oxygen instead of carbon dioxide during the light-independent reactions. When photorespiration occurs, plants lose carbon that was fixed, which wastes energy.

Most plants use a type of photosynthesis called C3 photosynthesis. These C3 plants do not have any specialized features to reduce photorespiration in warm, arid environments. Other plants, however, use different types of photosynthesis to survive in stressful environmental conditions and avoid photorespiration.

C4 Plants reduce photorespiration by physically separating the light-dependent and the light-independent reactions. During C4 photosynthesis, the light-dependent reactions occur in a leaf's mesophyll cells whereas the light-independent reactions take place in special cells around leaf veins called bundle sheath cells. C4 plants are commonly found in warm- to high-temperature environments, such as tropical grasslands and savannahs.

Crassulacean acid metabolism (CAM) plants minimize photorespiration and save water by temporally separating reactions. More specifically, CAM plants close their stomata and photosynthesize during the day, and then open their stomata to exchange gases (carbon dioxide and oxygen) at night. At night, the mesophyll cells in CAM plants collect carbon dioxide and store it in organic acids. During the day, these organic acids are converted back into carbon dioxide and used in photosynthesis. CAM plants are typically dominant in very hot and dry areas, such as deserts.

The increase of carbon dioxide in Earth's atmosphere may affect C3, C4, and CAM plants differently. For example, C3 plants (like rice) may experience more photorespiration as temperatures increase. So, C3 plants may decline in environments where temperatures are warming quickly. In contrast, C4 plants can photosynthesize more efficiently under warmer conditions. So, C4 plants may expand in environments as temperatures increase.

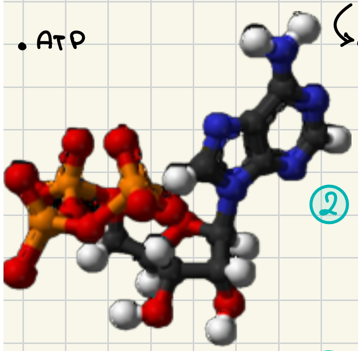
Cellular respiration

- Biochemical → to do things → maintain body homeostasis

- chemical Reaction :

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy (ATP + heat)}$$

- ATP



cellular respiration starts in cytosol. ①

- Cytosol : where glycolysis takes place
  - ↳ means breaking of glucose
  - ↳ break downs each glucose into two molecule known as pyruvate.
  - ↳ this process starts to produce some ATPs (Adenosine Triphosphate) and also helps produce NADH (Nicotinamide Adenine Dinucleotide).

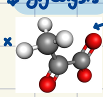
② • Mitochondria : AKA powerhouse of the cell, where pyruvate will enter and the citric acid cycle occurs.
Citric acid cycle uses a derivative of pyruvate (Called Acetyl-CoA) with the help of citrate. Produces more ATPs directly.
Also produces more NADHS. CAC is able to do a similar thing to another molecule named flavin adenine dinucleotide, FAD,
And make that FAD change into an $FADH_2$.

③ • ETC (Electron Transport Chain): after having NADHS, ATPs, FADHs, third stage of respiration starts.
- ↳ where electrons go from a high energy state & they get transferred from one molecule to another.
- ↳ The proteins that electrons interact with along their way are able to use that energy to pump hydrogen protons into the intermembrane of mitochondria
- ↳ Concentration gradient of the H^+ is released through another enzyme which is able to produce the actual ATP!

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy (ATP + heat)}$$

Stores energy, so we have to go through cellular respiration to convert it into ATPs.

↓ glycolysis ①

2 x  Pyruvate —acetyl-CoA→ Mitochondria

↓ produces NAD^+

$NAD^+ + 2H^+ + 2e^- \rightarrow NADH$ (reduction) (produced more)

(Similar) $FAD + 2H^+ + 2e^- \rightarrow FADH_2$

Cell's cytosol

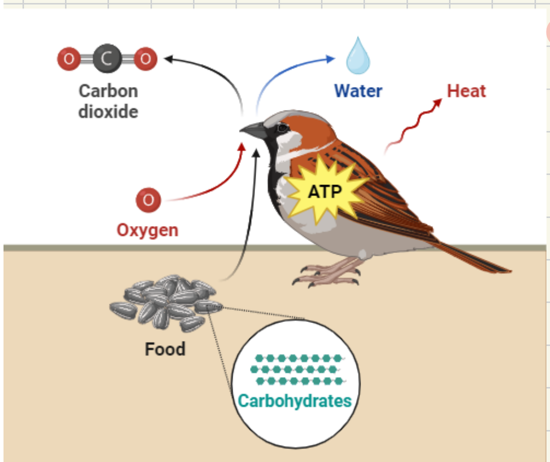
Citric Acid Cycle ② . output is CO_2.

Mitochondrial Matrix

ETC ③ : O_2 is an input to this chain and it accepts e^- and H^+ → H_2O

↓ ATP

Mitochondrial Cristae



Cellular respiration is an exothermic process

During cellular respiration, the bonds in the reactants (glucose and oxygen) are broken, atoms are rearranged, and bonds in the products (carbon dioxide and water) are formed. Importantly, the energy required to break the bonds in the reactants is less than the energy released during the formation of bonds in the products. Some of this energy difference is stored in the form of ATP molecules and the rest is released as heat energy.

In other words, cellular respiration is an exothermic process, which results in an overall release of energy. Organisms can then use this energy to power cellular processes.

Does that mean that organisms create new energy during cellular respiration?

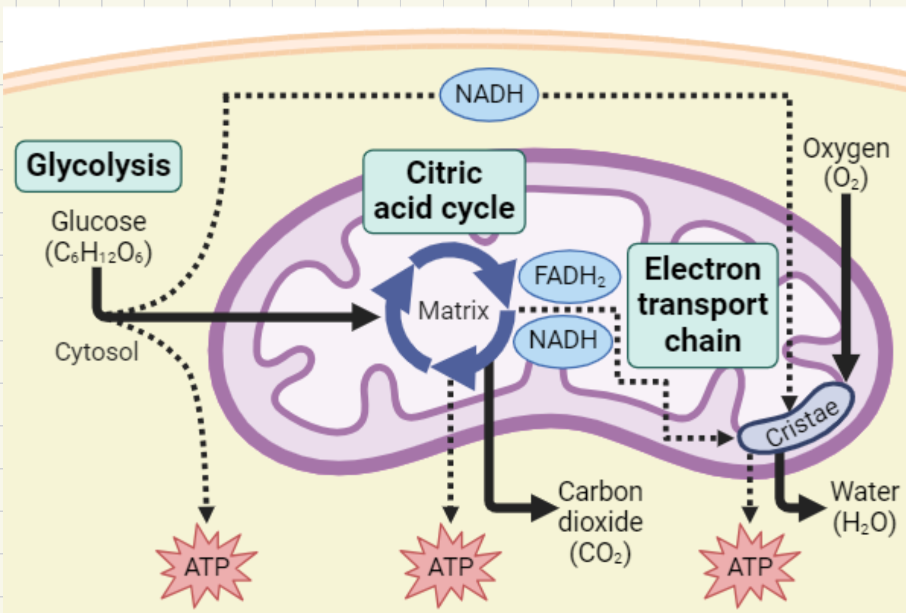
Cellular respiration involves three major stages

Cellular respiration involves many steps, which can be divided into three main stages: glycolysis, the citric acid cycle (also called the Krebs cycle), and the electron transport chain.

Glycolysis takes place in a cell's cytosol. During glycolysis, glucose is broken down into another molecule called pyruvic acid. As glucose is broken down, energy is released and stored in molecules of ATP and NADH.

The citric acid cycle takes place in the fluid space (matrix) of a cell's mitochondria. During the citric acid cycle, pyruvic acid (from glycolysis) is broken down through a series of chemical reactions to eventually produce carbon dioxide. As pyruvic acid is broken down, energy is released and stored in molecules of ATP, NADH, and FADH2 (another electron carrier).

The electron transport chain (ETC) takes place in the inner membranes (cristae) of a cell's mitochondria. NADH and FADH2 molecules from glycolysis and the citric acid cycle transport electrons to the ETC, where they are used to synthesize (make) ATP molecules. At the end of this process, oxygen combines with electrons from the ETC and hydrogen atoms to produce water.



Overall, some of the chemical energy stored in glucose is stored as usable energy in ATP; the rest of the energy in glucose is released as heat. Heat released during cellular respiration is crucial for maintaining an organism's temperature, ensuring that enzymatic and metabolic processes function properly.

Photosynthesis:

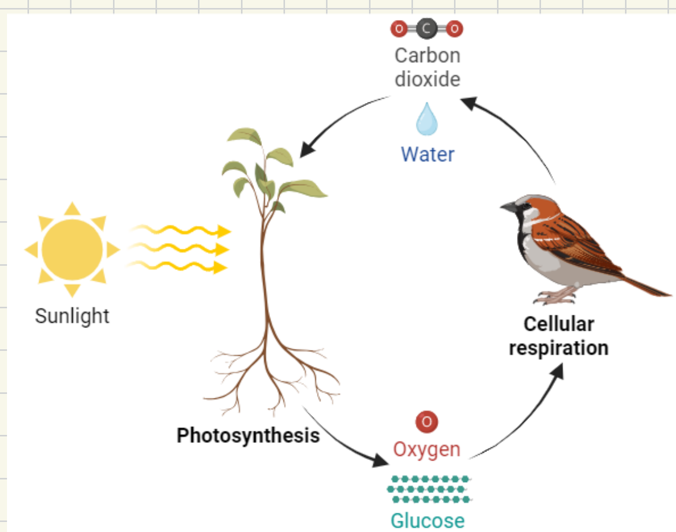
$$6\,CO_2 + 6\,H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6\,O_2$$

carbon dioxide | water | glucose | oxygen

Cellular respiration:

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O$$

glucose | oxygen | carbon dioxide | water



Cellular respiration can occur without oxygen

The term cellular respiration typically refers to the process used by organisms to break down food molecules (glucose) for energy in the presence of oxygen. However, organisms can perform cellular respiration aerobically (with oxygen) or anaerobically (without oxygen).

There are two processes that allow organisms to release energy from food without the use of oxygen: anaerobic respiration and fermentation.

Anaerobic respiration

In aerobic cellular respiration, organisms use oxygen at the end of the electron transport chain. However, in anaerobic respiration, organisms use a different inorganic molecule (such as sulfate) at the end of the electron transport chain. Many bacteria and archaea use anaerobic respiration.

For example, methanogens are microorganisms that perform anaerobic respiration and often occur in wetland ecosystems. However, some methanogens occur in the stomachs of ruminants (such as cows and sheep). Here, these microorganisms help to break down complex carbohydrates (such as cellulose) in the plant-based diets of ruminants. Methanogens produce methane through anaerobic respiration, which is exhaled by ruminants.

Fermentation

In the absence of oxygen, some organisms will use only glycolysis and the anaerobic process of fermentation to release energy from their food.

Alcohol fermentation occurs when an organism breaks down carbohydrates to release energy and produces ethanol (alcohol) and carbon dioxide in the process. This type of fermentation is used by yeasts (microscopic fungi) and some bacteria.

For example, the carbon dioxide bubbles made by baker's yeast during alcohol fermentation help bread to rise. During baking, the ethanol produced by the baker's yeast evaporates into the air.

Lactic acid fermentation occurs when an organism breaks down carbohydrates to release energy and produces a compound called lactate in the process. This type of fermentation is used by certain fungi and some bacteria. Many foods—including yogurt, cheese, and kimchi—are made through lactic acid fermentation, which gives them a sour flavor.

Lactic acid fermentation can also happen in animals when oxygen is limited. During intense physical movement, muscle cells may use lactic acid fermentation to quickly release energy.

Facultative and obligate anaerobes

Many bacteria and archaea use anaerobic respiration or fermentation. Some of these organisms can survive in environments with or without oxygen; other organisms can live only in environments without oxygen.

Facultative anaerobes can switch between aerobic respiration and anaerobic processes (anaerobic respiration or fermentation) based on oxygen availability.

Obligate anaerobes can live and grow only in the absence of oxygen. Oxygen is toxic to these types of organisms and injures or kills them on exposure.

stage	Substance	Reactant or product	place
Glycolysis	Glucose	Reactant	cell's Cytosol
citric Acid cycle	Carbon Dioxidie	Product	mitochondrial matrix
ETC	Oxygen	Reactant	mitochondrial cristae
ETC	water	product	mitochondrial cristae

Flow of energy and matter through ecosystems

Some organisms produce their own food, while others cannot

troph : feeding

In ecosystems, organisms can be categorized as producers or consumers.

Producers are autotrophs ("self-feeding" organisms) that make their own organic food molecules (carbohydrates) from inorganic sources. Energy stored in carbohydrates can be released and used to power cellular processes.

Consumers are heterotrophs ("other-feeding" organisms) that cannot make their own organic food molecules and must eat other organisms for energy and nutrients. Consumers can fall into one or more feeding categories.

Herbivores consume photosynthetic producers for energy and nutrients. For example, some herbivores may feed on the leaves and branches of plants. Other herbivores mainly feed on the fruits of plants (called frugivores) or seeds (called granivores).

Omnivores feed on both producers and other consumers.

Carnivores are predatory organisms that kill and eat other consumers. Some carnivores are also scavengers and consume the carcasses of dead organisms.

Detritivores feed on detritus, or small pieces of dead and decaying organism remains and waste. In doing so, detritivores physically break down this organic matter into smaller particles.

Decomposers chemically break down organic matter. Decomposers such as fungi and bacteria secrete enzymes to break down organic matter and then directly absorb the nutrients.

Food chains and trophic levels

In an ecosystem, energy flows in a one-way direction, from producers to various consumers. Unlike energy, matter is recycled in an ecosystem.

Food chains show how energy and matter transfer from one organism to another in an ecosystem. Arrows in a food chain point from an organism that is eaten to the organism that eats it. When an organism is eaten, the energy and matter stored in its tissues are transferred to the organism that eats it. So, the arrows in a food chain represent the direction of energy and matter flow, starting with producers and moving up through consumers.

The position of an organism in a food chain is called its trophic level. Organisms can have one or more trophic levels in a food chain, depending on what they consume. Organisms can also be part of multiple food chains. An organism's trophic level is the number of steps from the start of the chain to the organism.

For most food chains, the sun is the ultimate source of energy, so it represents level 0.

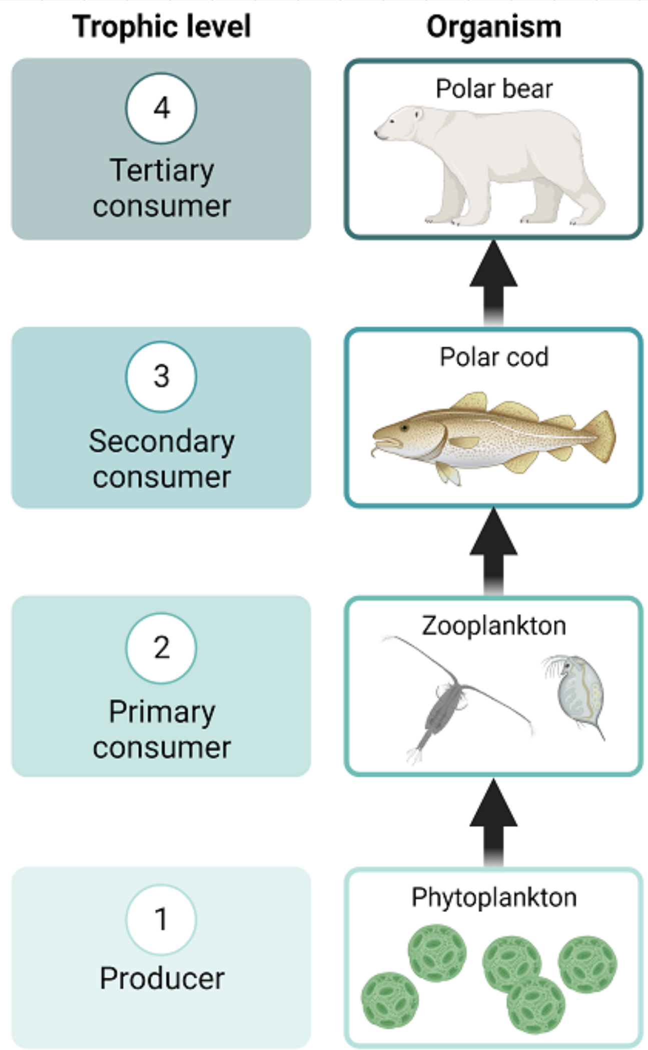
Food chains start at trophic level 1 with producers, which typically use sunlight to make organic food molecules.

Organisms that eat producers are found at trophic level 2. These organisms are called primary consumers, which are usually herbivores.

Secondary consumers occur at trophic level 3, which eat primary consumers. Secondary consumers are usually omnivores or carnivores.

Organisms that eat secondary consumers are found at trophic level 4. These organisms are known as tertiary consumers and are typically carnivores.

Some food chains have additional trophic levels and can include quaternary consumers (carnivores that eat tertiary consumers).



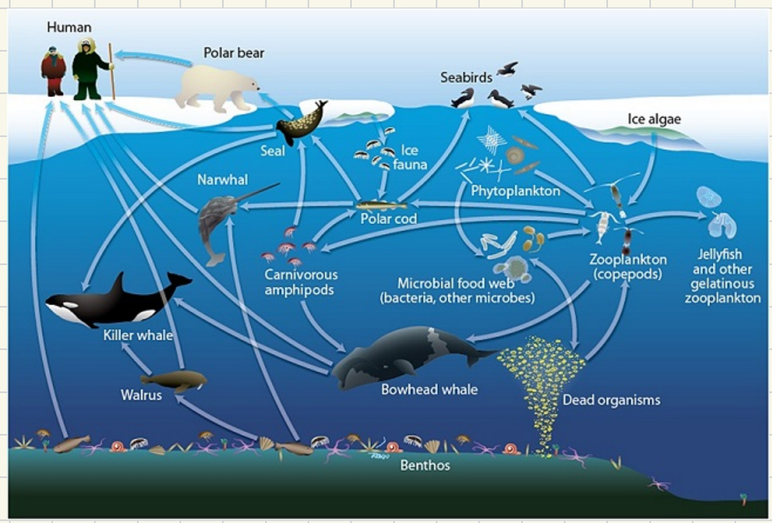
Food chains can vary in length. Food chains of terrestrial ecosystems typically have no more than five trophic levels, whereas marine ecosystems can have up to seven trophic levels in food chains. Some food chains can cross between different ecosystems. For example, seabirds feed only on organisms in the ocean—but, seabirds can be consumed by predators in terrestrial ecosystems where they breed.

Food webs model feeding interactions in an ecosystem

In most ecosystems, the flow of energy and matter is much more complicated than a linear food chain. For example, an organism can feed on multiple types of prey from different trophic levels. The complicated feeding interactions in ecosystems can be modeled with the help of food webs.

A food web is a network of feeding interactions through which both energy and matter move. In food webs, arrows point from an organism that is eaten to the organism that eats it. As the Arctic food web below shows, some species can eat organisms from more than one trophic level. For example, seabirds eat both primary consumers and secondary consumers.

Food webs are simplified models; they show many feeding interactions, but they may not show every feeding interaction in an ecosystem. In particular, food webs tend not to show all the connections between producers and consumers to decomposers.



The flow of energy and cycling of matter in ecosystems

Autotrophs form the base of all food chains and food webs. The energy that autotrophs capture from sunlight (in the case of photoautotrophs) or chemicals (in the case of chemoautotrophs) sustains all other organisms in an ecosystem. As energy is transferred from one organism to the next across trophic levels in an ecosystem, some of this energy dissipates as heat. Eventually, so little energy is left that no more trophic levels can be supported.

Unlike energy, matter is recycled in an ecosystem. In particular, decomposers play an important role in food webs by recycling matter. When they break down organic matter, they release nutrients that can be used again as building blocks by primary producers. Without decomposers, nutrients would remain locked within dead organisms and waste.

Producers allow energy and matter to enter ecosystems

Energy enters an ecosystem through producers, which make their own organic food molecules (carbohydrates) from inorganic sources. Energy and matter move up the trophic levels of an ecosystem as producers are eaten by primary consumers, which are then eaten by secondary consumers, and so on.

Production in ecosystems

Producers support all other organisms in an ecosystem. So, the abundance of producer organisms and their rate of production can influence how energy and matter move through an ecosystem.

Production describes the rate at which chemical energy is stored in organic molecules by living organisms. In ecosystems, primary production occurs in producers through photosynthesis or chemosynthesis.

Primary production is divided into two categories: gross primary production and net primary production.

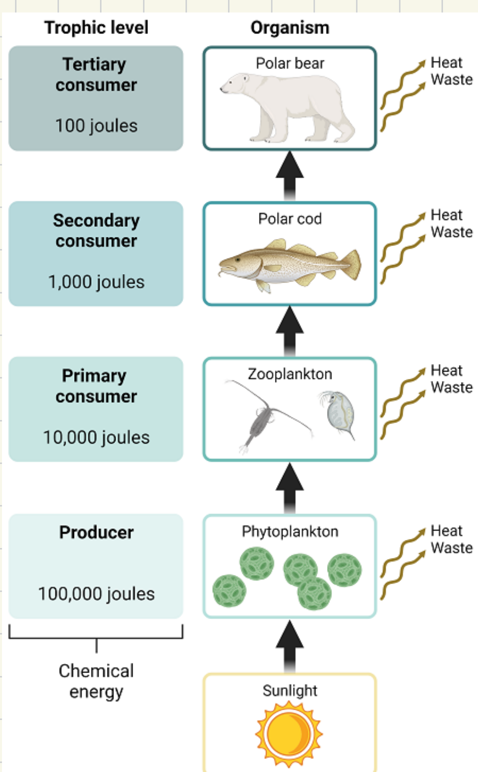
Gross primary production (GPP) is the amount of chemical energy that producers store over time in a specific geographic area. GPP is usually described in terms of carbon biomass—the amount of carbon that is fixed in the organic molecules of organisms. Much of an ecosystem's GPP supports cellular respiration in producers.

Net primary production (NPP) is gross primary production minus the amount of chemical energy used by producers for cellular respiration. The remaining amount of chemical energy (NPP) can be used by producers for growth and reproduction. For example, NPP is used by plants to grow structures such as stems, leaves, roots, and fruits. In addition, NPP represents the chemical energy available to organisms in the next trophic level: consumers.

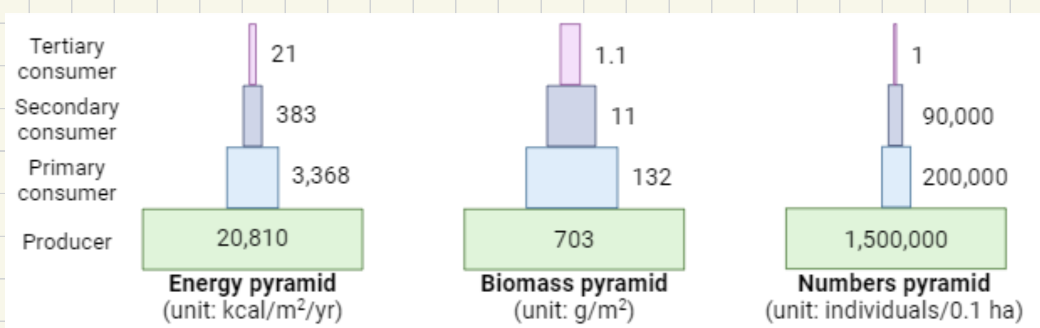
The movement of energy and matter in ecosystems

Energy and matter pass from one trophic level to the next when organic molecules from an organism are eaten by another organism. However, the transfer of energy between trophic levels is not very efficient.

The amount of energy transferred from one trophic level to the next is called trophic efficiency. Trophic efficiency is typically around 10%, but varies from 5% to 29%. So, only about 10% of the total energy available at a trophic level is transferred to the next level. The rest of the energy is used to power cellular processes, released as heat, or discarded through waste. This pattern of trophic efficiency is called the "10% rule".



Trophic efficiency also limits the number of trophic levels in a food chain. Very few food chains have more than seven trophic levels, and most have less. After a certain number of trophic levels, there is just not enough energy available to support a population at a higher trophic level.



Ecological pyramids model energy loss

Ecological pyramids show the relative amounts of energy or matter in different trophic levels of an ecosystem. There are three types of ecological pyramids: energy, biomass, and numbers pyramids.

An energy pyramid shows the amount of energy available at each trophic level. An energy pyramid also shows how trophic efficiency results in less energy available at each trophic level.

Energy pyramids often use units of kilocalories per square meter per year kcal/m^2/yr. This measurement explains how much energy is produced and transferred through an ecosystem's trophic levels in a specific area over time. Taking the measurement over the span of a year helps to account for seasonal variation.

A biomass pyramid shows the amount of biomass (the mass of living organisms) at each trophic level. Energy pyramids and biomass pyramids usually have a similar shape.

Biomass pyramids often use units of grams per square meter g/m^2. This measurement explains how much biomass is distributed throughout an ecosystem's trophic levels at a specific point in time. However, this measurement does not account for changes in biomass over time due to growth, reproduction, or death.

A numbers pyramid shows the number of organisms at each trophic level. In general, there are fewer organisms in higher trophic levels because only a small amount of energy is transferred from one trophic level to the next (10% rule). However, a numbers pyramid can sometimes look inverted. In some ecosystems, a small number of producers can support many organisms at higher trophic levels. For example, a large Ponderosa pine tree can support many individual consumer organisms.

Numbers pyramids often use units of individual organisms per hectare (individuals/ha). This measurement explains how many individuals are found within each trophic level of an ecosystem at a specific point in time. However, this measurement does not account for changes in abundance over time, such as reproduction or death.

Communities are regulated by organism abundance at trophic levels

Producers and consumers can affect community structure, which is the occurrence and distribution of species in a community.

In bottom-up control, organism abundance at each trophic level is limited by nutrients or food availability at lower trophic levels. For example, nutrient supply can control the number of plants (producers) in an ecosystem. If nutrients are low, fewer plants are able to grow. Fewer plants support fewer primary consumers, which can lead to fewer secondary consumers.

In contrast, top-down control occurs when organism abundance at each trophic level is controlled by consumer abundance at higher trophic levels. For example, predators (secondary consumers) may prey upon herbivores (primary consumers), which can lead to fewer herbivores. With fewer herbivores eating plants (producers), more plants would be able to grow.

feeds on photosynthetic producers → herbivore

feeds on small pieces of organism remains and waste → detritivore

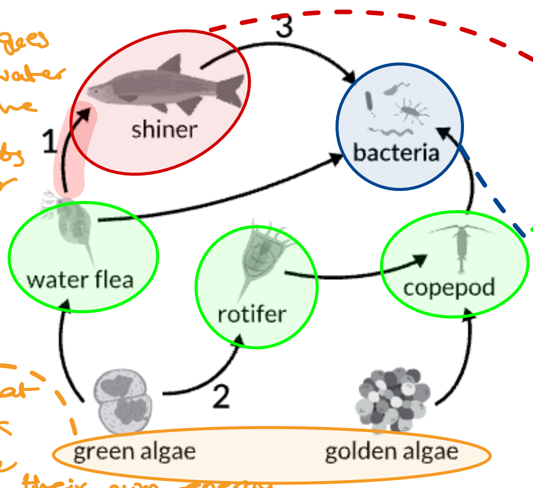
feeds on and chemically breaks down organic material → decomposer

kills and eats other consumers → carnivore

feeds on both producers & consumers → omnivore

A simplified food web of a freshwater lake ecosystem is shown below.

the energy goes from the water flea to the shiner → shiner eats the water flea.



producers they don't eat anything & they produce their own energy.

Complete the statements about each numbered arrow in this food web.

- Arrow 1 shows a [secondary consumer] feeding on a [primary consumer].
- Arrow 2 shows a [primary consumer] feeding on a [producer].
- Arrow 3 shows a [decomposer] feeding on a [secondary consumer].

- In a food web, arrows show the flow of energy as an organism consumes another.
- primary consumers : herbivores that feed on producers.
- secondary consumers : carnivores that feed on primary consumers.
- Decomposers: organisms that break down dead material and recycle nutrients. (e.g. bacteria)

Another example

Gray wolves preying on ungulates such as elk & deer.
Elk feeds on aspen sapling (small, young tree)

Biogeochemical cycles

carbon, nitrogen, oxygen!

- Everything is made up of chemical elements.

These elements are transferred through the Earth's natural systems by a series of chemical, physical, geological, and biological processes known as biogeochemical cycles (also called nutrient cycles).

Matter is conserved throughout a biogeochemical cycle. However, matter can pass from one natural system to another and it may be transformed into different chemical forms as it cycles. In addition, the biogeochemical cycles of different elements can interact with one another.

An overview of the carbon cycle

Carbon is an essential element that forms the base of all organic matter, including living organisms.

The carbon cycle describes the continuous flow of carbon between organic and inorganic carbon reservoirs, or areas of Earth where large amounts of carbon are stored.

Most of Earth's carbon is found in inorganic reservoirs such as rocks, water, and sediments (inorganic carbon storage). Only a small portion is stored in organic reservoirs, such as in living organisms (organic carbon storage). As carbon is transferred between reservoirs, processes which release carbon into the atmosphere are called sources, and processes which remove carbon from the atmosphere are called sinks.

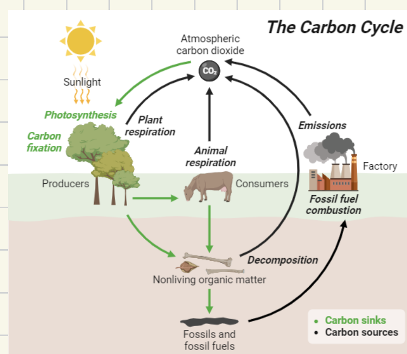
The carbon cycle can be split into two cycles:

The biological carbon cycle (or fast cycle) moves carbon from the atmosphere to the biosphere, and then back to the atmosphere again. The biological carbon cycle can exchange carbon between organic and inorganic reservoirs (such as the atmosphere) within years.

The geological carbon cycle (or slow cycle) mainly occurs in the geosphere and can extend deep into the Earth's mantle. The geological carbon cycle can take millions of years to complete as carbon moves through the geosphere (in rocks and sediments), hydrosphere (oceans), and atmosphere.

- Biological Carbon cycle: carbon from atmosphere to biosphere and back
  - ↳ atmosphere ⇄ biosphere
  - ↳ exchanges carbon between organic & inorganic carbon reservoirs within years

- Geological Carbon Cycle: happens in the geosphere & can be extended the Earth's mantle
  - ↳ can take millions of years to complete
    because carbon moves through the
    - → geosphere (rocks & sediments)
    - → hydrosphere (oceans)
    - → atmosphere



Biological carbon cycle

Carbon enters all food webs—both terrestrial and aquatic—through autotrophs.

Photoautotrophs remove carbon dioxide from the atmosphere and convert it into organic molecules, such as glucose. Heterotrophs consume these organic molecules, which moves organic carbon through food chains and webs. Through cellular respiration, organisms release carbon dioxide back into the atmosphere. Decomposers also release carbon dioxide as they break down dead organisms and other nonliving organic matter.

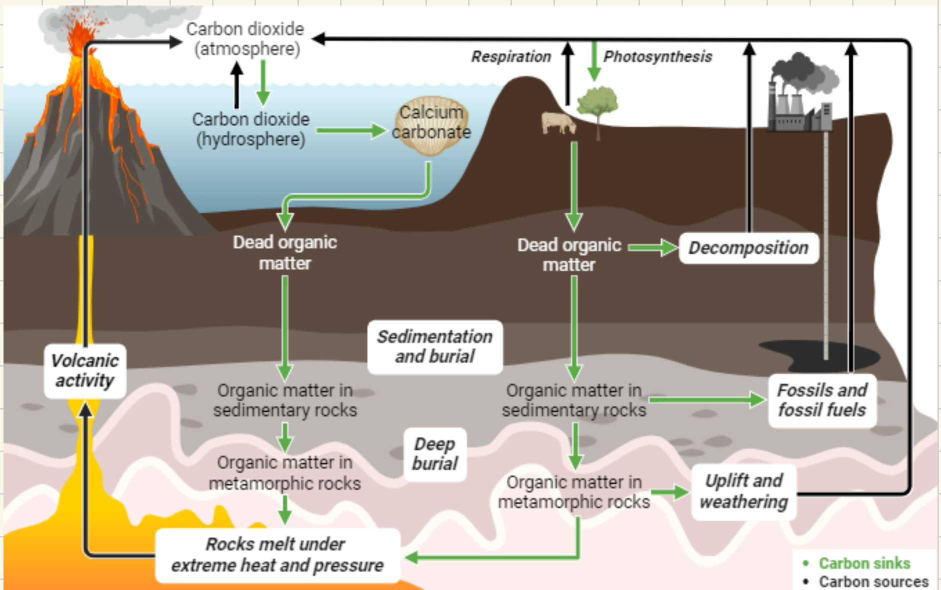
Organic matter that is not immediately broken down may accumulate and become buried. For example, much of the carbon in aquatic environments is found in the shells of mollusks (such as snails, clams, and oysters). When these organisms die, they sink to the bottom and become buried in sediment. Given enough time, pressure, and heat, this organic matter can transform into fossils, fossil fuel deposits, and rocks.

Geological carbon cycle

In terrestrial environments, carbon enters the geosphere in the form of dead organisms and other nonliving organic matter. Over the course of thousands to millions of years, this organic matter may become buried deeper underground, where—with enough pressure and heat—it becomes sedimentary or metamorphic rocks. Some organic matter, such as plant remains, may decompose deep underground in anaerobic (oxygen-free) conditions and transform into fossil fuels such as oil, coal, and natural gas.

In aquatic environments (especially oceans), carbon enters the hydrosphere when carbon dioxide dissolves into water. In water, carbon bonds with other chemical elements to form calcium carbonate, a major part of marine organism shells. When these organisms die, they sink to the bottom and become buried in sediment. With time, these sediments can form limestone and other sedimentary rocks as well as fossil fuel deposits.

Carbon may remain stored deep in sediments and rocks for millions of years until an event such as a volcanic eruption returns it to the atmosphere. In addition, when humans extract fossil fuels from underground and burn them for energy, carbon is released back to the atmosphere (in the form of carbon dioxide).



Nitrogen is essential for life

Nitrogen is essential for life—many of the biomolecules that make up organisms contain nitrogen atoms, including nucleic acids and proteins.

N_2

The majority of nitrogen on Earth is found in the atmosphere, with nitrogen gas N2 making up about 78% of air. However, many organisms (such as plants and animals) cannot directly use nitrogen gas. To obtain nitrogen, these organisms rely on the nitrogen cycle. The nitrogen cycle describes how nitrogen moves between living organisms and the environment. Through this cycle, nitrogen takes on different chemical forms.

The nitrogen cycle involves four main processes: nitrogen fixation, ammonification (also called mineralization), nitrification, and denitrification. Most of the nitrogen cycle is driven by microorganisms, such as bacteria.

Processes of the nitrogen cycle

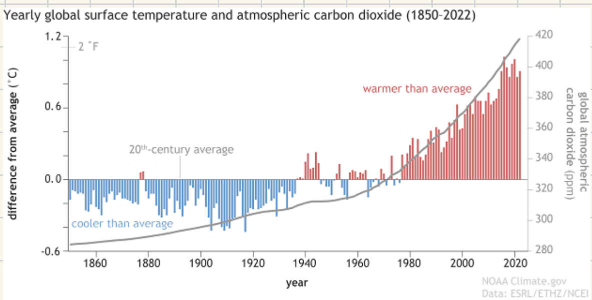
Nitrogen enters the biosphere through bacteria and other prokaryotes, which convert atmospheric nitrogen N2 into biologically usable forms through a process called nitrogen fixation. Some of these microorganisms live in the soil, and others are found in the roots of plants such as peanuts and peas. A small amount of atmospheric nitrogen is also fixed through lightning.

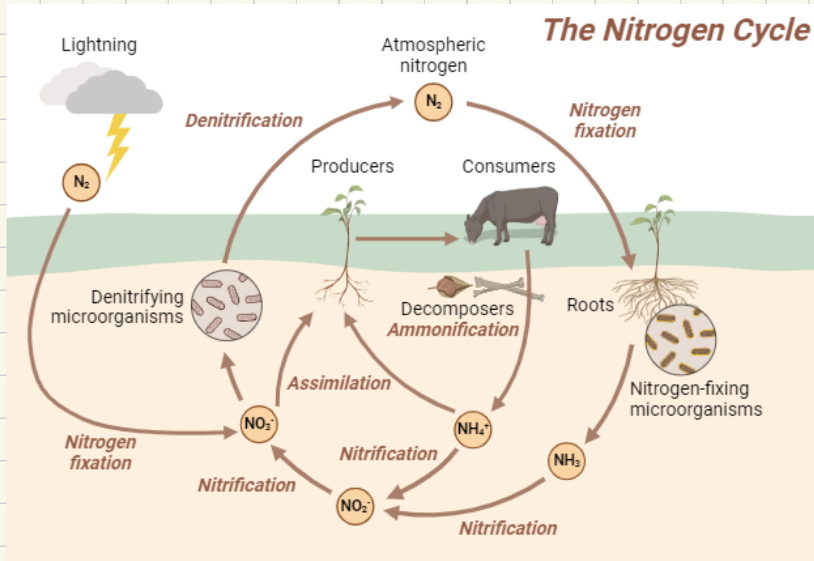
Nitrogen-fixing microorganisms capture atmospheric nitrogen by converting it to ammonia NH3 , which can be used by producers (such as plants) to make biomolecules. These biomolecules are then passed along to consumers through food chains and food webs. Nitrogen-containing biomolecules are incorporated into an organism's cells or are broken down and leave the organism as waste.

As dead organisms and waste decompose, ammonium NH4+ is returned to the environment through ammonification. This process is carried out by certain bacteria and fungi.

Through nitrification, microorganisms convert ammonia and ammonium to nitrites NO2- and nitrates NO3- which can be used by producers (via assimilation). Some nitrites and nitrates are also transformed back into nitrogen gas through denitrification (by denitrifying microorganisms), returning nitrogen to the atmosphere.

Ammonia NH_3 Nitrite NO_2^-
Ammonium NH_4^+ Nitrate NO_3^-





Biogeochemical cycles are influenced by human activities

Biogeochemical cycles, such as the carbon and nitrogen cycle, are influenced by one another. These biogeochemical cycles are also affected by human activities that change how chemical elements (such as carbon and nitrogen) are stored or released.

Human impacts on the carbon cycle

During the carbon cycle, carbon is removed from the atmosphere and is fixed (or stored) in organic and inorganic reservoirs. Some organic matter (such as dead organisms and waste) can become buried. Over thousands to millions of years, heat and pressure cause chemical and physical changes in this organic matter, transforming it into coal, oil, or natural gas. That's why coal, oil, and natural gas are called fossil fuels—they are the products of fossilized organic carbon.

Fossil fuels can be burned (combusted) to generate energy. Fossil fuels are common energy sources used to power vehicles, heat homes and buildings, and provide electricity. However, fossil fuels also release carbon dioxide into the atmosphere when they are burned.
The amount of carbon dioxide in the atmosphere has increased rapidly over the past century, and this increase is largely the result of human activities. Carbon dioxide is a greenhouse gas, meaning that it traps heat and keeps it from radiating into space. With more carbon dioxide in the atmosphere, global temperatures have risen.

Although photosynthetic organisms and oceans absorb some carbon dioxide, they cannot absorb all of the additional carbon dioxide emissions from fossil fuels. So, carbon is entering the atmosphere faster than it can cycle back into reservoirs for long-term storage. This excess atmospheric carbon dioxide contributes to climate change.

Human impacts on the nitrogen cycle

There are two main processes by which human activities release nitrogen into the environment: the combustion of fossil fuels and the use of artificial fertilizers in agriculture.
When fossil fuels are burned, they release nitrogen oxides NO_x into the atmosphere. These nitrogen oxides can produce acid rain (as nitric acid, HNO3) and form a greenhouse gas (as nitrous oxide, N2O) that contributes to climate change.

Artificial fertilizers are commonly used in agriculture and landscaping. However, excess fertilizer may wash into streams, rivers, lakes, and oceans as runoff. This nitrogen-rich runoff can lead to cultural eutrophication, which is the rapid growth of algae and other microorganisms that occurs when human activities introduce excess nutrients (such as nitrogen) to a body of water.

The rapid growth (or "bloom") of algae and cyanobacteria can harm other aquatic organisms. Algal and bacterial blooms quickly use up dissolved oxygen in the water (through cellular respiration) and block sunlight from reaching other organisms deeper underwater. Over time, these blooms can lead to fish die-offs and form dead zones.

Summary

Carbon fixing (fixation) : CO_2 in the atmosphere —producers→ Glucose

photosynthesis
respiration
combustion
decomposition
} moves CO_2 around

carbon reservoirs:
- ocean
- terrestrial ecosystems
- fossil fuels
- rocks & sediments

Nitrogen fixing : N_2 in the atmosphere —(eukaryotes) bacteria→ Some form that's usable for organism

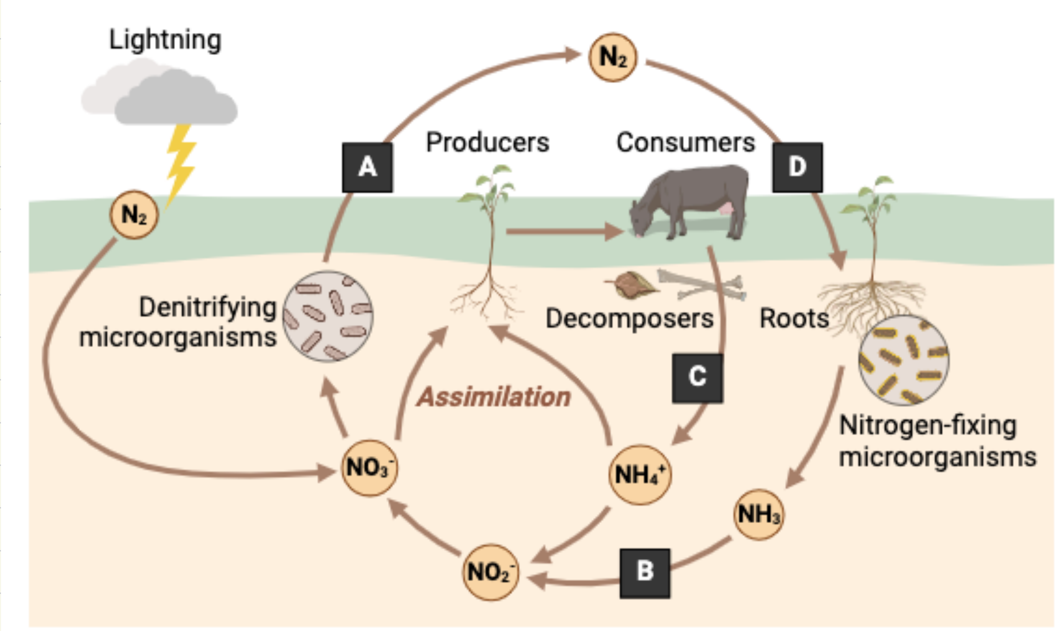
such as ammonia NH_3

Ammonification : when an organism dies and decomposes, the waste is converted back into ammonia (NH_3) or ammonium ions (NH_4^+)

Nitrification : where ammonia (NH_3) is converted into nitrites (NO_2^-) and then into nitrates (NO_3^-) by specific bacteria.
- ↳ Step 1: Ammonia oxidized to nitrate by bacteria like Nitrosomonas.
- ↳ Step 2. Nitrite is further oxidized to nitrate by bacteria like Nitrobacter.

- In photosynthesis, the energy required to break bonds in the reactants is [greater than] than the energy released during the formation of bonds in the products.
- This difference in energy is [stored as chemical energy].
- So, photosynthesis is an [endothermic] process.

🌱 Carbon dioxide (CO_2) and water (H_2O) are the reactants involved in photosynthesis.
☀️ Glucose ($C_6H_{12}O_6$) and oxygen (O_2) are the products of photosynthesis.



A: Denitrification

Denitrification is the process in the nitrogen cycle where nitrate (NO_3^-) is converted back into nitrogen gas (N_2) or nitrous oxide (N_2O) by bacteria under low-oxygen (anaerobic) conditions. This returns nitrogen to the atmosphere and completes the nitrogen cycle.

✅ It's mainly carried out by bacteria like Pseudomonas and Clostridium.
✅ Common in wet soils, swamps, and waterlogged environments.
✅ Important for balancing nitrogen levels but can lead to nitrogen loss in soil, affecting plant growth.

B: Nitrification

Nitrification is a two-step process in the nitrogen cycle where ammonia (NH_3) or ammonium (NH_4^+) is converted into nitrate (NO_3^-) by specialized aerobic bacteria.

✅ Step 1: Nitrosomonas bacteria convert ammonia to nitrite (NO_2^-).
✅ Step 2: Nitrobacter bacteria convert nitrite to nitrate (NO_3^-).
📍 This happens in well-aerated soils and is important because nitrate is a form of nitrogen that plants can easily absorb and use.

C: Ammonification

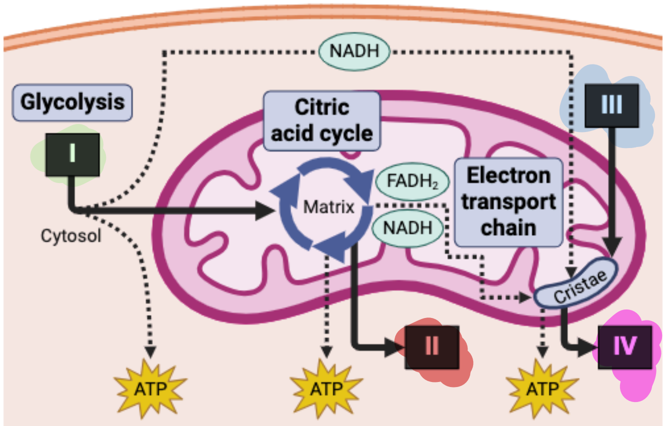
Ammonification is the process in the nitrogen cycle where organic nitrogen from dead organisms, feces, or waste products is converted into ammonia (NH_3) or ammonium (NH_4^+) by decomposer bacteria and fungi.

✅ Happens during decomposition of plants, animals, and waste.
✅ Releases nitrogen back into the soil in a form that can re-enter the cycle through nitrification or assimilation.
📍 It's essential for recycling nitrogen and maintaining soil fertility.

D: Nitrogen Fixation

Nitrogen fixation is the process where atmospheric nitrogen gas (N_2) is converted into ammonia (NH_3) or ammonium (NH_4^+) — forms that plants and other organisms can use.

✅ Done naturally by nitrogen-fixing bacteria like Rhizobium (in legume root nodules) and Azotobacter (in soil).
✅ Can also happen through lightning or industrial processes (like the Haber-Bosch process).
📍 This is the first step of the nitrogen cycle — essential because most organisms cannot use nitrogen gas (N_2) directly.



Complete the table by selecting the correct reactant or product for each box from the cellular respiration diagram above.

Box	Reactant or product
I	glucose
II	carbon dioxide
III	oxygen
IV	water

Stage	Substance	Reactant or product
glycolysis	glucose	reactant
citric acid cycle	carbon dioxide	product
electron transport chain	oxygen	reactant
electron transport chain	water	product

Type of biomolecule	Cellular functions
proteins	Provide defense, movement, storage, cellular communication, structural support, and facilitate chemical reactions
carbohydrates	Store energy and are also used for structural support and protection
lipids	Store energy, create waterproof coverings, and form part of the cell membrane
nucleic acids	Encode the cell's genetic material and provide instructions for building other organic molecules

Role in cellular respiration	Substances
reactants	oxygen and glucose
products	carbon dioxide and water

- In cellular respiration, the energy required to break bonds in the reactants is less than the energy released during the formation of bonds in the products.
- This means that cellular respiration is an exothermic process.
- Cellular respiration results in an overall release of energy, some of which is used to power cellular processes.

Genes, proteins, and traits

Unit 5

Inherited traits are passed from parents to offspring

All organisms inherit traits, or observable characteristics, from their parents. Inherited traits can include:

physical features, such as hair and eye coloration;
behaviors, such as feeding and mating patterns; and
the risk of getting certain diseases, such as heart disease.

Traits examples:
- Spiders making 7 types of silk
- Elephants having lower risk of cancer
- Some jellyfish having the ability to glow (bioluminescence)

Information about inherited traits is found in genes. Genes are pieces of hereditary material that are passed from parents to offspring.

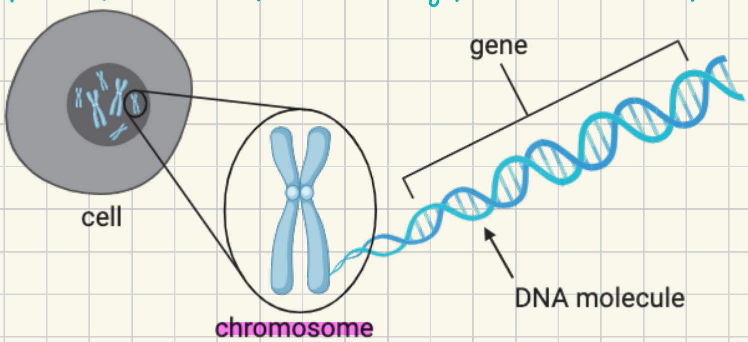
Genes, chromosomes, and DNA

Genes are part of structures called chromosomes, which in eukaryotes are found in the nucleus. A cell typically contains multiple chromosomes, each of which consists of a single, long DNA molecule. Each chromosome also includes proteins called histones that help to organize the DNA. Chromosomes are typically arranged loosely in the nucleus. However, as a cell gets ready to divide after replicating its DNA, its chromosomes coil up and condense into the characteristic "X" shape that we often see depicted in diagrams (including in the one shown below).

DNA is a type of nucleic acid made up of monomers, or subunits, called nucleotides. Four different nucleotides (often called bases) compose DNA: adenine (A), thymine (T), guanine (G), and cytosine (C). The nucleotides in a DNA molecule are connected in a specific order.

The genes that make up an organism's hereditary material are actually specific stretches of nucleotides within the DNA molecule of a chromosome. Each chromosome in the cell contains many genes.

proteins: provide defense, movement, storage, cellular Communication, structural support, and facilitate chemical reaction.

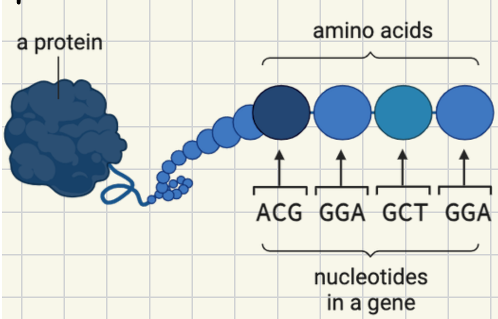


Proteins influence traits

The cell uses the information found in genes to build other molecules, primarily proteins. Proteins are molecules that perform many different functions in a cell. For example, proteins are involved in defense, storage, transport, cellular communication, movement, and maintaining cell structure.

Proteins are made up of monomers called amino acids. These monomers are connected in long chains to form polymers called polypeptides. Each protein is made up of one or more polypeptides, which are folded and coiled into a specific three-dimensional (3D) structure. This 3D structure determines the protein's function.

So, how does the cell turn the information in genes into proteins? Specifically, the order of nucleotides in a gene determines the order of amino acids in one or more proteins. This means that variation in the order of nucleotides in a gene can produce variation in the order of amino acids in a protein, which can affect the protein's function.



An organism has many different genes, and so can produce many different proteins. These proteins carry out a variety of functions that, in turn, affect the organism's traits.

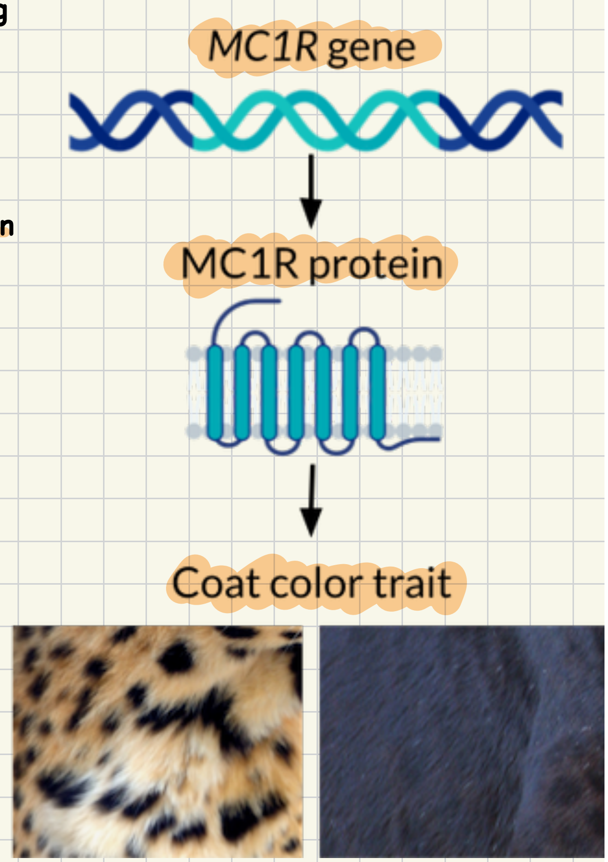
- The glowy jellyfish have a particular gene (made up of ±700 nucleotides) that produces a particular protein named GPF (Green Fluorescent Protein) that makes the jellyfish glowy! (Fluorescent)
- The order of nucleotides in a gene determines the order of amino acids in a protein that makes or forms the function or the role of that protein.

Illustrative example: coat color in leopards

Leopards and some of the cats known as black panthers are the same species (Panthera pardus), but they differ in their coat color trait. Leopards have a golden coat with black markings, while black panthers have a black coat.

In these cats, the coat color trait is influenced by the MC1R gene, which encodes the MC1R protein. The MC1R protein is a receptor located on the surface of cells responsible for producing melanin—the pigment that gives color to animals' skin and hair. When the MC1R receptor is activated, it triggers cells to produce eumelanin, which is a dark form of melanin. The more eumelanin produced, the darker the skin or hair color.

Leopards and black panthers have different variations in the MC1R gene, and therefore different versions of the MC1R protein. In black panthers, the MC1R protein is highly active, resulting in a higher production of eumelanin and a darker coat. In leopards, the MC1R protein is less active, resulting in the golden coat color trait.



Summary

Gene ⟶ Protein ⟶ Traits

In summary, an organism's genes determine the structure and function of its proteins. These proteins in turn carry out functions in the cell that influence an organism's traits.

In fact, it is the variation in genes among different organisms that leads to the vast diversity of life on Earth, as each unique genetic makeup leads to distinct physical and behavioral characteristics.

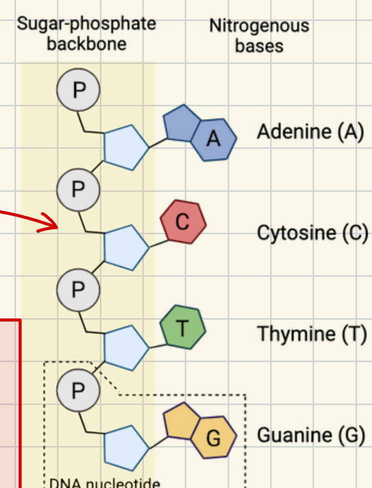
DNA is made up of nucleotides

DNA (deoxyribonucleic acid) is a nucleic acid biomolecule made up of subunits called nucleotides. Nucleotides make up an organism's genetic information—certain stretches of nucleotides in a DNA molecule are genes, which encode the proteins that affect an organism's traits. In addition, some stretches of nucleotides are involved in regulating when and how strongly those genes are expressed (used to make proteins).

gene expression: how genes are put together to make protein!

A DNA nucleotide has three components: a 5-carbon sugar (deoxyribose), a phosphate group, and a nitrogenous base. There are four types of nitrogenous bases found in DNA nucleotides: adenine, guanine, cytosine, or thymine. Scientists refer to nucleotides by the first letter of their base (A, G, C, and T, respectively).

Nucleotides are joined together by covalent bonds, which form between the deoxyribose sugar of one nucleotide and the phosphate group of the next. This arrangement makes an alternating chain of sugars and phosphate groups—a structure known as the sugar-phosphate backbone. Nucleotides can join together in any order, which means that any sequence of bases is possible.



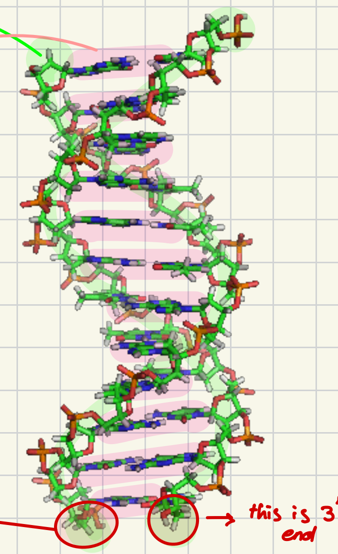
The structure of a DNA strand. DNA is made up of four types of nucleotides: adenine (A), cytosine (C), thymine (T), and guanine (G). Each nucleotide consists of a phosphate group (P), a deoxyribose sugar, and a nitrogenous base. The phosphate of one nucleotide is covalently bonded to the sugar of the next, forming a sugar-phosphate backbone.

DNA forms a double helix

In the cell, DNA takes on the form of a double helix, which consists of two DNA strands that wind around each other like a twisted ladder. The sugar phosphate backbones of the DNA strands are on the outside of the double helix, forming the sides of the ladder. The nitrogenous bases point inward towards one another, forming the rungs of the ladder.

strong bond : Sugar phosphate

weak hydrogen bonds : nitrogenous bases



A DNA double helix has three primary features that are important for its function: antiparallel strands, hydrogen bonds between strands, and complementary base pairing.

Antiparallel strands

Each strand of DNA in the double helix has directionality—that is, it has two ends that are different from each other. At one end, we find the phosphate group of the first nucleotide in the chain. This is called the 5′ end. At the other end, we find the deoxyribose sugar of the last nucleotide in the chain. This is called the 3′ end. When the two strands of DNA come together in a double helix, the strands are antiparallel. This means that they point in opposite directions—the 5' end of one strand aligns with the 3' end of its partner strand, and vice versa.

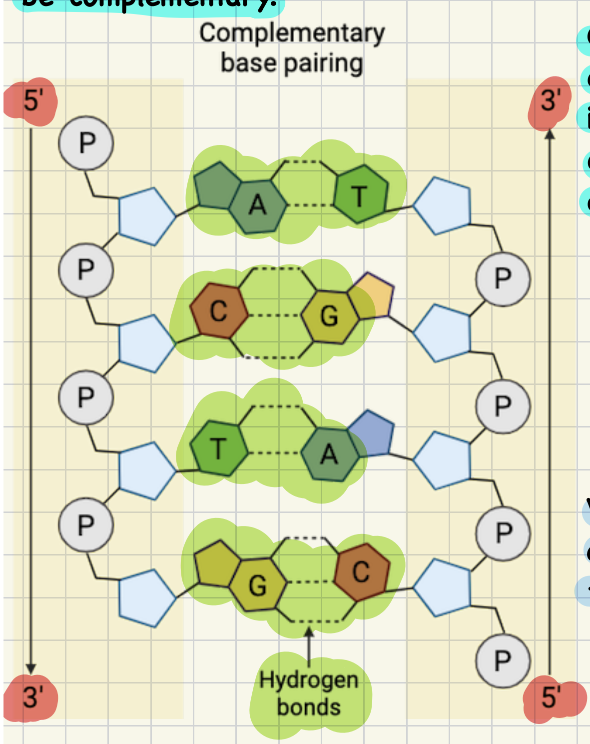
antiparallel ⇐ if this is 5′end,

Hydrogen bonds between strands

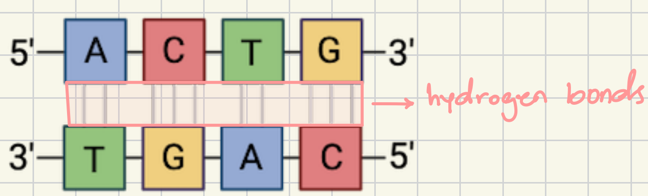
The two strands of DNA in a double helix are joined by hydrogen bonds, which form between the nitrogenous bases of nucleotides on opposite strands. Each individual hydrogen bond is relatively weak compared to the bonds that hold together the sugar-phosphate backbone. However, collectively the bonds provide enough force to hold the strands together while still allowing the strands to be separated during DNA replication (when DNA is copied).

Complementary base pairing

The hydrogen bonds between DNA strands occur between specific pairs of nitrogenous bases: T only pairs with A, and C only pairs with G. This specificity comes from the shapes of the bases and their chemical properties. Because the DNA strands are matched according to these base pairing rules, the strands are said to be complementary.



Complementary base pairing means that the two strands of a DNA double helix have a predictable relationship to each other. For instance, if we know that the sequence of one strand is 5′-ACTG-3′, then the complementary strand must have the sequence 3′-TGAC-5′. This allows each base to match up with its partner:



When scientists write out the sequence of a gene, they typically write only the nucleotides from one strand, in the 5′ to 3′ direction. So, if the above sequence were part of a gene, it would be written as ACTG.

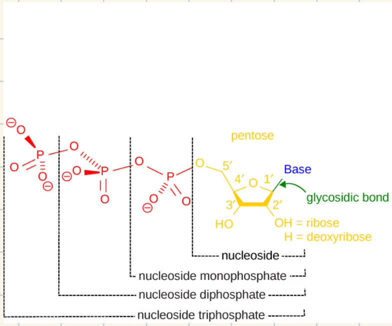
- The radius of a chromosome is about 1 nanometer !! (10^{-9} m)
- If we have half of the ladder, we can construct the rest.

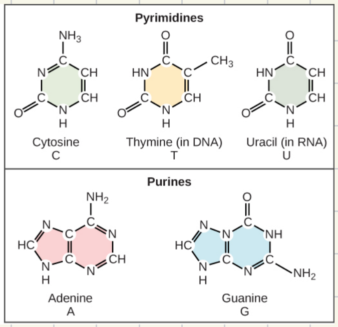
5′ TAATGGCAAAGCTA 3′
3′ ATTACCGTTTCGAT 5′

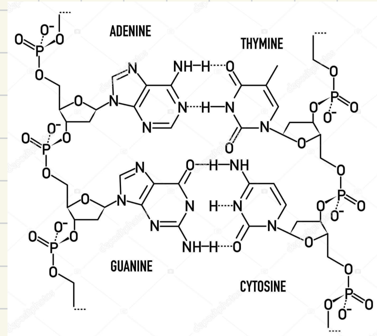
Adenine ___ Thymine

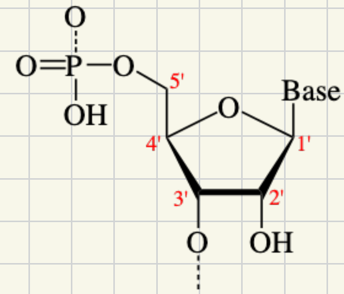
Guanine ___ Cytosine

6 billions base-pairs in 46 chromosomes. Human Genome





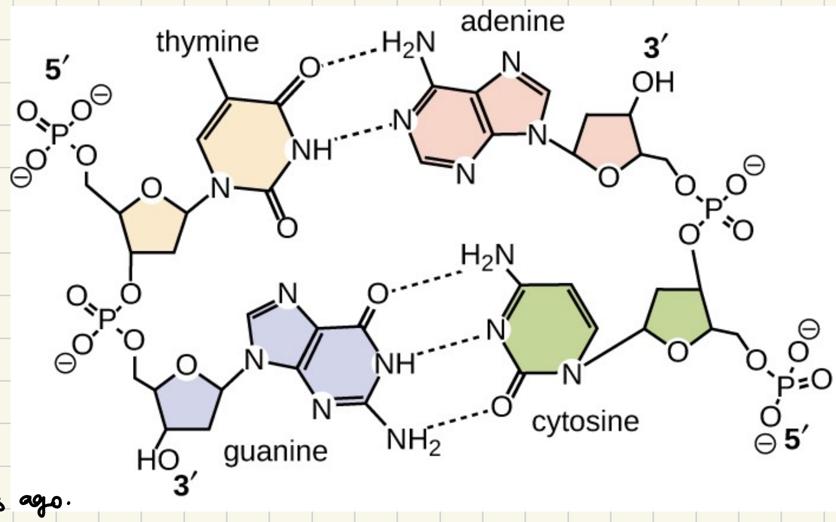




Directionality of DNA

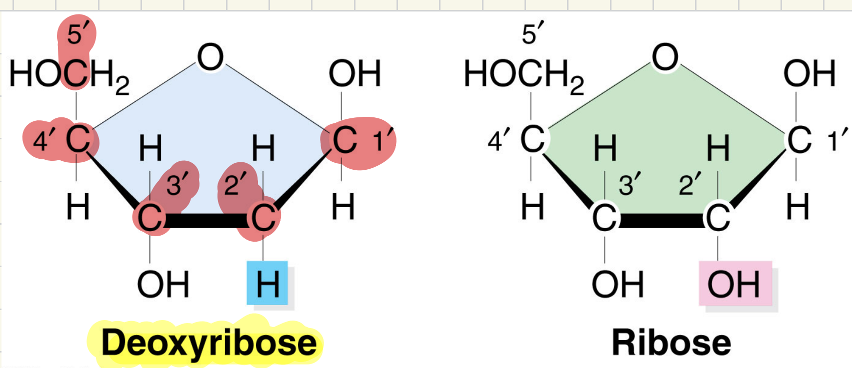
meaning of 5' to 3' and 3' to 5' in a molecular scale.

- Carbon 1' is connected to the nitrogenous base (Adenine, Thymine, Cytosine, Guanine)
- Carbon 2' has only a hydrogen (-H) in DNA.
- Carbon 3' has a hydroxyl (-OH) group, critical for phosphodiester bond.
  - → a type of chemical bond that holds the nucleotides of the DNA together. So phosphodiester bond is a bond where one phosphate groups connects two sugar molecules thro two easter linkages.
- Carbon 4' connects to the 3' carbon and 5' carbon.
- Carbon 5' sticks out from the ring and binds to the phosphate group.

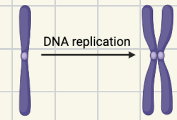


DNA: we didn't even know about DNA until 60 years ago.
↳ polymer
↳ monomer: nucleotide

we're gonna need 3 things to make a DNA molecule.
- a 5-carbon Sugar — Deoxyribose
- a phosphate group
- 1 of 4 Nitrogenous bases — what makes us, us!



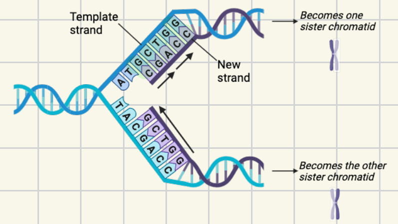
DNA replication occurs in preparation for cell division



As a eukaryotic cell prepares to divide, it copies all of its DNA through DNA replication, which takes place during the S phase of the cell cycle. During DNA replication, each of the cell's chromosomes is copied, forming a pair of sister chromatids attached at the centromere, ready to be divided into two daughter cells. When dividing, DNA gets copied through DNA replication.

DNA replication is semi-conservative

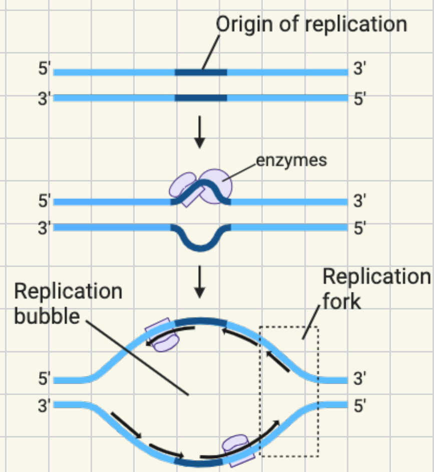
During DNA replication, the two strands of the DNA double helix are unwound and separated by enzymes. Each strand then serves as a template, or guide, for synthesizing a new, complementary strand. New DNA strands are built by enzymes using base pairing rules: adenine (A) is paired with thymine (T), and guanine (G) is paired with cytosine (C). This process ensures that each new DNA molecule is an exact copy of the original.



During DNA replication, the double helix is unwound and its strands are separated. Enzymes then pair complementary nucleotides to the template strand, creating new strands of DNA. Each new DNA double helix consists of one original (template) strand and one newly synthesized strand.

Each newly formed DNA double helix consists of one original strand (the template) and one newly synthesized strand. This pattern of replication, where each double-stranded DNA molecule contains one old strand and one new strand, is described as semi-conservative.

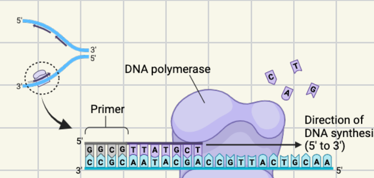
DNA replication begins at specific sites on the chromosome



DNA replication begins at sites on the chromosome called origins of replication. These short stretches of nucleotides serve as the sites where enzymes and other proteins can bind and begin to separate the DNA strands in preparation for replication. A eukaryotic chromosome has hundreds, or even a few thousand, origins of replication al'ong its length. This helps speed up the process of copying an entire chromosome.

To separate the DNA strands, enzymes disrupt the hydrogen bonds that hold the strands together. The area of the DNA where the strands have been separated is called a replication bubble. Each end of the replication bubble is called a replication fork. DNA replication proceeds outward in both directions from each origin of replication.

DNA polymerase synthesizes DNA



DNA polymerase is the enzyme responsible for synthesizing new DNA. To do this, DNA polymerase moves along a template strand and adds complementary nucleotides one at a time to a growing DNA molecule. DNA polymerase has the following key features:

DNA polymerase always needs a template strand in order to synthesize a new strand of DNA.

DNA polymerase can only add nucleotides to the 3' end of a DNA strand. This means that a new DNA molecule is always synthesized from its 5' end to its 3' end.

DNA polymerase cannot initiate the synthesis of a new DNA strand without a primer—a short stretch of complementary nucleotides that are added to the template strand by a different enzyme.

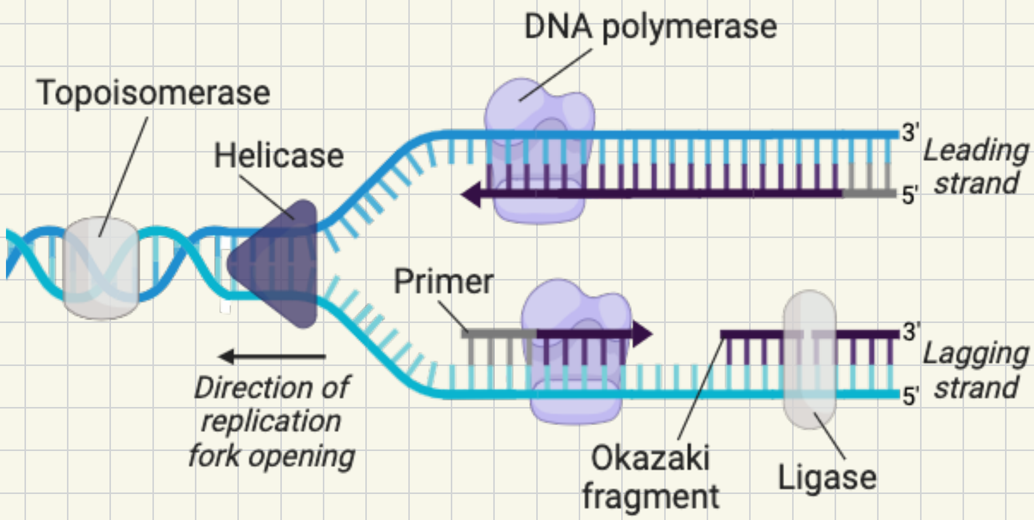
DNA polymerase proofreads, or checks its work. This allows the enzyme to remove and replace the vast majority of mismatched nucleotides that are accidentally added to a new DNA strand.

Leading and lagging strand synthesis

At each replication fork, two new DNA strands are made, each one complementary to a template strand. The new strands must be antiparallel to their template strands (the 5' end of the template strand must align with the 3' end of the new strand, and vice versa). This, together with the fact that DNA polymerase can add nucleotides only in the 5' to 3' direction, means that the two new strands must be synthesized differently:

Leading Strand Synthesis: The leading strand is synthesized continuously (in one long piece) as nucleotides are added in the 5′ to 3′ direction moving toward the unwinding replication fork. Only one primer is required for DNA polymerase to synthesize the entire leading strand.

Lagging Strand Synthesis: In contrast, the lagging strand is synthesized discontinuously (in short fragments) because DNA polymerase must work in the direction opposite the direction in which the replication fork is opening. These short fragments are called Okazaki fragments. Later, another enzyme called ligase joins the Okazaki fragments into one long, continuous strand. Each Okazaki fragment requires a primer to begin its synthesis.



Summary table

The following table summarizes the functions of enzymes involved in DNA synthesis.

Enzyme	Function
DNA polymerase	synthesizes new DNA strands by pairing nucleotides with a template strand
topoisomerase	makes temporary cuts in DNA to help relieve the stress that builds up as the DNA double helix is unwound
helicase	separates double-stranded DNA by disrupting the hydrogen bonds between complementary bases
primase	synthesizes short nucleic acid primers that provide a starting point for DNA polymerase to begin DNA synthesis
ligase	joins together discontinuous fragments of DNA (such as Okazaki fragments on the lagging strand) into a single continuous strand

Replicating the ends of DNA molecules

The mechanics of DNA replication make it difficult for the cell to replicate the ends of DNA molecules. As a result, repeated rounds of replication cause a cell's chromosomes to become shorter. In order to protect the cell from losing important genetic information, chromosomes have special nucleotide sequences on their ends called telomeres.

Telomeres consist of short, repeated nucleotide sequences that act as a buffer zone during DNA replication. For example, human telomeres consist of the TTAGGG sequence repeated 100-1,000 times. Telomeres shorten with every cell division—a phenomenon which is linked to aging.

Telomerase, an enzyme active in germ cells, can extend telomeres, ensuring that offspring inherit chromosomes with complete ends. Telomerase is typically inactive in somatic (body) cells, which is thought to defend against cancer by limiting the number of times a cell can replicate. However, in many cancer cells, telomerase is reactivated, potentially allowing these cells to multiply indefinitely.

DNA proofreading and repair

DNA replication is highly accurate—typically only 1 in 100,000 nucleotides is added to a growing DNA molecule incorrectly. However, the cell has additional mechanisms to correct mistakes, bringing the final error rate of DNA replication to only 1 mistake per 10 billion replicated nucleotides! These mechanisms include proofreading by DNA polymerase, and a process called mismatch repair.

Proofreading: DNA polymerase checks each added nucleotide for errors during DNA replication. If it finds a mistake, it removes the incorrect nucleotide and then continues synthesis with the correct nucleotide in place.

Mismatch repair: Mismatch repair is a cellular process that corrects errors in DNA that escape the initial proofreading by DNA polymerase. Specialized enzymes recognize and fix these mismatches, ensuring the accuracy of DNA replication.

Accuracy of DNA replication is important—without repair mechanisms, mutations (changes) in the DNA accumulate in cells, which can lead to cancer.

In DNA replication, which of the following events happens during both leading and lagging strand synthesis?

- (Choice A) DNA polymerase synthesizes a single, continuous strand of DNA.
- (Choice B) Topoisomerase separates complementary strands of DNA.
- (Choice C) Ligase joins together multiple Okazaki fragments.
- (Choice D) RNA primers help initiate DNA synthesis.

The correct answer is:

(Choice D) RNA primers help initiate DNA synthesis.

Explanation:

During both leading and lagging strand synthesis, RNA primers are required to initiate DNA synthesis. DNA polymerase cannot begin synthesis on a bare single-stranded template; it needs a primer with a free 3' hydroxyl group to add nucleotides.

On the leading strand, a single RNA primer is used at the origin, and DNA polymerase continuously extends the new strand.

On the lagging strand, multiple RNA primers are needed to initiate synthesis of each Okazaki fragment.

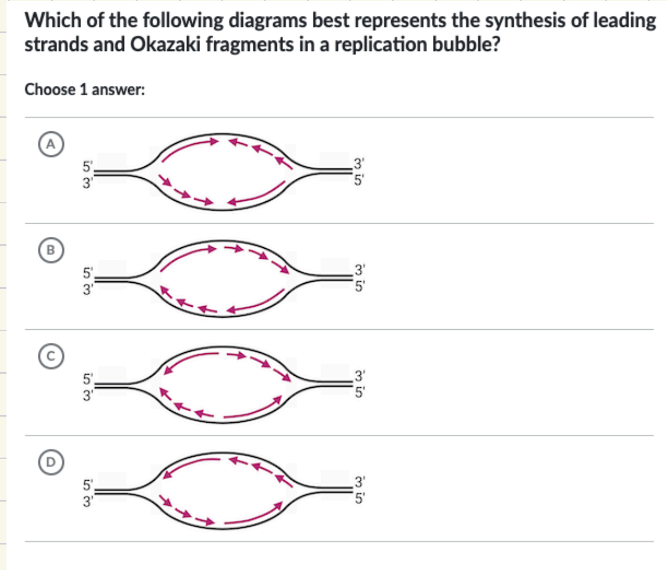
Let's briefly address why the other choices are incorrect:

(A) DNA polymerase synthesizes a single, continuous strand — this only happens on the leading strand.

(B) Topoisomerase relieves supercoiling ahead of the replication fork, but it does not separate complementary strands — that's the job of helicase.

(C) Ligase joins Okazaki fragments — this is specific to the lagging strand only.

🔁 What is happening in the replication bubble?
Each side of the bubble has:
Two template strands (top and bottom), each with a direction: 5′ → 3′ or 3′ → 5′.
DNA polymerase can only build in the 5′ → 3′ direction — this means it must read the template 3′ → 5′ (because synthesis is antiparallel).
🧠 Key ideas from the image:
Arrows = direction of DNA synthesis.
Long arrows = leading strand (continuous synthesis).
Short arrows = Okazaki fragments on the lagging strand (discontinuous synthesis).
Each new DNA strand must point toward the 5′ end of its template — because DNA synthesis always happens 5′ → 3′ relative to the new strand.
Correct diagram (D):
It shows all arrows pointing in the right 5′ → 3′ direction.
This ensures synthesis is happening antiparallel to each template strand.



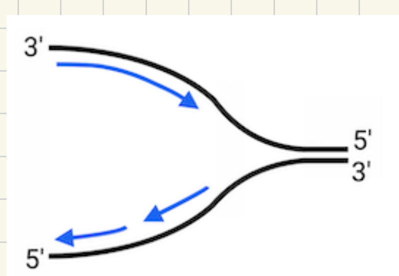
The answer is D.

🧬 Example:
Let's look at the top-left fork in Diagram D:
Template strand is 3′ → 5′ (top to bottom), so new strand must go 5′ → 3′ (bottom to top).
That's exactly what the arrow shows.
Same logic applies to all arrows in Diagram D.
✅ Summary:
DNA synthesis is antiparallel, and always 5′ → 3′.
Arrows in diagram D all point in the correct direction of synthesis.
That's why diagram D is correct — it shows both leading and lagging strands correctly oriented.

During lagging strand synthesis, ligase joins together multiple Okazaki fragments.
Why the other options are incorrect:
(A) ❌ Topoisomerase doesn't separate complementary strands — that's helicase's job. Topoisomerase relieves supercoiling stress ahead of the fork.
(C) ❌ DNA synthesis is initiated by an RNA primer, not a DNA primer. Primase makes the RNA primer.
(D) ❌ The leading strand is synthesized continuously, not in short, discontinuous pieces — that's the lagging strand.

All of the diagrams depict one long arrow, which represents a growing leading strand, and two short arrows, which represent growing Okazaki fragments. However, the diagrams differ in how these arrows are oriented relative to the template strands. In the correct diagram, all of the arrows will point in the direction of DNA synthesis, as is convention.

DNA synthesis always occurs antiparallel to the template DNA and in the 5′ to 3′ direction. So, in the correct diagram, each arrow will point towards the 5′ end of its template strand:



Proteins do the work of cells

Proteins are a diverse group of biomolecules that carry out many important functions in the cell. The table below summarizes the major types of proteins and their functions, and provides an example of each protein type.

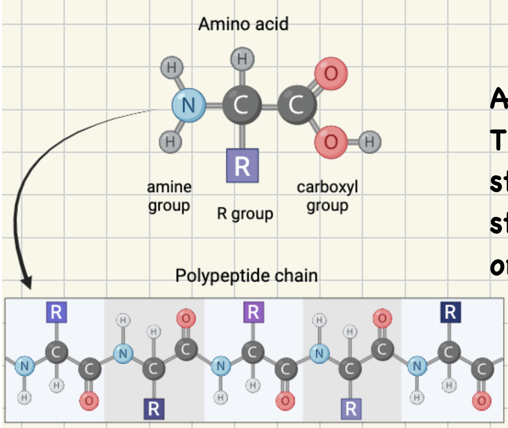
Protein type	Function	Example
Enzymes	catalyze (help speed up) chemical reactions in the cell	Amylase is found in saliva and helps break down starch into simple sugars.
Structural proteins	provide physical support to the cell	Keratin is the protein that gives hair, horns, and feathers their strength.
Transport proteins	facilitate the transport of materials across cellular membranes	Aquaporins form channels in the cell membrane and regulate water movement in and out of cells.
Motor proteins	aid with movement	Actin and myosin are responsible for the contraction of muscles.
Receptor proteins	help the cell sense and respond to stimuli	Rhodopsin is found in the eye where it senses light and helps transmit signals to the brain.
Regulatory proteins	control and coordinate biological processes in the organism	Insulin is a protein hormone that helps regulate glucose metabolism in the body.
Defensive proteins	help protect against disease	Interleukin-2 promotes the growth, proliferation, and differentiation of immune cells.

Proteins are made up of amino acids

Despite their varied functions, all proteins are made up of subunits called amino acids. An amino acid consists of a central carbon atom (C) bonded to by an amine group (NH2), a hydrogen atom (H), a carboxyl group (COOH), and a variable component called a functional group Functional groups are also called side chains or R groups, because they are typically designated with an "R" in molecular models.

There are 20 standard amino acids, each with a unique R group that ranges from a simple hydrogen atom (in the amino acid glycine) to more complex ring or chain structures. The properties of the R group influence the overall properties of the amino acid (such as whether it is hydrophobic, hydrophilic, acidic, or basic), which in turn affect the protein's structure and function.

Amino acids are covalently bonded together, forming a chain called a polypeptide. One or more polypeptides are then folded into a specific three-dimensional (3D) shape to become a biologically active protein.



A protein's function depends on its 3D shape

The formation of a functional protein from amino acids occurs in several stages, referred to as primary, secondary, tertiary, and quaternary structures. Each stage represents a progressively complex level of organization for the protein.

Primary structure: A protein's primary structure is the polypeptide chain—a specific sequence of amino acids linked by covalent bonds. The order of amino acids in the polypeptide chain lays the foundation for the protein's final shape and function.

Secondary structure: A protein's secondary structure involves folding of the amino acid chain into repeating structures such as alpha helices and beta sheets. These structures are primarily stabilized by hydrogen bonds between backbone (non-R-group) atoms.

Tertiary structure: A protein's tertiary structure refers to the overall 3D shape of a single protein molecule, formed by the folding of the secondary structures. It is stabilized by various interactions among R groups, including hydrophobic interactions, hydrogen bonds, ionic bonds, and disulfide bridges.

Quaternary structure: Quaternary structure describes when two or more folded polypeptides come together to form a functional protein complex.

In summary, the type and sequence of amino acids (and their R groups) determine how a protein folds. The process of going from primary structure to tertiary or quaternary structure establishes a protein's final shape, chemical properties, and cellular functions.