Name: ______________________________ Period: _________ Date: ________

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Chloroplasts

Chloroplasts in plant and algal cells absorb light energy from the sun during the **light dependent reactions** of photosynthesis.

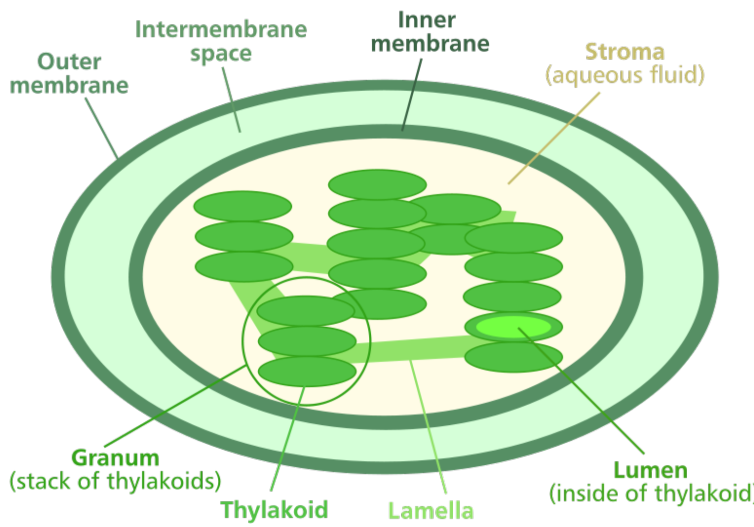
Chloroplasts are double membrane organelles with an inner membrane folded into disc-shaped sacs called **thylakoids**.

Thylakoids

Thylakoids occur in stacks called **grana**.

Grana are connected to each other and surrounded by a gel-like material called **stroma**.

Light-capturing pigments in the grana are organized into **photosystems**.



Light Energy

Light travels as waves and packets called **photons**.

A **wavelength** of light is the distance between 2 consecutive peaks or troughs. Sunlight, or white light, is made of different wavelengths or colors carrying different amounts of energy.

A **prism** separates white light into 7 colors called the **visible spectrum**.

Pigments

When light strikes an object, it is absorbed, transmitted, or reflected.

A **pigment** is a substance that only absorbs certain wavelengths.

When all colors are absorbed, the object appears black.

When all colors are reflected, the object appears white. If only one color is reflected, the object appears that color.

Pigments in Chloroplasts

Thylakoids contain a variety of pigments.

Chlorophyll is the most common pigment in plants and algae. **Chlorophyll a** and **chlorophyll b** are the two most common types of chlorophyll in autotrophs. Chlorophyll absorbs only red, blue, and violet light.

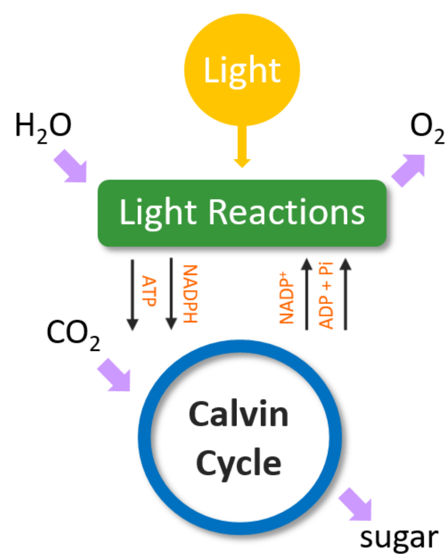
Chlorophyll b absorbs colors or light energy not absorbed by chlorophyll a. The light energy absorbed by chlorophyll b is transferred to chlorophyll a in the light reactions.

Carotenoids are yellow, orange, and red accessory pigments in the thylakoids.

- Light independent, or dark reactions

Light Dependent Reactions

Light reactions take place in thylakoids and depend on sunlight for activation energy.



Light Independent Reactions

Although **dark reactions** depend on the products from light reactions, they do not directly require energy from light.

Dark reactions take place in the stroma.

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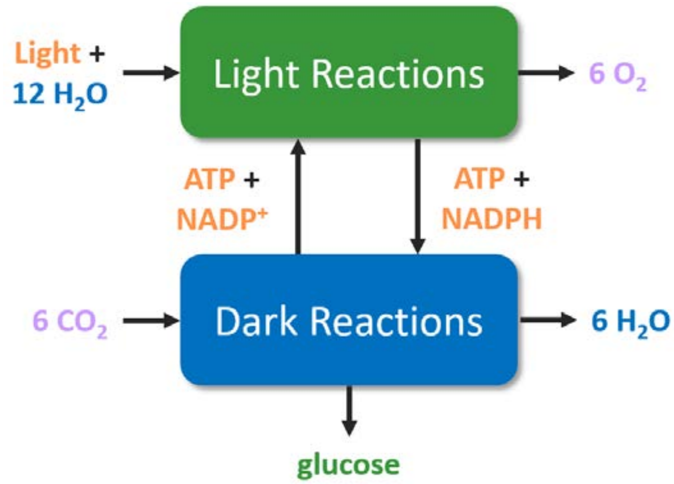
The Calvin Cycle



In the Calvin Cycle, carbon atoms from CO_2 are bonded into organic compounds during a process called **carbon fixation**.

Since each turn fixes 1 CO_2, it takes 6 turns to make 1 molecule of glucose.

Alternate Pathways

The Calvin Cycle is the most common pathway used by autotrophs called **C_3 plants**.

C_4 plants exist in hot, dry climates and use **alternate pathways** to fix carbon and transfer it to the Calvin Cycle.

Stomata are small openings on the underside of leaves that exchange O_2 and CO_2 with the environment.

Guard cells close the stoma during the hottest part of the day so that plants don't lose too much H_2O.

Cellular Respiration

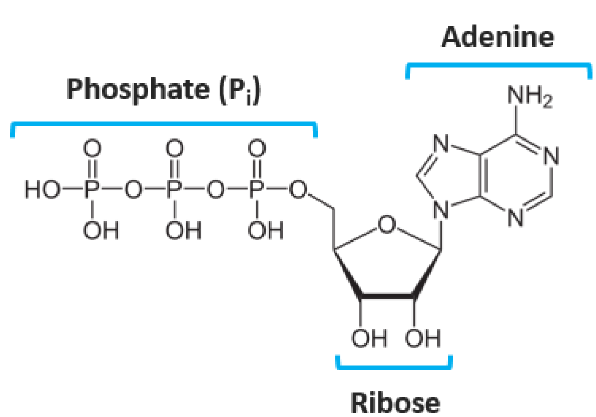
Oxygen is vital to the process of aerobic respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy

However, anaerobic respiration takes place without oxygen: $C_6H_{12}O_6 \rightarrow C_3H_6O_3$ + energy

Cellular respiration takes place within **mitochondria**.

Adenosine Triphosphate (ATP)

ATP Structure



ATP is the primary energy carrying molecule used by cells to fuel their cellular processes.

The 3 phosphate groups within ATP are commonly referred to as **P_i**.

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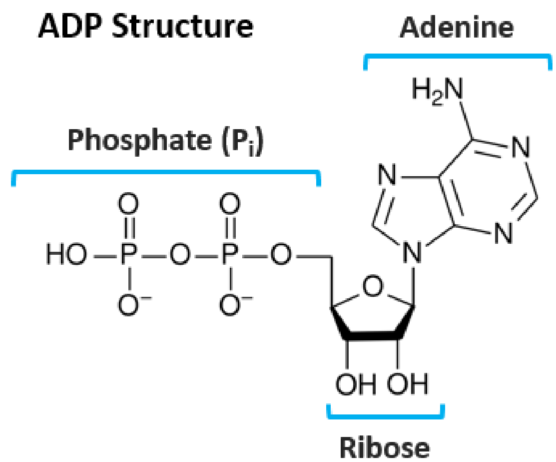
Adenosine Diphosphate (ADP)

Phosphorylation refers to the chemical reactions that make ATP by adding P_i to ADP, an energy molecule containing 2 phosphate groups.

ADP + P_i + energy → ATP + H_2O

Enzymes help break and reform PO_4 bonds in a process called **substrate-level phosphorylation**.



4 Series of Reactions

Aerobic cellular respiration is a biochemical pathway made up of 4 series of reactions:

1. **Glycolysis:** A reaction that converts glucose into 2 pyruvates.
2. **Pyruvate Oxidation:** A reaction that converts each pyruvate into Acetyl CoA.
3. **Citric Acid Cycle (Krebs Cycle):** A reaction that completes the breakdown of glucose and fuels the production of ATP.
4. **Oxidative Phosphorylation:** A reaction that uses energy carrying molecules produced in the citric acid cycle to mass produce ATP.

What is Anaerobic Respiration?

Anaerobic respiration takes place when there is too little oxygen for aerobic respiration to take place.

Organisms that live in low-oxygen environments, such as certain types of bacteria and archaea, depend on anaerobic pathways for all of their energy production.

Fermentation

Fermentation is an anaerobic pathway that is commonly seen in plants and animals. During fermentation, **glycolysis** is the only energy extraction pathway that takes place.

The NADH produced during glycolysis deposits its electrons into the pyruvates, returning to its empty NAD^+ form. This steady supply of NAD^+ ensures that glycolysis can keep running.

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Lactic Acid Fermentation

In animals, a type of anaerobic respiration called **lactic acid fermentation** takes place when the heart and lungs are unable to supply enough oxygen to meet the body's energy demand.

- Example**:** After strenuous exercise, muscle cells lack enough oxygen to carry out aerobic respiration. As anaerobic respiration takes place, lactic acid builds up in the muscle tissue, causing soreness.

The impulse to breathe in large amounts of oxygen after exercise is the body's way of removing lactic acid from its tissues.

Alcohol Fermentation

Yeast are capable of aerobic respiration and a type of anaerobic respiration called alcohol fermentation.

In alcohol fermentation, a carboxyl group is removed from each pyruvate and released as CO_2, producing a 2-carbon molecule called **acetaldehyde**. NADH deposits its electrons into the acetaldehydes, producing 2 **ethanol** molecules.

Since ethanol is toxic to yeast, only a certain percentage of alcohol can be produced before the yeast die.

Energy Production

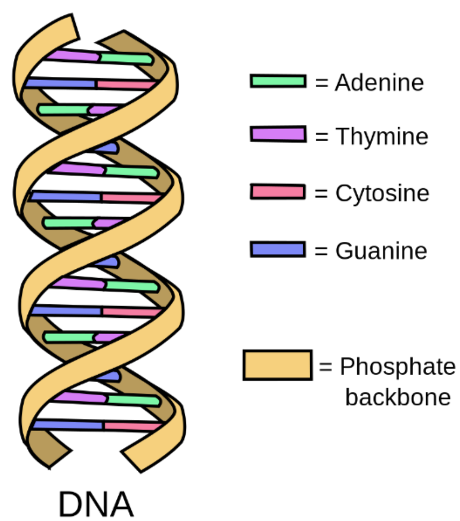
Since fuel molecules are not completely broken down in anaerobic respiration, less energy is produced as a result.

In total, only 2 ATP are produced from anaerobic pathways like fermentation.

DNA in Chromosomes

In the early 1900s, **Walter Sutton** deduced that units of inheritance are contained within chromosomes.

After demonstrating that chromosomes occur in distinct pairs during cellular division, Sutton became the first to explain the inheritance patterns first observed by Gregor Mendel in the 1860s.



The Molecule of Heredity

In 1952, **Martha Chase** and **Alfred Hershey** confirmed that DNA is genetic material.

By demonstrating that bacteriophages infect bacterial cells with their DNA and not their proteins, the Hershey-Chase experiments revolutionized the role of DNA in science.

The Double Helix

Also in 1952, **Rosalind Franklin** and her student, Raymond Gosling, captured a striking image of the structure of DNA using X-ray crystallography.

Nitrogen Bases

The rungs of DNA are composed of 2 classes of nitrogen-containing bases:

1. **Purines** are double carbon-nitrogen rings that include adenine (A) and guanine (G).
2. **Pyrimidines** are single carbon-nitrogen rings that include thymine (T) and cytosine (C).

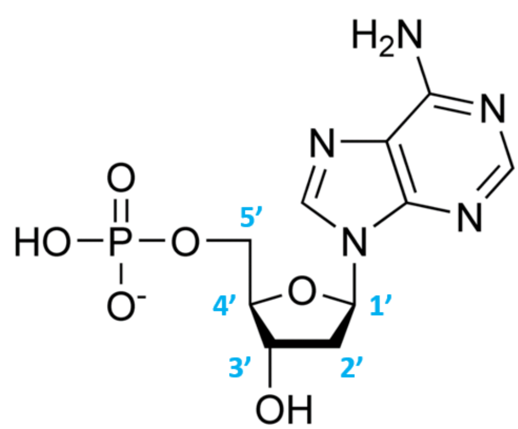
Base pairing occurs when a purine joins with a pyrimidine. Adenine always pairs with thymine, while guanine always pairs with cytosine.

Phosphodiester Bonds

The nucleotide monomers within DNA are connected by strong electromagnetic attractions called **phosphodiester bonds**.

Carbons within a deoxyribose sugar are systematically numbered starting at 1’ on its right side and continuing in a clockwise fashion to 5’.

When nucleotides within DNA link together, the 5’ carbon of the first molecule always joins with the 3’ carbon of the second molecule. These bonds are called **5’-3’ phosphodiester bonds**.



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Hydrogen Bonds

When a double helix is forming, the nucleotides within one DNA strand are connected to the nucleotides within the second DNA strand by **hydrogen bonds**.

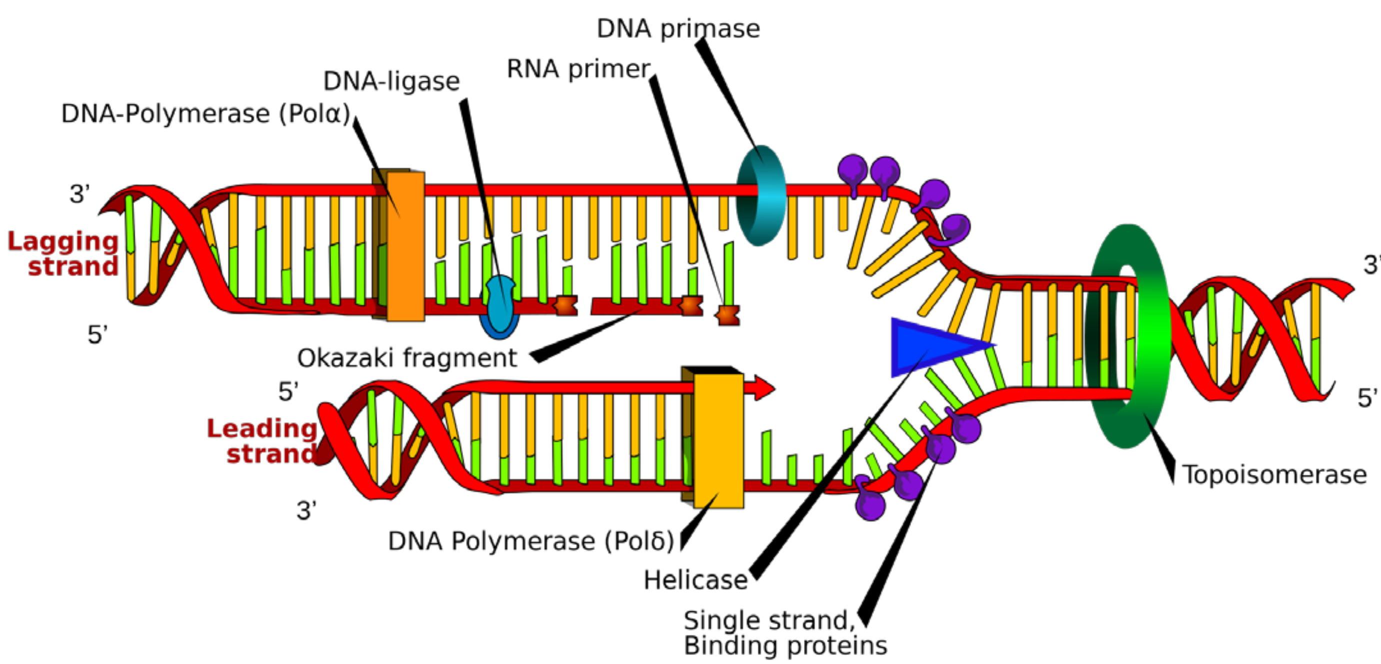
DNA Function

Housed within a cell's nucleus, DNA contains all of the instructions for making **proteins**, a polymer made up of amino acid monomers.

Proteins are versatile molecules within cells that are capable of carrying out a wide variety of functions. All of an organism's traits are determined by interactions between proteins and their environments.

DNA Replication

DNA replication is the process by which DNA makes a copy of itself. When a cell divides, the DNA within its nucleus is split into two single strands. Each strand is a template for a new complementary strand of DNA.



Origin of Replication

DNA replication always begins at a specific point called the **origin of replication**. Specialized proteins bind to the origin and open the DNA, creating two Y-shaped structures called **replication forks**.

Helicase

Cells utilize enzymes and proteins in order to carry out DNA replication in a rapid, accurate manner.

Helicase is the first enzyme that acts on the origin point. Its main job is to break the hydrogen bonds between complementary nitrogenous base pairs. This process unzips the double helix into 2 single strands.

Replication Cleanup

Once **DNA polymerase** reaches the end of a strand, it cleans up leftover primers and seals any gaps in the DNA.

Meanwhile, **DNA ligase** seals the Okazaki fragments together in the lagging strand and **nuclease** proofreads the DNA and fixes any errors.

Types of RNA

There are three types of RNA:

1. **Messenger RNA (mRNA)** is a single, uncoiled, straight strand of nucleic acid.
2. **Transfer RNA (tRNA)** is a single stranded molecule in the shape of a cloverleaf.
3. **Ribosomal RNA (rRNA)** is a single stranded molecule with a globular shape.

Messenger RNA

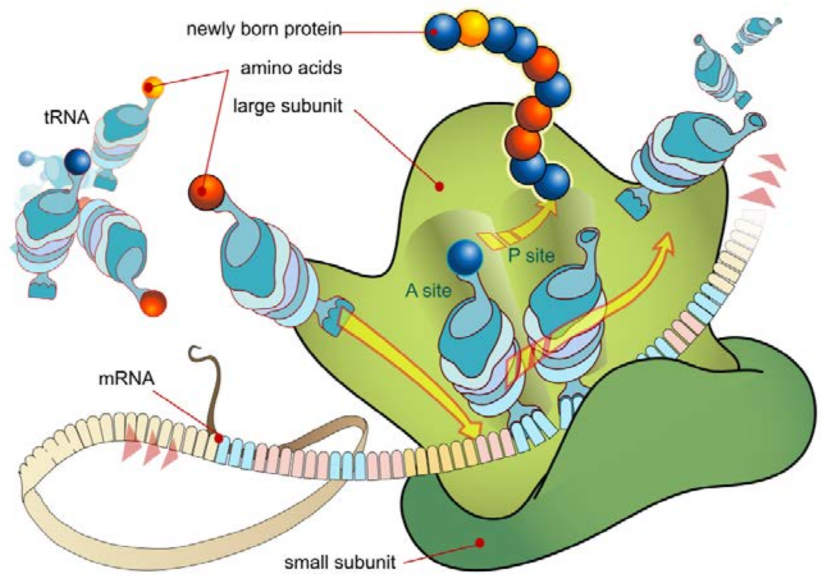
Messenger RNA (mRNA) is found in a cell's nucleus and cytoplasm. Its function is to copy DNA's protein-making instructions in a process called **transcription** and carry them to ribosomes.

The base sequence of mRNA is translated into the amino acid sequence of a protein. The three consecutive bases on mRNA are called a **codon**.

Transfer RNA

Transfer RNA (tRNA) contains 80 nucleotides. Its function is to carry amino acids from cytoplasm to ribosomes for protein assembly.

After entering a ribosome, tRNA reads mRNA codons and links the correct sequence of amino acids together to make a protein. The 3 bases of tRNA that are complementary to a codon on mRNA are called **anticodons**.



Ribosomal RNA

Ribosomal RNA (rRNA) is a structural component of ribosomes.

Along with ribosomal proteins, rRNA form the large and small subunits that make up ribosomes.

Ribosomes are the site of **translation**, the production of polypeptides.

Protein Synthesis

Amino acids are linked together into polypeptides during a process called **protein synthesis.**

DNA Replication in Cell Division

As cells divide, DNA must be copied into 2 identical sets of the original DNA molecule. This process is called **DNA replication**.

Chromosomes

Within a cell's nucleus, DNA is stored inside of giant molecules called **chromosomes**. Each chromosome is made of proteins and a single, tightly coiled DNA molecule.

DNA in eukaryotic cells wraps tightly around proteins called **histones** to help pack the DNA during cell division.

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The center point of a chromosome is called the **centromere**. Centromeres hold duplicated chromosomes together before they are separated in mitosis.

The tips of chromosomes are called **telomeres**. Telomeres play an important role in cell aging.

While DNA is replicating, each half of the chromosome is called a **sister chromatid**.

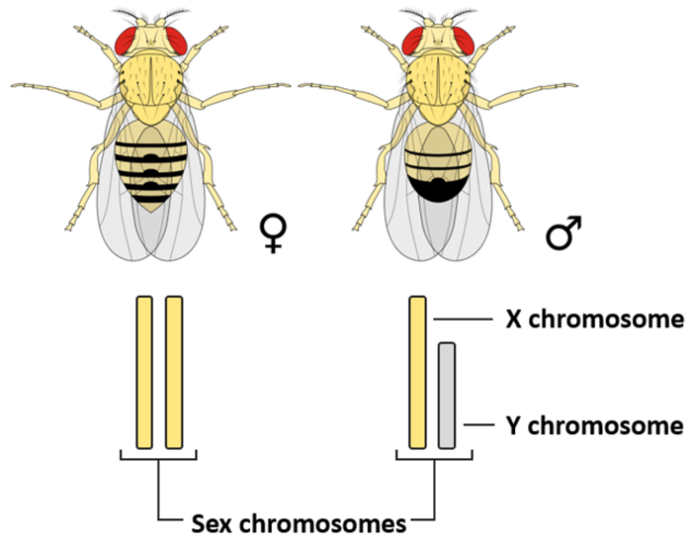
Chromosome Numbers

The 2 chromatids in a chromosome pair are called **homologues**, meaning they have genes for the same trait at the same location.

Sex Chromosomes

Sex chromosomes, either X or Y, determine the sex of an organism.

An organism with two X chromosomes (XX) will be female, while an organism with one X chromosome and one Y chromosome (XY) will be male.



Karyotypes

With the exception of X and Y chromosomes, all other chromosomes are called **autosomes**.

The complete number and arrangement of chromosomes within an organism is called a **karyotype**.

Cell Cycle Phases

Cells undergo several phases called **the cell cycle** during their lifetime.

The cell cycle includes 2 main stages:

1. **Interphase:** also called the resting phase.
2. **Cell division:** also called the mitotic phase.

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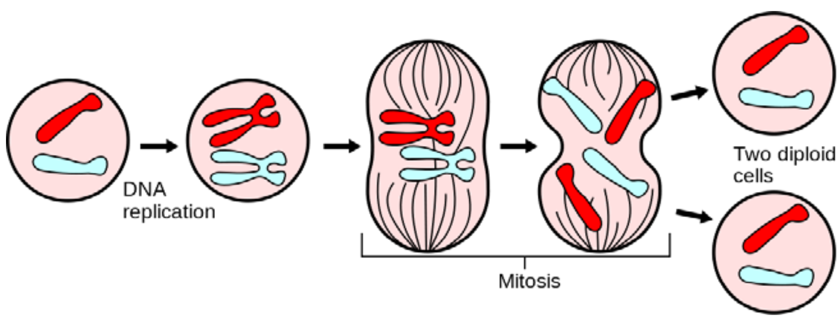
Interphase

Interphase, the longest part of the cell cycle, consists of 3 phases:

1. **1st Growth Phase (G_1)** occurs after a cell has undergone cell division. During this phase, cells increase in size by making more cytoplasm and organelles.
2. **Synthesis Phase (S)** follows the G_1 phase. During this phase, DNA is replicated.
3. **2nd Growth Phase (G_2)** occurs after the S phase. During this phase, the cell makes all the structures necessary for division.



Mitosis

During the mitotic phase, the mother cell divides into 2 daughter cells that are genetically identical to itself.

Mitosis consists of 4 phases:

1. **Prophase**
2. **Metaphase**
3. **Anaphase**
4. **Telophase**

Meiosis

Meiosis is a type of cell division that only takes place in gametes, sex cells like egg and sperm.

Gametogenesis

The meiotic production of a mature ovum, or egg cell, is called **oogenesis**.

The meiotic production of mature sperm cells is called **spermatogenesis**.

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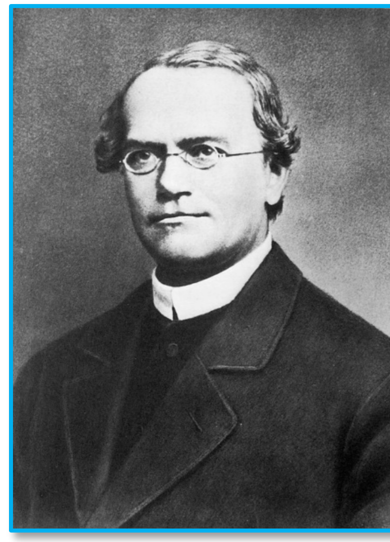

Gregor Mendel

Gregor Mendel was an Austrian monk that studied science and math at the University of Vienna.

During a statistical study of traits in garden peas, Mendel established rules of heredity that laid the groundwork for the modern field of genetics.

Although his work was ignored by fellow scientists of his day, Mendel is now widely regarded as the **father of modern genetics**.

Blending Inheritance

Before Mendel's experiments, scientists largely accepted the **blending theory of inheritance**.

This theory incorrectly stated that an offspring would have traits between those of its parents, such as red and white flowers producing pink flowers.

According to this theory, the appearance of red or white flowers was evidence of instability in genetic material.

Mendel's Laws

As a result of his work with garden peas, Gregor Mendel came to three generalized conclusions that disproved blending inheritance. These conclusions are now known as **Mendel's Laws of Inheritance**:

1. **Law of segregation:** As gametes form, alleles separate so that each gamete only carries one allele for each gene.
2. **Law of independent assortment:** The segregation of alleles for a gene is independent of other genes.
3. **Law of dominance:** Organisms with a dominant and recessive allele will express the dominant allele.

Pisum sativum

Mendel chose to work with ***Pisum sativum***, a pea variety that produces lots of offspring and grows well in confined areas.

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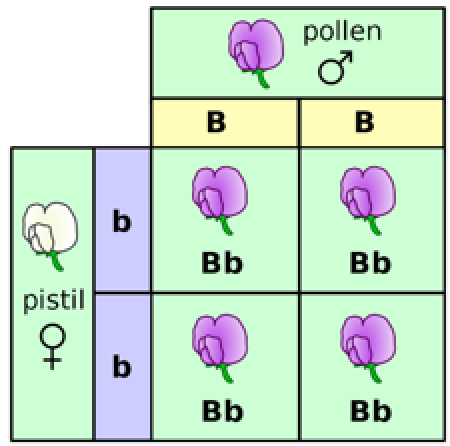
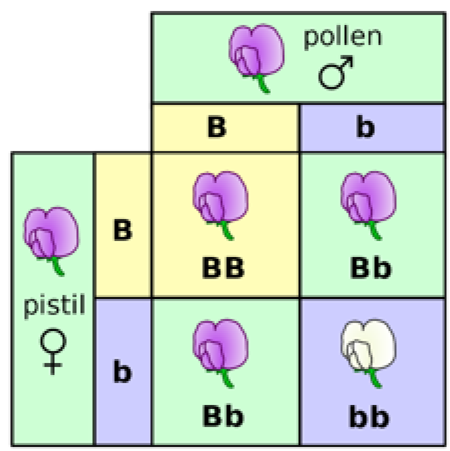
During his study, Mendel tracked 7 traits:

- **Plant height:** Tall (T) or short (t)
- **Flower color:** Purple (P) or white (p)
- **Flower position:** Axial (A) or terminal (a)
- **Pea color:** Yellow (Y) or green (y)
- **Pea shape** Round (R) or wrinkled (r)
- **Pod color:** Green (G) or yellow (g)
- **Pod shape:** Smooth (S) or wrinkled (s)

Allele: B or b
Genotype: BB, Bb, or bb
Phenotype: purple or white



F_1 generation



F_2 generation

Pea Experiments

Mendel began his experiments by allowing the plants to self-pollinate for several generations. These pure strains were called the **Parental generation**, or **P generation**.

Offspring produced from crosses between the P generation plants were called the **first filial generation**, or **F_1 generation**. This generation was made up entirely of hybrids (Bb) displaying dominant traits.

An entirely dominant (BB) or recessive (bb) trait is **homozygous**, while a mixed (Bb) trait is **heterozygous**.

When 2 hybrids from the F_1 generation were crossed, 75% of the offspring displayed the dominant trait, and 25% displayed the recessive trait. This generation was called the **F_2 generation**.

Mendel's Results

After conducting his garden pea experiments, Mendel discovered that inheritable factors, or **genes**, are responsible for all heritable characteristics.

Each trait is based on two genes, one from the mother and one from the father.

An offspring's **phenotype**, its observable characteristics, will be determined by its **genotype**, the collective alleles inherited from each parent.

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Incomplete Dominance

In a typical scenario, such as free (G) or attached (g) earlobes, heterozygous offspring always display the dominant (G) trait.

However, **incomplete dominance** can occur when there is more than one version of a gene type.

- Example: There are 2 versions of the hair type gene: curly (CC) and straight (ss).

	C	C
s	Cs	Cs
s	Cs	Cs

Offspring that receive the Cs genotype will display wavy hair, a phenotype between curly and straight.

Multiple Alleles

In some populations, 3 or more alleles may determine a trait.

- Example: The ABO blood group is made up of 3 alleles that form the following blood types: A , B, AB, and O.

  Since O is recessive, heterozygous O offspring will always have the blood type of the other allele, such as A or B.

	A	B	O
A	AA	AB	AO
B	AB	BB	BO
O	AO	BO	OO

Polygenic Inheritance

Polygenic inheritance occurs whenever there are many variations in resulting phenotypes, such as hair, skin, and eye color.

- Example**:** A father with the eye color genotype AaBb and a mother with the eye color genotype AaBb would be capable of producing many eye colors.

  AaBb → AB, Ab, aB, ab

	AB	Ab	aB	ab
AB	**AA BB** dark brown	**AA Bb** med. brown	**Aa BB** med. brown	**Aa Bb** light brown
Ab	**AA Bb** med. brown	**AA bb** light brown	**Aa Bb** light brown	**Aa bb** green
aB	**Aa BB** med. brown	**Aa Bb** light brown	**aa BB** light brown	**aa Bb** green
ab	**Aa Bb** light brown	**Aa bb** green	**aa Bb** green	**aa bb** blue

Punnett Square Limitations

A Punnett square is a visual way of representing mathematical probabilities. However, calculating more than 2 alleles with Punnett squares can become tedious and error-prone.

- Example: It would require a Punnett square with 1,024 boxes in order to cross a father with the genotype AaBbCcDdEe and a mother with the genotype AaBbCcDdEe.

Human Chromosomes

Humans receive most of their chromosomes in **homologous pairs**.

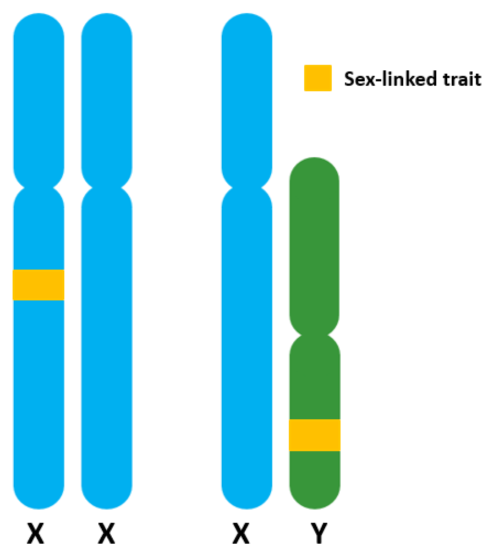
Within a homologous pair, each chromosome contains genes in the same order. However, these chromosomes sometimes carry different versions of those genes.

Although all chromosomes in females are homologous pairs, the X and Y sex chromosomes in males are not a homologous pair.

Sex-Linked Traits

Genes located on sex chromosomes are referred to as **sex-linked**.

A gene that is only present on the X chromosome is referred to as **X-linked**, while a gene that is only present on the Y chromosome is referred to as **Y-linked**.



X-Linked Genes

Since they are present in different copy numbers in males and females, X-linked genes have different **patterns of inheritance** than autosomes.

- Example: Male offspring of an unaffected father and a carrier mother will have a 50% chance of receiving the X-linked gene. In this scenario, female offspring would require the father to be affected in order to have a 50% chance of being affected by the X-linked gene.

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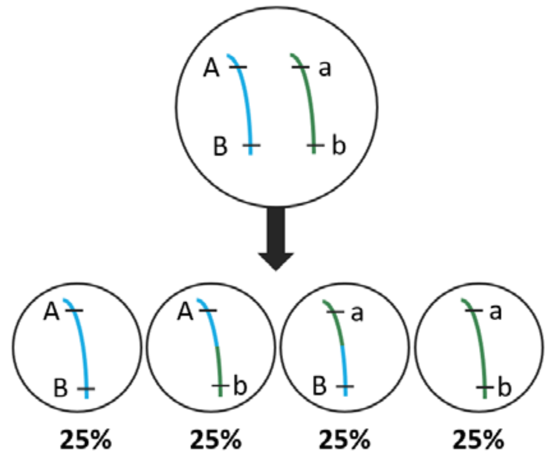
Pedigrees

Sex-linked traits can be traced using a **pedigree**, a type of family tree that displays a genetic lineage.

Unlinked Genes

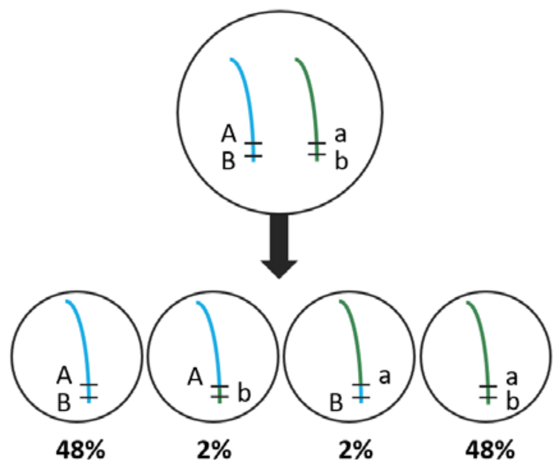


There are thousands of genes on each chromosome.

Genes that are positioned far apart from each other are called **unlinked genes**. Unlinked genes follow Mendel's law of random assortment.

- Example: Each of the 4 possible types of gametes produced by a double heterozygous organism (AaBb) will have equal 25% frequencies.

Linked Genes



Genes that are packed tightly together are called **linked genes**.

Instead of following Mendel's laws, linked genes travel as a unit and are typically inherited together.

- Example: Linked genes are most often inherited as they were arranged on parental chromosomes. Reconfigurations of linked genes (Ab or aB) are called **recombinants**.

Crossing Over

During meiosis, crossovers happen randomly along the chromosome.

The frequency of crossovers between two genes depends on the distance between them.

- Example: Fewer crossovers occur between linked genes due to the small amount of space between them. Fewer crossovers result in a smaller frequency of recombinants (Aa).

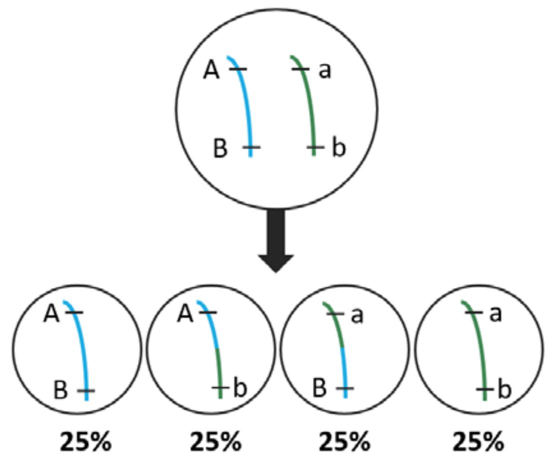
Determining Gene Linkage

In order to determine if two genes are linked, such as eye and body color in fruit flies, the phenotypes of offspring generations must be examined.

If a small number of offspring are recombinant, we can assume that the two genes are linked.

If the phenotype distribution is equal, we can assume that the two genes are unlinked.

Chromosome Mapping



Geneticists use recombination data to map **gene loci**, the positions of genes on a chromosome.

Since unlinked genes always produce equal numbers of phenotypes, the highest possible recombination frequency is 50%.

When mapping chromosomes, geneticists sometimes express values in map units. 1 map unit equals 1% recombination frequency.

What Are Mutations?

Mutations are changes in genes or chromosomes that can be passed on to offspring.

Mutations that are classified based on structural changes to DNA include:

- **Point mutations**
- **Frameshift mutations**

Nonsense Mutations

Mutations that are classified based on changes in the composition of proteins include nonsense and missense mutations.

Nonsense mutations are mutations that result in an RNA sequence becoming a stop codon. Since stop codons can prevent the full production of a protein, nonsense mutations have a significant effect on protein composition.

Hereditary Mutations

While some hereditary mutations are dominant, most are recessive and are not expressed unless two copies of the mutation are received.

Acquired Mutations

Exposure to carcinogens, such as ultraviolet radiation, can cause mutations to occur as DNA is copied during cell division.

Many cancers are the result of acquired mutations.