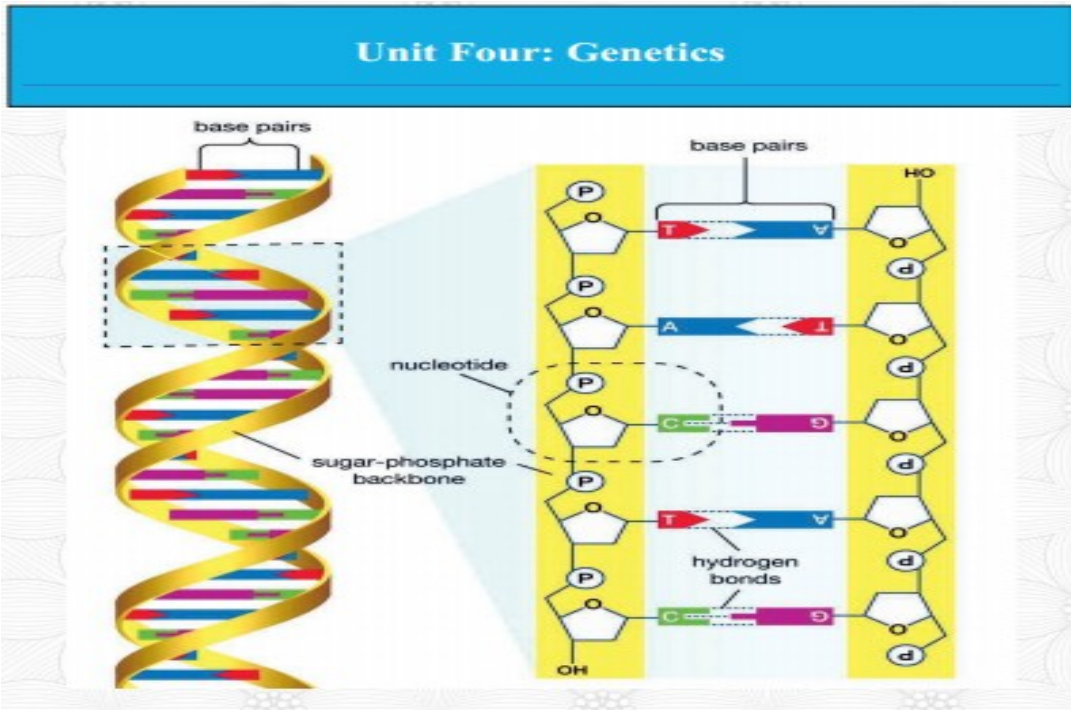


Unit learning outcomes

After the successful completion of this unit, the student will be able to:

1. Describe terms in Genetics
2. Describe Cell division
3. Explain Functions of DNA and RNA
4. Differentiate Mendelian and non-Mendelian inheritances
5. Complete Punnett Squares of monohybrid and dihybrid crosses
6. Calculate the probabilities of offspring
7. Design a test-cross to identify homogeneity and heterogeneity of unknown genotypes
8. Describe Genetic disorders, Genetic testing, counseling, and Gene therapy
9. Investigate how Ethiopian farmers select and breed quality plants and animals

4.1. The genetic materials

- After the successful completion of this section, the student will be able to:
  - ✓ Define genetics, genes, chromosomes, DNA, and RNA.
  - ✓ Describe DNA and RNA
- Look at your family, your classmates, and the peoples in your surroundings.
  - ✓ Are all the people the same?
  - ✓ Are all your classmates the same?
  - ✓ Are all members of your family the same or different?
  - ✓ If not, what do you think is the reason behind it?
- If your answer is yes and you think it is due to the genetic material, you are right.

Recall your learning from the previous grade, grade 10 Biochemical molecules

- ✓ Definition of genetics
- ✓ The structure and function of DNA and RNA.

Genetics

- ✓ The **branch of biology** concerned with the study of the genetic materials of organisms and how traits are passed from one generation to the next generation through genes.

Genetic Material

- ✓ The genetic material of an organism refers to material that carries genetic information and passes it from one generation to the next generation to perpetuate life.
- ✓ DNA is a genetic material in almost all organisms.
  - o DNA (deoxyribonucleic acid) is the hereditary material in humans and other organisms
- ✓ RNA is also a genetic material in some viruses like HIV, COVID-19.

- RNA (ribonucleic acid) serves as the genetic codes in some viruses.
- It is involved in protein synthesis in cells.

4.2. The structure and function of DNA and RNA

- After the successful completion of this section, the student will be able to:
  - ✓ Describe the structures of DNA and RNA.
  - ✓ Draw and label the structures of DNA and RNA.
  - ✓ Describe the process of DNA replication.
  - ✓ Explain the functions of DNA and RNA.
  - ✓ Compare DNA with RNA with respect to structure and function.

4.2.1. The Structure and function of DNA

The structure of DNA

- The structure of DNA is a ladder-like double helix twisted into a spiral shape, in which the sugar and phosphate groups form the two vertical ladder and the nitrogenous bases form the ladder's rungs (Figure 4.3).
- It consists of two long chains of chemicals called polynucleotide (Figure 4.1) that twist around each other to form a double helix.
- Nucleotides are the basic building blocks of a DNA molecule.

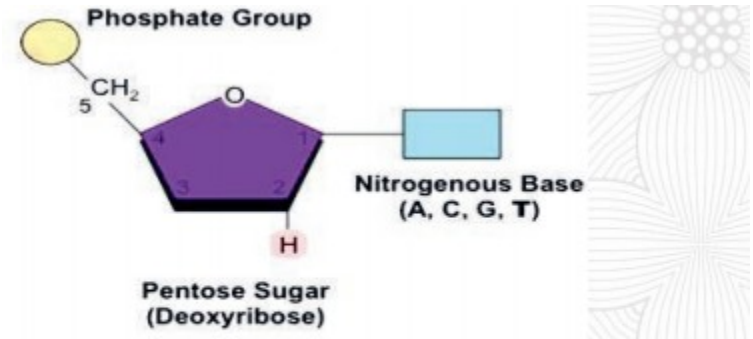


Figure 4.1 The structures of a single nucleotide

Each nucleotide is composed of:

- a sugar_ pentose sugar(five carbon sugar)
- phosphate group and
- a nitrogenous base.
  - ✓ There are four types of nitrogenous bases.
  - ✓ These are: Adenine (A), Thymine (T), Guanine (G) and Cytosine (C).
  - ✓ The nitrogen bases belong to the two large chemical families.
    - Purine _ A and G
    - Pyramidine_ C and T
  - ✓ Always purine pair with pyramidine to form units called base pairs
    - A pairs with T and
    - C pairs with G
  - ✓ Each base is also attached to a sugar molecule and a phosphate molecule to form a nucleotide, the building blocks of the DNA called nucleotide.

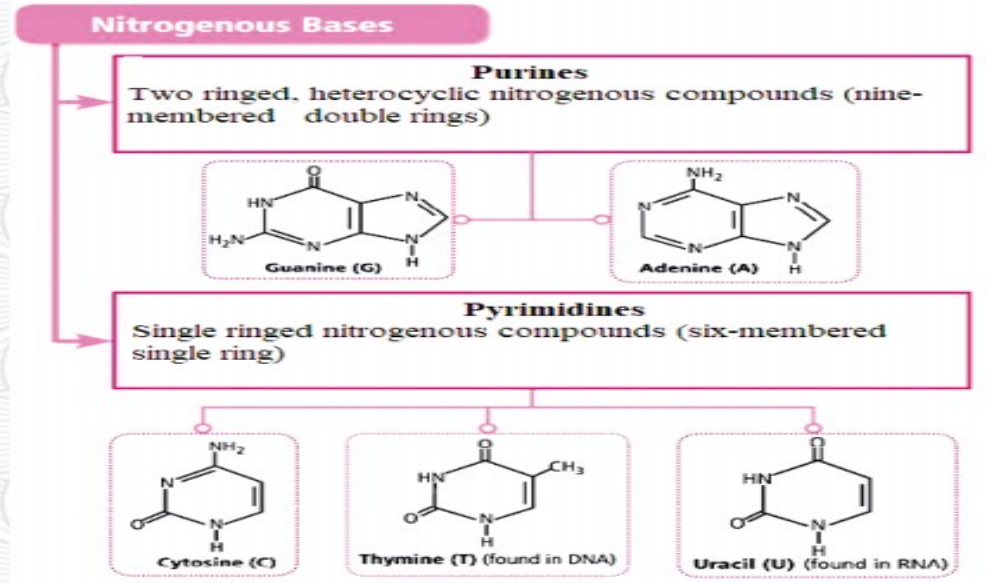


Figure 4.2 Structures of purine and pyrimidine

In the DNA structure,

- ✓ The sugar (Deoxyribose) and phosphate form the backbone of the DNA molecule and

- ✓ The nitrogenous bases form hydrogen bonds between the two strands (backbone), to form a ladder-like structure.
- ✓ Each strand of DNA shows polarity (two ends are different).
  - o The one is referred as 5’ end and
  - o The other is 3’ end.
- ✓ The two strands of DNA run in opposite directions.
- ✓ The strands are helically twisted where each strand forms a right-handed coil.
- ✓ James Watson and Francis Crick discovered the double helix structure of a DNA molecule.

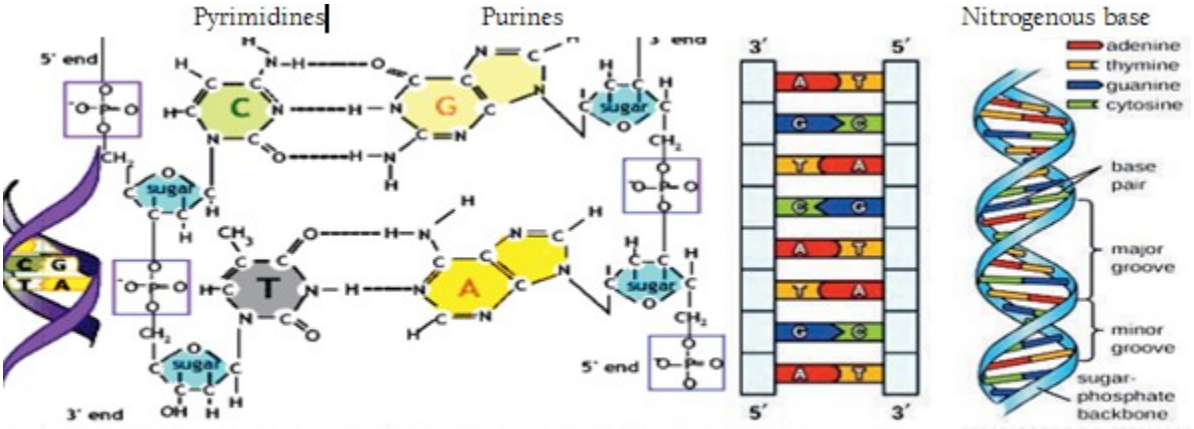


Figure 4.3 DNA Structure

Genes and chromosomes

Genes

- ✓ Sections of the DNA structure that contain the set of instructions that determine the characteristics of an organism.
- ✓ Genes are the basic structural and functional units of inheritance in nature.
- ✓ Genes pass from parents to offspring during both sexual and asexual reproduction through cell division.
- ✓ Genes are located on chromosomes.

Chromosomes

- ✓ Chromosomes are threadlike structures made of a protein called **histone** and DNA molecule.
- ✓ Each chromosome may contain **hundreds to thousands** of genes.

- ✓ Genes are arranged linearly along the length of each chromosome (like beads on a string).
- ✓ Each gene having its own unique position on to chromosomes called locus / loci (plural).

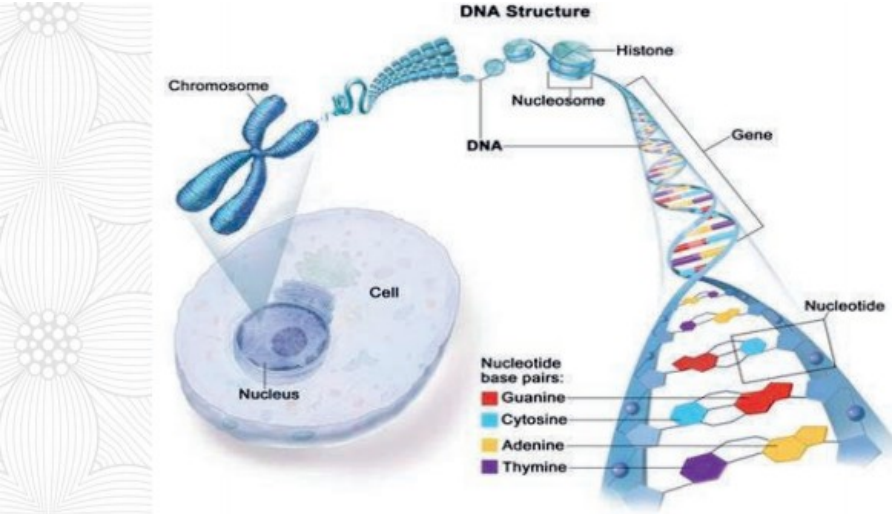


Figure 4.4 Chromosome with DNA structure, histone protein and gene

- ✓ Chromosomes exist in pair in diploid organisms.
  - o One is always inherited from the mother and
  - o The other from the father.
- ✓ For example a human cell contains 46 chromosomes which exist in 23 pairs of chromosomes (Figure 4.5).

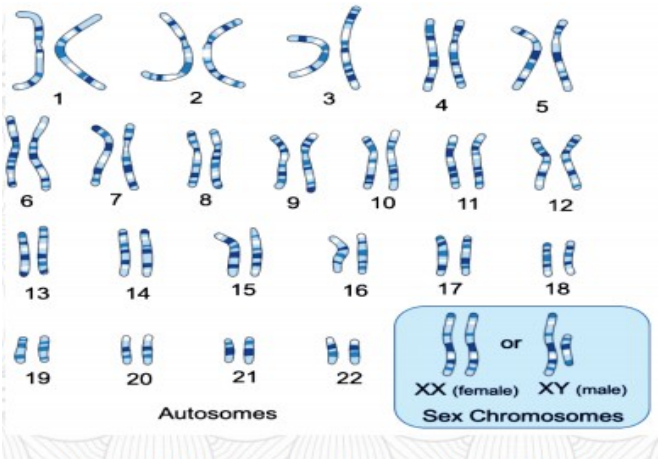


Figure 4.5.Human Karyotype, male and female

The Function of DNA

- ✓ Store all of the genetic information that an organism needs to grow, develop, reproduce, control the cell and survive.
- ✓ Carrying and transmitting the hereditary materials or the genetic instructions from parents to the offspring.
- ✓ The transmission of this information occurs through the process of DNA replication during cell division.

4.2.3 DNA replication

- DNA has a unique property of replication or production of carbon copies.
- It is a semiconservative, which means:
- The two original DNA strands separate during replication; each strand then serves as a template for a new DNA strand.
- Each newly synthesized double helix is a combination of one old and one new DNA strand.
- DNA replication involves the following enzymes.
- DNA gives rise to RNAs through the process of transcription.

Table 4.1 Enzymes and their functions

No	Enzymes	Function
1	DNA Helicases	It binds to the double stranded DNA and stimulates the separation of the two strands.
2	DNA polymerase	It adds new nucleotides to a growing strand of DNA, and links together, or polymerizes, DNA bases in the correct sequence using the template DNA strand.
3	RNA primase	It synthesizes RNA primers complementary to the DNA strand.
4	DNA ligase	links two fragments of DNA by forming a phosphodiester bond.
5	Topoisomerase	It prevents super coiling at the region ahead of the replication fork.

Replication fork

- It is the point formed due to unwinding and separations of two strands appear like Y –shaped fork is called replicating fork.

Leading strand

- The strand of new DNA, which is synthesized in the same direction as the growing replication fork.

Lagging strand

- The strand of new DNA whose direction of synthesis is opposite to the direction of the growing replication fork.

There are three stages in DNA replication. These are:

Stage one

- The DNA helix structure is unwound and unzipped, hydrogen bonds between bases, which are holding the two strands together break.

- The double helix structure of the DNA molecule separate in to two strands.

Stage two

- The two separated strands will act as templates for making the new strands of DNA.
- DNA polymerase will add the free DNA nucleotides using complementary base pairing (A_T and C_G). One of the strands is synthesized in the same direction as the growing replication fork (leading strand). DNA polymerase adds nucleotides to the deoxyribose (3') ended strand in a 5' to 3' direction.
- The other strand synthesizes opposite to the direction of the growing replication fork (lagging strand).

Stage three

- The two new strands twist to form a double helix. Each is identical to the original strand

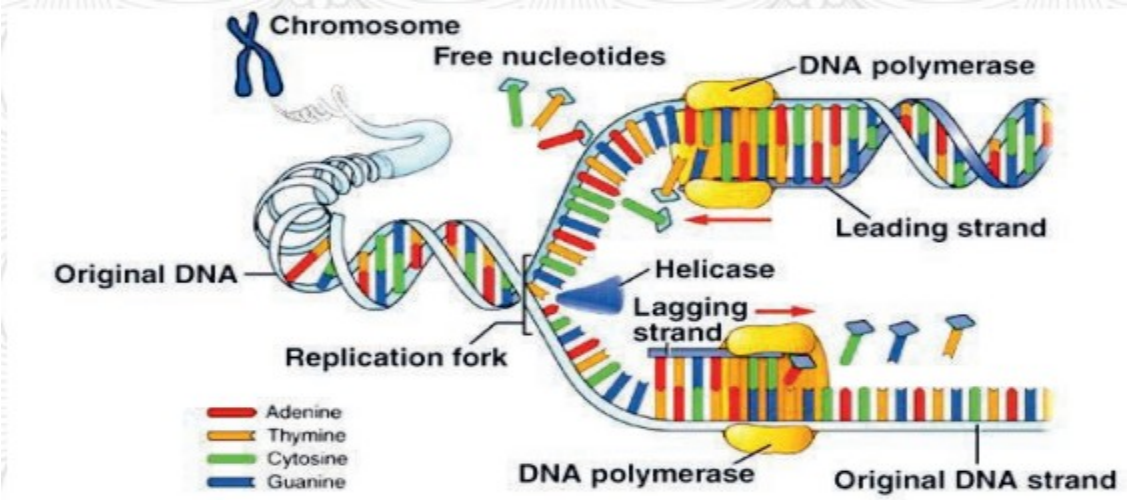


Figure 4.6 DNA replication

4.2.2. The structure and function of RNA

The structure of RNA

- It has single strand structure.
- RNA contains:
  - The sugar ribose
  - Phosphates, and
  - The nitrogenous bases adenine (A), guanine (G), cytosine (C) and uracil (U) which replaces thymine in DNA.

There are three most well-known types of RNA in all organisms.

- Messenger RNA (mRNA)
- Transfer RNA (tRNA) and
- rRibosomal RNA (rRNA).

All types of RNAs are formed on DNA strands by transcription process.

The function of RNA

- RNA functions in protein synthesis
- Also used as a storage of genetic information in some viruses.
- RNA facilitates the translation of the DNA into different proteins required by organisms.
- It serves as a messenger in conveying instructions between the DNA and the ribosome during proteins synthesis.

4.3. The process of cell division

4.3.1. Cell Division

- In cell division, each cell divides to make two cells and these two cells then divide to make four cells, and so on.
- The process that repeats in this way is called the cell cycle.
- The cell cycle is an ordered series of events that involve cell growth and cell division to produce new daughter cells.
- The cell cycle has two major phases: interphase and mitotic phase (M phase).

I. The Interphase

- Period of preparation for a cell to divide and start the cell cycle.
- The three stages of interphase are called G1 (first gap stage), S (synthesis stage), and G2 (second gap stage).

The G1 Phase (First Gap)

- The first stage of interphase in which the cell is quite active at the biochemical level.
- The cell accumulates the building blocks of chromosomal DNA and the associated proteins.
- Sufficient energy reserves to complete the task of replicating each chromosome in the nucleus.
- ❖ The G0 phase (resting phase), is a phase in which the cell is neither dividing nor preparing to divide but performs regulatory and basic cellular functions.

The S Phase (Synthesis of DNA)

- A stage in which DNA replication proceeds to form identical pairs of DNA molecules (sister chromatids) that are firmly attached to the centromeric region.
- The centrosome duplicates and centrioles develop to help organize cell division.

G2 Phase (Second Gap)

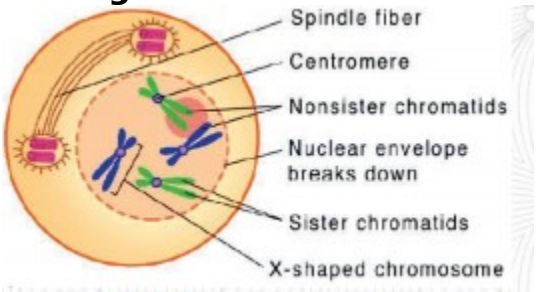
- A stage in which, the cell replenishes its energy stores that exhausted during DNA replication at S_ phase.
- Synthesizes proteins necessary for chromosome manipulation.
- In this phase, some cell organelles duplicate and the cytoskeleton disintegrates to provide resources for the mitotic phase.
- The cell performs the final preparations for the mitotic phase to enter the first stage of mitosis. After completing the interphase, the cell undergoes either mitotic or meiotic cell divisions.

I. Mitosis

- It is the basic process for life.
- The division of somatic cells.
- Somatic cells make up most of your body's tissues and organs, including skin, muscles, lungs, gut, and hair cells.
- It undergoes multistep processes.
- There are two mitotic phases
    1. Karyokinesis (the nuclear division)
    2. Cytokinesis (the physical separation of the cytoplasmic components into the two daughter cells).

1. Prophase

- First step in mitotic cell division
- Nuclear envelope starts to dissociate into small vesicle
- Chromosomes become more condensed, discrete, and visible through compound microscope.
- Centrosomes move to opposite poles.
- Mitotic spindle microtubules also extend between the centrosomes.
- Sister chromatids begin to coil more tightly to develop a **kinetochore** in the **centromeric region.**



- The kinetochore attracts and binds mitotic spindle microtubules.
- Moreover, organelles such as the Golgi apparatus and Endoplasmic reticulum fragment disperse toward the periphery of the cell.
- At the end, the sister chromatids will be attached via their kinetochores to microtubules from opposing poles

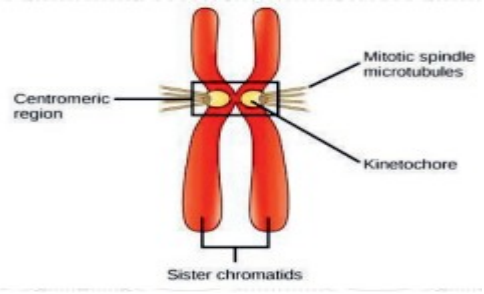
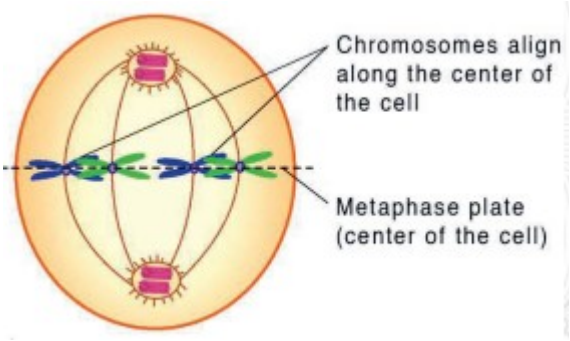


Figure 4.10 Chromosome with kinetochore

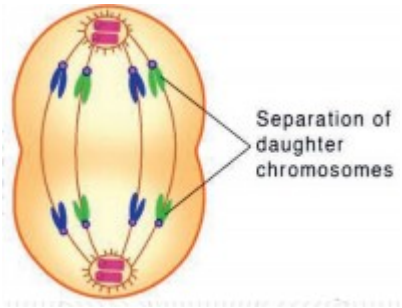
2. Metaphase

- The second step in the mitosis process.
- All the chromosomes are aligned at the metaphase plate or the equatorial plane, which is at the middle of the cell between the two poles of the cell.
- The sister chromatids are still tightly attached to each other by cohesion proteins.



3. Anaphase

- Anaphase is the third step.
- The sister chromatids separate at the centromere and are pulled rapidly toward the centrosome to which its microtubule is attached.
- The connection between the sister chromatids breaks down and the microtubules pull the chromosomes toward opposite poles.



4. Telophase

- The fourth step
- Chromosomes reach the opposite poles.
- Chromosome begin to decondense (unravel).
- The mitotic spindles are depolymerized, the nuclear envelopes form around the chromosomes.
- Nucleosomes appear within the nuclear area.

Cytokinesis

- Final phenomenon in which division of cell is completed by the physical separation of the cytoplasmic components.
- It resulting in two genetically identical daughter cells

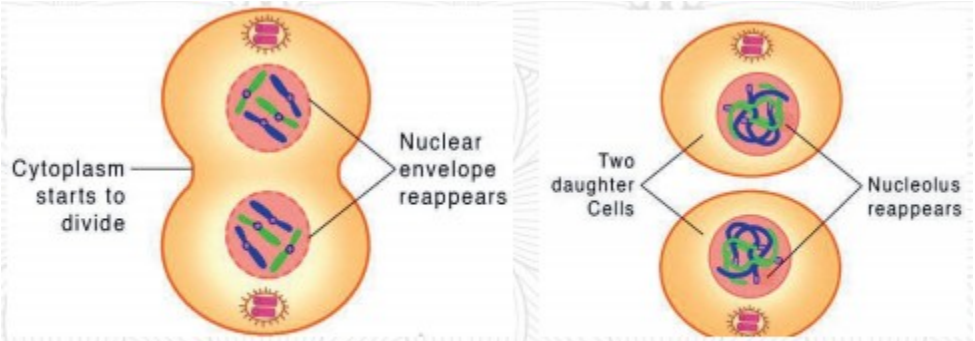


Figure 4.13. Telophase of mitosis (left) and Cytokinesis (right)

II. Meiosis

- Division of diploid cell into four haploid cells which produces sex cells (gametes).
- It has two phases, **Meiosis I** and **Meiosis II.**
- **Meiosis**
  - Reduces the number of chromosome by half
  - Produces genetic variation through a process of crossing over and independent assortment.
  - It has eight stages (four stages for each meiosis)

A. Meiosis I

- In diploid organisms, chromosome exists in pairs.
- Each member of the pair are called homologous chromosomes.
- Homologous chromosomes are separated into two cells consisting of two chromatids (chromosome pair) in each daughter cell.
- Meiosis I is also called reduction division. Why?

1. Prophase –I

- It is the first step in part one of the meiosis stage.
- In this step,
  - Nuclear envelope disintegrates
  - Chromosomes begin to condense
  - Spindle fibers appear.
- A diploid cell contains two copies of every chromosome, one derived from male gamete and the other from the female gamete.
  - These pairs of chromosomes are called homologous chromosomes.
  - Sister chromatids are the two chromatids of a replicated chromosome that are connected by the centromere.
  - A non-sister chromatid is one of the two chromatids of two homologous chromosomes.
- Non-sister chromatids of homologous chromosomes form chiasmata to exchange genetic material during prophase I of meiosis I.
- In this phase, homologous chromosomes pair each other and crossing overtakes place.
- During crossing over, homologous chromosomes exchange small parts to each other so that one chromosome contains parts of male and female DNA.
- This results in an increase in genetic variation
- Crossing over increases the variability of a population.

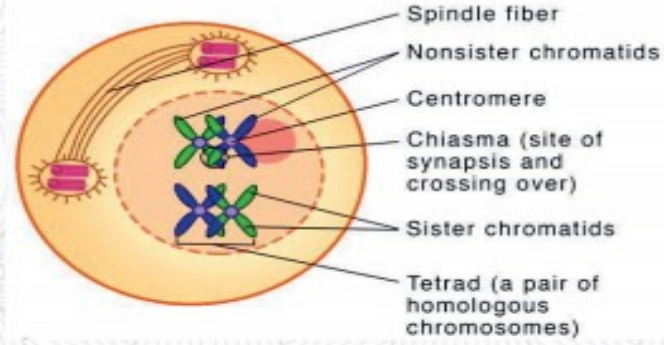


Figure 4.14 Prophase I of Meiosis

2. Metaphase I

- The pairs of chromosome align next to each other along the center (equator) of the cell.
- When the pairs of chromosomes line up randomly, they align themselves on either side of the equator.
- The meiotic spindles extend from centrioles at opposites poles of the cell and attach to one chromosome of each pair.

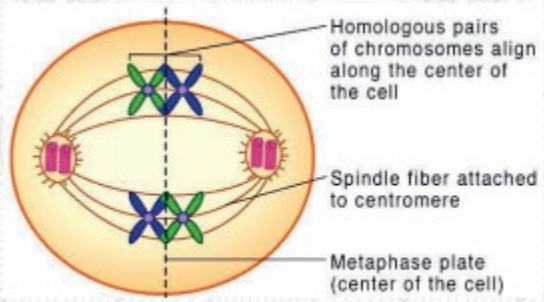


Figure 4.15 Metaphase I of Meiosis

3. Anaphase I

- The pair of chromosomes are pulled apart by the meiotic spindle.
- Each of the homologous chromosomes gets pulled towards opposite poles of the cell as the spindle fibres retract.
- This equally divides the DNA between the two cells to be formed.
- Unlike what happens in mitosis and meiosis II, the sister chromatids stay together.

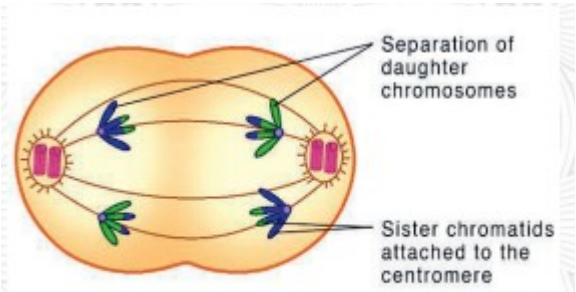


Figure 4.16 Anaphase I of Meiosis

4. Telophase I

- Chromosomes complete their move to the opposite poles of the cell.
- During this step,
- The spindle fibres disappear
- The full set of chromosomes gather together
- The nuclear envelope reforms and a membrane forms around each set of chromosomes.

Cytokinesis

- It is the final stage in meiosis I
- The single cell pinches in the middle to form two separate daughter cells each containing a half set of the parent chromosomes within a nucleus.

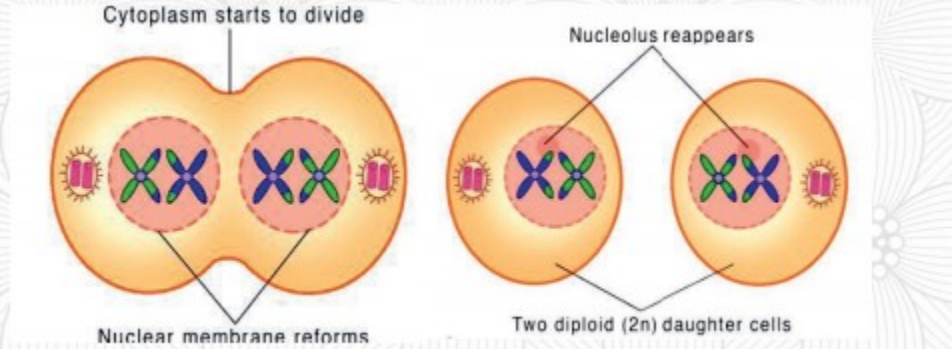


Figure 4.17 Telophase I of Meiosis (right) and Cytokinesis (left)

Meiosis II

1. Prophase II

- Chromosomes condense again into visible X shaped structures in each of the two daughter cells.
- In this step,
  - The membrane around the nucleus in each daughter cell dissolves away releasing chromosomes.
  - The centrioles duplicate and the meiotic spindle forms again.
  - This stage is similar to prophase in meiosis I

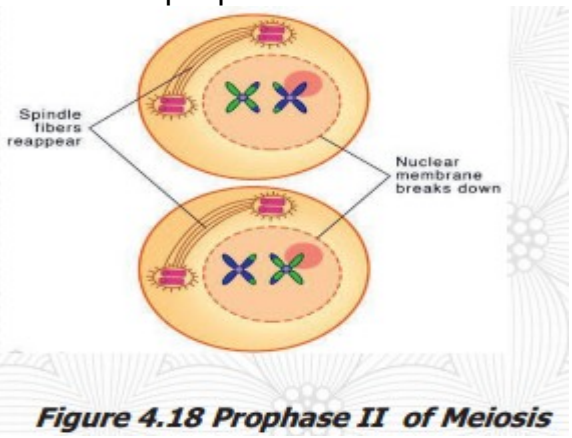


Figure 4.18 Prophase II of Meiosis

2. Metaphase II

- Metaphase II is the second step in part two of meiosis.
- Unlike metaphase I where chromosomes line up in homologous pairs, sister chromatid line up end-to-end in a single line along the equator of the cell.

- Meiotic spindle fibers from the centrioles at opposite poles attach to each of the sister chromatids.

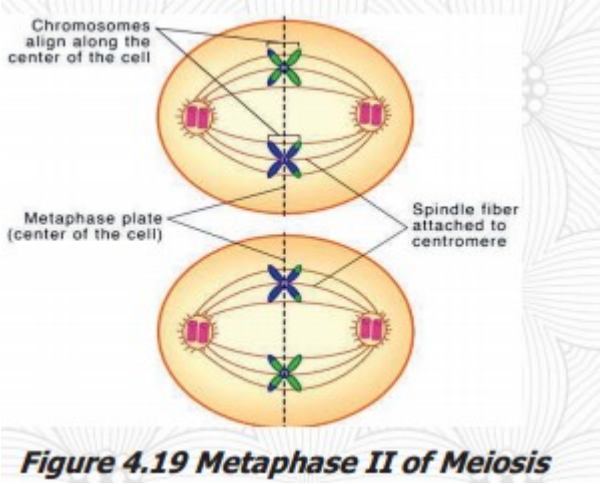


Figure 4.19 Metaphase II of Meiosis

3. Anaphase II

- Sister chromatids are pulled to opposite poles of the equator due to the action of the meiotic spindle.
- The separated chromatids are now individual chromosomes.

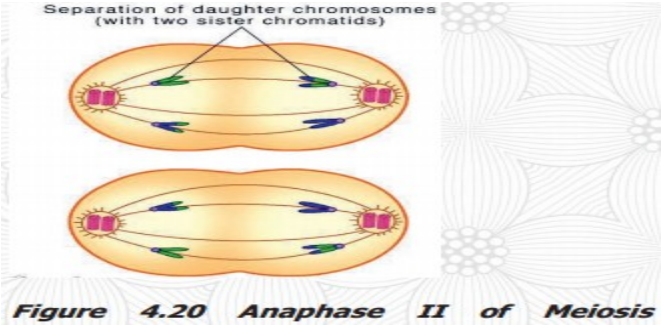


Figure 4.20 Anaphase II of Meiosis

4. Telophase II

- Chromosomes complete their move to the opposite poles of the cell, a membrane forms around each set of chromosomes.

Cytokinesis

- The cytoplasm and the cell divide producing 4 non identical haploid daughter cells.

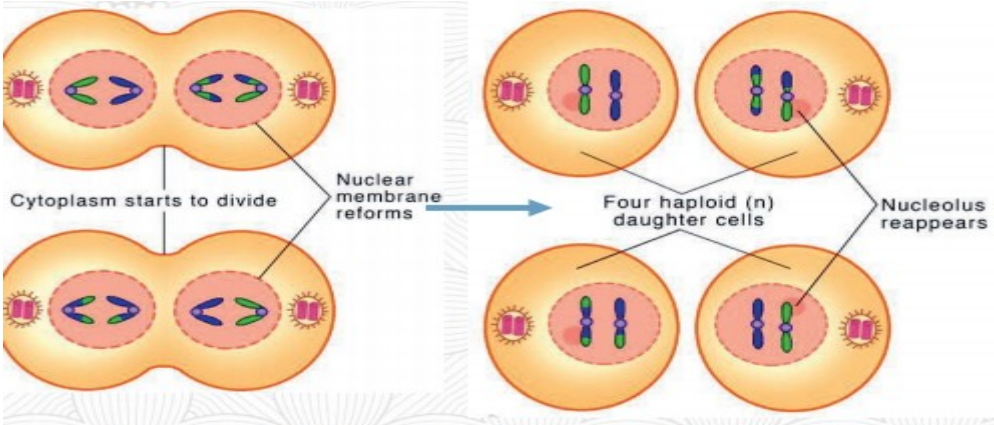


Figure 4.21 Telophase II of Meiosis (left) cytokinesis (right)

4.4 Protein synthesis

Proteins are:

- Organic compound made of amino acids joined together by peptide bonds.
- Essential for the maintenance of structural attributes and the functioning of all living cells and viruses.
- There are 20 different naturally occurring amino acids
- Each protein is different in structure and function due to the sequence in which these amino acids are arranged.

Protein synthesis

- It is the stepwise process of the production of different types of proteins from amino acids.
- It involves DNA, RNA (mRNA, tRNA and rRNA), amino acids, various enzymes and ribosome.
    - **DNA**: stores genetic information used to produce different proteins.
    - **mRNA**: transcribes genetic information from DNA in the nucleus with the help of enzyme RNA polymerase.
    - **tRNA**: brings amino acids from the cytoplasm to the ribosome and it translates the message within the nucleotide sequence of mRNA to a specific amino acid sequence.
    - **rRNA**: forms part of the ribosome that helps translate the information in mRNA into protein.
    - **Ribosomes**: cytoplasmic organelles that translate the mRNA template into a polypeptide chain.

- The process of protein synthesis involves the conversation of instructions in DNA into a functional product (proteins) through **transcription** and **translation**.
- **Reverse transcription** is a process in which a DNA molecule is synthesized from an RNA template.
- These all process of biological information flow is called **central dogma.**

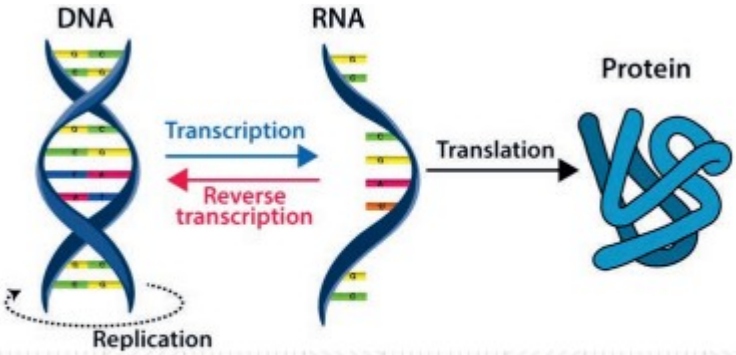


Figure 4.22 The central dogma of life

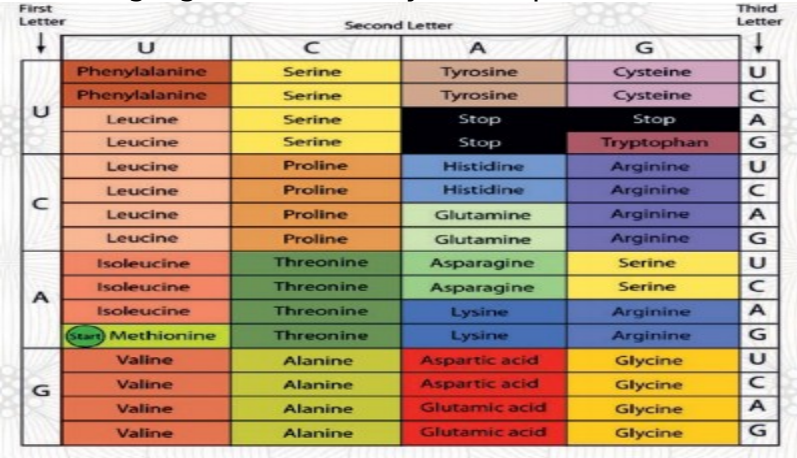
Transcription

- Transcription is the synthesis of mRNA molecules within the cell nucleus with the code for a protein copied from the genetic information contained in the DNA.
- mRNA carries complementary genetic code copied from DNA during transcription, in the form of triplets of nucleotides called codons.
- A codon is a sequence of three nucleotides and four nitrogenous bases on an mRNA strand derived from the DNA that encodes a specific amino acid.
- Each codon specifies a particular amino acid.
- For example
  - Tryptophan is coded by a codon TAG
  - Alanine by GCA, GCC
  - Glycine by GGA, AGG
- There are only 20 naturally existing amino acids but the number of possible amino acids combination is 4^3= 64 triplets.

Out of the 64 codons,

- three are stop codons, which stop the process of protein synthesis (UAG, UAA, and UGA)
- one of the codons is an initiator codon or start codons that initiates protein synthesis (AUG).

- Use the following figure to identify the triplets for all amino acids.



First Letter	Second Letter: U	C	A	G	Third Letter
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
	Phenylalanine	Serine	Tyrosine	Cysteine	C
	Leucine	Serine	Stop	Stop	A
	Leucine	Serine	Stop	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
	Leucine	Proline	Histidine	Arginine	C
	Leucine	Proline	Glutamine	Arginine	A
	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
	Isoleucine	Threonine	Asparagine	Serine	C
	Isoleucine	Threonine	Lysine	Arginine	A
	(Start) Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartic acid	Glycine	U
	Valine	Alanine	Aspartic acid	Glycine	C
	Valine	Alanine	Glutamic acid	Glycine	A
	Valine	Alanine	Glutamic acid	Glycine	G

Figure 4.23 The genetic code

During Transcription:

- Inside the nucleus a small portion of the DNA separates
- Free RNA nucleotides attach to appropriate base pairs on the DNA template and mRNA is formed with code (triplets of nucleotides called codons) for protein synthesis.
  - Similarly, tRNA and rRNA also transcribed from DNA.
- mRNA detaches from the DNA
- mRNA leaves the nucleus to go out into the cytoplasm and binds to ribosome

Translation

- Translation is the synthesis of protein from the building blocks of protein /amino acids/ based on the genetic information instructed on mRNA with the help of rRNA, tRNA and enzymes.
- Transfer RNA
  - Carries a specific amino acid from cytoplasm.
  - Contains an anticodon which is three nucleotides long that is complementary to the three nucleotides long genetic codon on the mRNA.
  - The anticodon on tRNA enables to recognize the codon of mRNA through complementary base pairing.
  - For example, the genetic codon GUG (guanine-uracine- guanine) specifies particular amino acid valine.
  - By binding its anticodon (CAC) that is complementary with mRNA codon /GUG/, the tRNA acts as an adapter, bringing the specific amino acid based on base complementarily (Figure 4.24).

- The complementary bases on the codon and anticodon held together by hydrogen bonds to from peptides bond in growing protein chain.

- The ribosome guides the tRNA to bind to the mRNA if it is carrying an amino acid.

During Translation:

1. mRNA carries the information from DNA align on the ribosome in the cytoplasm
2. The ribosomes attach on to mRNA and let the tRNA loaded with specific amino acid to enter
3. tRNA with anti-codon brings amino acids from the cytoplasm to the ribosomes
4. The anti-codon of tRNA pairs with the codon of mRNA on the ribosome
5. the information in messenger RNA (mRNA) translated into protein with the help of rRNA
6. A polypeptide chain of amino acids will then form a protein.

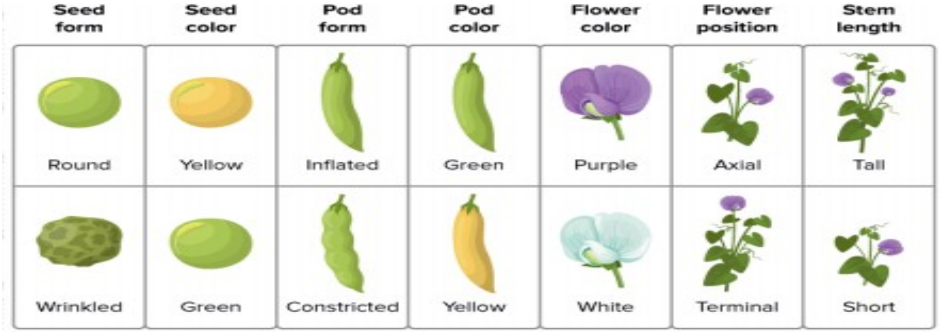
4.5. Mendelian inheritance

- Gregor Mendel an Austrian monk in the middle of the 19th century:
  - Studied how **traits and characteristics were transferred** and
  - Discovered the principles of heredity.
- After eight years of tedious experiments with Pea plants,
  - he discovered two foundational principles of inheritance and
  - established different terminologies used in genetics, such as:
    - factors (later genes, alleles) _homozygous,
    - dominant _ heterozygous
    - Recessive _phenotype, etc.
    - genotype
- The principles of Mendelian inheritance, or Mendel's principles of heredity, are:
  - law of segregation and
  - Law of independent assortment.

4.5.1. Mendelian Crosses

- Mendel studied seven pairs of different characters of pea plants with contrasting traits that exist in two forms.
  - Dominant traits_ 1st row
  - Recessive traits_ 2nd row

The seven pairs of traits

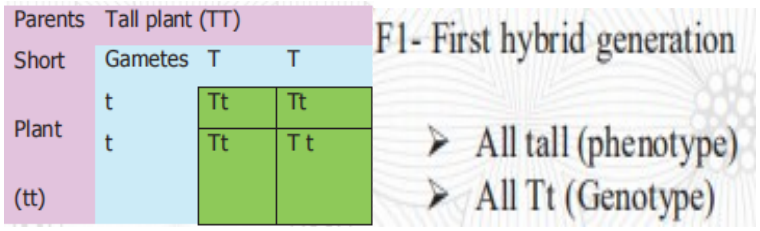


In order to determine the mechanism of inheritance Mendel conducted different types of crosses such as:

- Monohybrid crosses
- Dihybrid crosses and
- Test crosses.

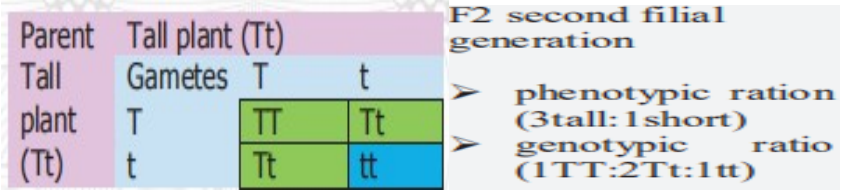
4.5.2 Monohybrid Cross

- Cross between two parents to study the inheritance of a single character from each parent.
- He cross-pollinated two pure lines for contrasting characters and the resultant offspring were called the first filial generation (F1).
  - In F1 generation, one of the traits was always seen in the offspring but not the other one. Why
- The F1 generations were then self-pollinated which gave rise to the second filial generation (F2 generation).
  - In this generation, both traits were observed.
  - He found a 3:1 ratio of dominant to recessive traits.
    - Dominant (Capital letter)_ characters that appear in the F1 generation
    - Recessive (Small letter) _ that appear for the first time in the F2 generation recessive traits.
- His cross can be easily shown through a Punnett Square (a chart used to determine the expected ratios of the possible genotypes and phenotype)
- In using the Punnett square.
  - The first column and row show parental generation.
  - The second column and row show the gametes of the two plants.
  - The box shows the first hybrid generation or F1 generation.



F2 generation

- Mendel self-crossed the F1 generation and obtained both tall and short plants.
- F2 generation
  - Genotypes TT, Tt, Tt and tt,
  - Genotypic ratio of 1:2:1 (1 TT, 2 Tt and 1 tt)
  - Phenotypic ratio 3:1. (3tall and 1 short).
- Mendel observed that:
  - 3/4th of the offspring possess at least one copy of the dominant tall gene
  - 1/4th of the offspring possess two copies of the short gene.



F2 generations and phenotypic ratios from Gregor Mendel

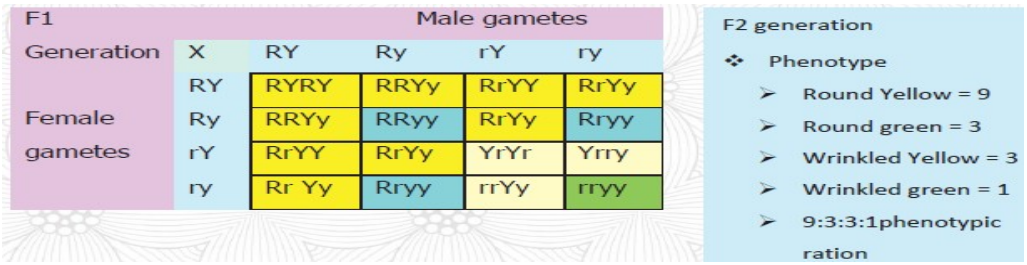
Characters	P1 crosses Dominant traits x recessive traits	F1	F2	Dominant : Recessive Ratio
Flower color	Purple x white	All purple	Dominant (705) : Recessive (224)	3.15:1
Flower position	Axial x terminal	All axial	Dominant (651) : Recessive (207)	3.14:1
Seed color	Yellow x green	All yellow	Dominant (6022) : Recessive (2001)	3.01:1
Seed shape	Round x wrinkled	All round	Dominant (5474) : Recessive (1850)	2.96:1
Pod shape	Smooth or inflated x constricted	All inflated	Dominant (882) : Recessive (299)	2.95:1
Pod color	Green x yellow	All green	Dominant (428) : Recessive (152)	2.82:1
Stem length	Tall x short	All tall	Dominant (787) : Recessive (277)	2.84:1

- **Mendel drew the following conclusions:**
  - F1 generation starts with two hereditary “factors.” One factor is dominant and the other is recessive.

- The factors separate in the parent. Only one factor from each parent is contributed to the offspring.
- Each offspring inherits one factor from each parent. If the dominant factor is present, it will be expressed even if the recessive factor is also present.
- The recessive factor will be expressed if only recessive factors are present.

4.5.3 Dihybrid Cross

- A Dihybrid cross is a cross between two traits of individuals at a time.
- The cross between round-yellow seed (RRYY) and wrinkled-green seed (rryy) resulted in all round yellow seeds (RrYy). This is the F1 generation.
- The outcome of the cross between F1 generations (RrYy x RrYy) resulted in round-yellow, wrinkled yellow, wrinkled-green and round-green, as follow.



F1 Generation	X	Male gametes: RY	Ry	rY	ry
Female gametes	RY	RYRY	RRYy	RrYY	RrYy
	Ry	RRYy	RRyy	RrYy	Rryy
	rY	RrYY	RrYy	YrYr	Yrry
	ry	Rr Yy	Rryy	rrYy	rryy

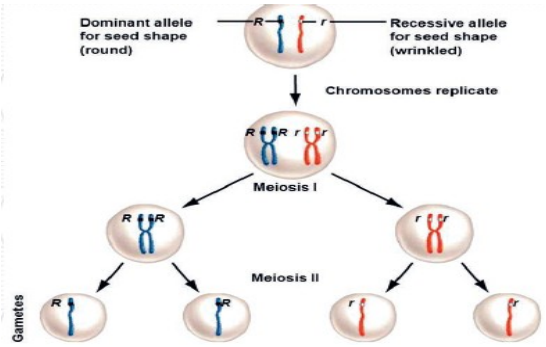
F2 generation
- Phenotype
  - Round Yellow = 9
  - Round green = 3
  - Wrinkled Yellow = 3
  - Wrinkled green = 1
  - 9:3:3:1phenotypic ration

- From monohybrid and dihybrid crosses, Mendel discovered the two foundational laws of inheritance.
  - **laws of segregation**
  - **Law of independent assortment.**

The Law of segregation

- The law states that copies of genes randomly separate or segregate during meiosis so that each gamete receives only one allele.
- Each unit of inheritance(heritable factors) can have alternate states (alleles) that segregate at meiosis
- The physical basis of Mendel's law of segregation is the first division of meiosis in which the homologous chromosomes with their different versions of each gene are segregated into daughter nuclei.
- As chromosomes separate into different gametes during meiosis, the two different alleles for a particular gene also segregate so that each

gamete acquires one of the two alleles as chromosomes separate into different gametes during meiosis (Figure 4.27).

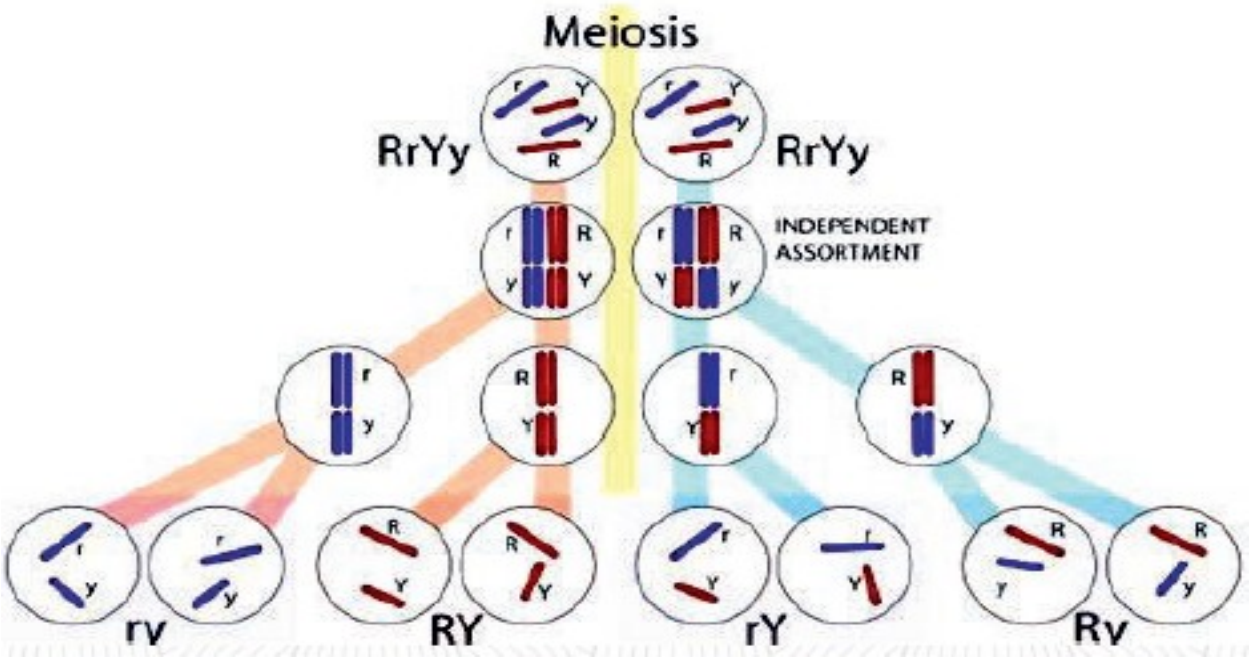


The Law of Independent Assortment

- The second Mendel's law of heredity which states that genes do not influence each other with regard to the sorting of alleles into gametes.
- According to this law, the separate genes for separate traits are passed independently of one another from parents to the offspring.
- The Law of independent assortment occurs in metaphase I of meiosis when pairs of chromosomes randomly align next at the center.
- For example, in the dihybrid cross with characteristics of seed color and seed texture for two pea plants, the one that has yellow, round seeds (YYRR) and another that has green, wrinkled seeds (yyrr) alleles sort into gametes independently and every possible combination of alleles for every gene is equally likely to occur (Figure 4.28).
- The genotype of the F1 generation of all offspring is YyRr.
- In the F2 generation, according to the law of independent assortment, a gamete in which an r allele sorted would be equally likely to contain either a Y allele or a y allele.
- Here the chances of formation of gametes with the R allele and the r allele are 50:50.
- The chances of formation of gametes with the Y allele and the y allele are also 50:50.
- Thus, each gamete should have either R or r and Y or y.
- The Law of Independent Assortment states that the segregation of R and r is independent of the segregation of Y and y.

Hence, four equally likely gametes (YR, Yr, yR, and yr) can be formed when the YyRr heterozygote is self-crossed.

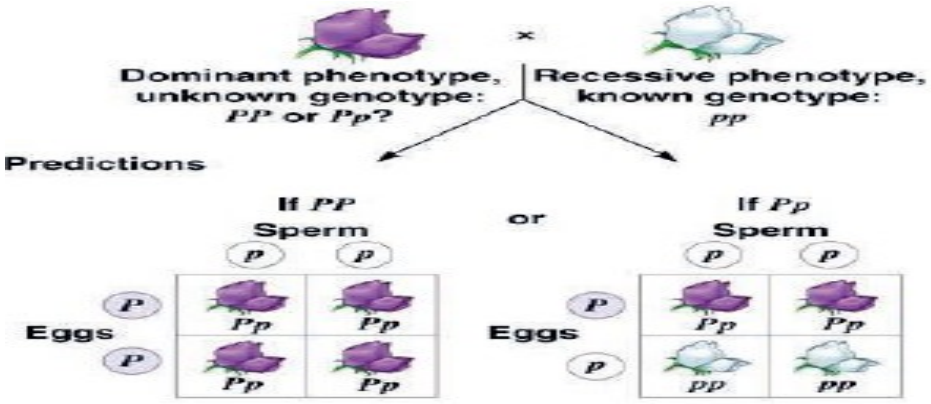
Independent assortment of alleles during gametes formation



4.5.4 Test Crosses

- A test cross is used to determine the unknown genotype of an organism by crossing with a known homozygous recessive genotype.
- For example,
  - When we cross a known parent of a homozygous recessive with an unknown parent and if the dominant trait is observed in all progenies, the unknown genotype is homozygous dominant.
  - In contrast, when we cross a known homozygous recessive and an unknown genotype of parent and if the recessive trait is manifested in any of their progenies, it means that the unknown genotype is heterozygous dominant.
- For example, if you have a pea plant with a purple flower it might be either a homozygote (PP) or a heterozygote (Pp).

- You can cross a purple flower to a white flower plant, because you know the genotype of a white flower plant is homozygous recessive (pp).
- If the phenotypic ratio in the F1 generation were all plants with purple flowers, the unknown genotype of the parent would be homozygous (PP).
- If the phenotypic ratio in the F1 generation were 1:1, the unknown genotype of the parent would be heterozygouse (Pp).
- The following figure (Figure 4.29) shows the cross using Punnett square.



In addition, Gregor Mendel introduced a backcross which is a cross between the F1 individual and either of the two parents.
In a back cross, the F1 hybrid is crossed back with any of the parents, either recessive/or dominant.

4.6. Sex determination

- Sex refers to categorized as female or male in organisms.
- Sex determination in organism is remarkably diverse.
- In some organisms,
  - **Hermaphroditic species**_ both male and female resides within the same individual.
  - **Dioecious**_ separate male and female sexes
  - **Haplodiploidy**
    - Males develop from unfertilized eggs and are haploid
    - Females develop from fertilized eggs and are diploid.
- The sex of human beings and other mammalian is determined genetically by sex chromosomes.

- In humans, out of 23 pairs of chromosomes, one pair is sex chromosomes and 22 pairs are autosomal chromosomes.
- During meiosis, the sex chromosome pair of male XY and female XX separates.
  - Male passes on an X or a Y to separate gametes.
  - Female has two X chromosomes and passes on X chromosomes to egg cell.
  - The eggs fertilized by X-bearing sperm become females (XX), whereas those fertilized by Y-bearing sperm become males (XY).

4.7. Non-Mendelian inheritance

- Genetic Inheritance that is not in accordance with Mendel's law.
- It is any inheritance patterns that don't follow one or more laws of the Mendelian genetics.
- Gregor Mendel explained that gene might exist indifferent forms (alleles) that are either dominant or recessive.
- However, there are other conditions in which alleles show different dominance relationships.
- Example
  - Co-dominance and Incomplete dominance) and
  - Modes of inheritance (Gene linkage and Multiple allelism).
  - These are examples of non-Mendelian inheritance.

4.7.1 Co-dominance, Incomplete dominance and Multiple alleles

Co-dominance

- When an organism has two different alleles (heterozygote), it will express both alleles at the same time rather than a dominant allele taking complete control over a recessive allele.

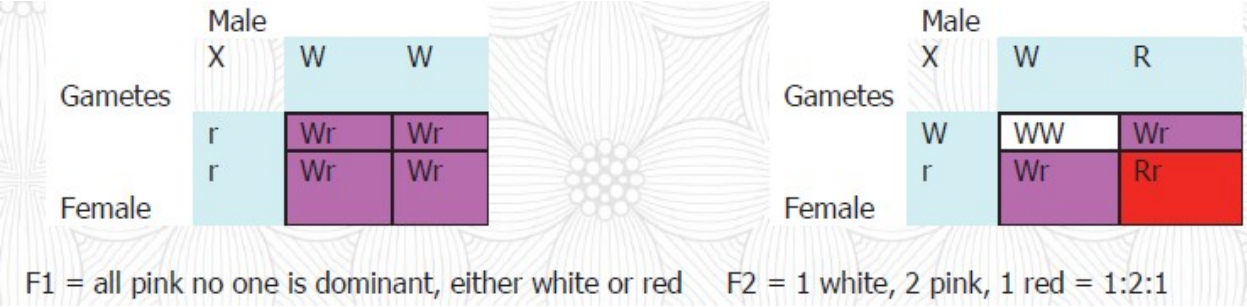
Example

- Coat color in short-horned cattle.

Incomplete dominance

- In incomplete dominance, Mendel's principle of dominance is not applicable.
- In incomplete dominance, the mix of genetic traits that produce an intermediate phenotype result in heterozygotes in terms of physical traits.

Example: The pink rose is a great example.
Example: __Phenotype = white rose; genotype = WW;
__Phenotype= red rose; genotype=rr



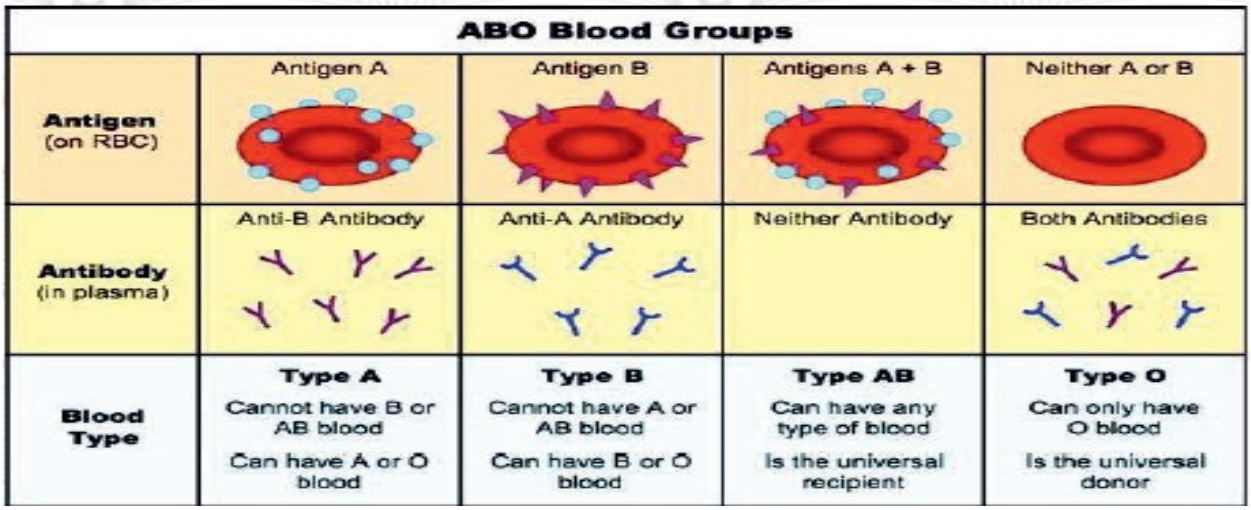
Multiple alleles

- Gregor Mendel suggested that each gene would have pair of factors (alleles), which are inherited from two parents (one from each parent).
- However, in ABO blood group system in human allele exists in more than two allele it is an example of a traits with multiple alleles because it exists in three allelic forms: **A, B, and O.**
- ABO blood group system is the classification of human blood based on the presence or absence of the antigens A and B on the surface of the red blood cells.
- As a result, people may have type A, B, O, or AB blood.

The genotype and phenotype of ABO blood groups

ABO Blood Group	
Genotype	Phenotype (Blood type)
AA	A
AO	A
BB	B
BO	B
OO	O
AB	AB

- The A and B blood types are also **co-dominant**.
  - Thus, if two people with AA and BB blood type alleles have children, every single child (male or female) from this couple would be heterozygotes (AB) with AB blood type.



4.7.2 Rh factor inheritance in humans and its medical importance

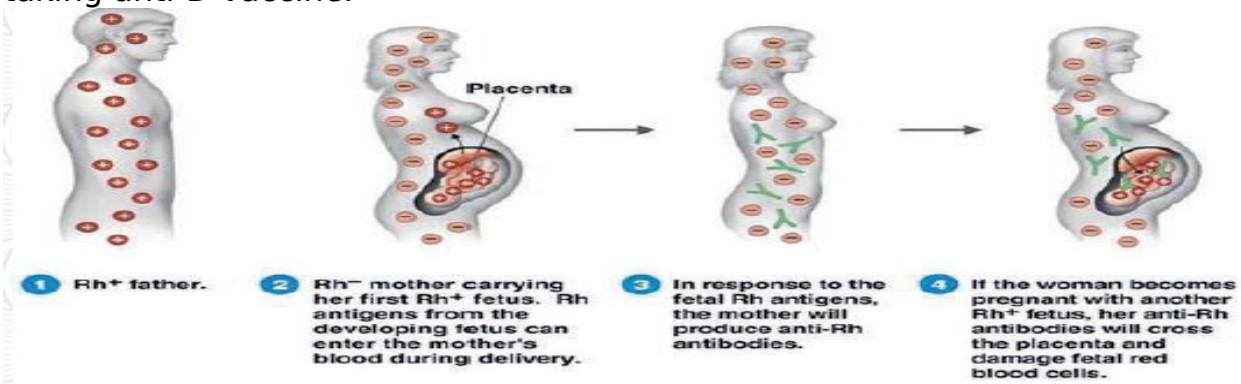
- The Rh factor_ is the inheritance of a blood group other than the ABO blood group.
- The Rh factor is inherited independently of the ABO blood types.
- There are two different alleles for the Rh factor:
  - Rh^+ with dominant Rhesus D antigen
  - Rh- without antigen.
- Rh positive people who possess Rh (D) antigen:
  - Genotype: Rh+/Rh+ or Rh+/Rh-.
- Rh negative do not D antigen
  - Genotype it possesses: Rh-/Rh-
- Just like the ABO alleles, each biological parent transmits one of their two Rh alleles to their child.

Genotype	Phenotype	Blood Proteins(Antigen)	Blood transfusion	
			Donates to	Receives from
Rh+/ Rh +	Rh+	Rh(D) proteins	Rh+	Rh+, Rh-
Rh +/ Rh -	Rh+	Rh(D) proteins	Rh+	Rh+, Rh-
Rh-/ Rh-	Rh-	None	Rh-	Rh-

- **Rh negative parent:**
  - Can only pass an Rh- allele to her/his son or daughter.
- **Rh positive parents:**
  - Can pass either an Rh+ or Rh- allele to his/her son or daughter.
  - These parents would have:
    - Rh^+ children (Rh- from one parent and Rh^+ from the other) or (Rh^+ from both parents)or
    - Rh- children (Rh- from both parents).
- An Rh^+ father and Rh- mother

- They can have a child with Rh^+/ or Rh^-.
- The baby with Rh+ causes Rh sensitization in the mother because she is exposed to Rh antigen, which she builds up antibodies against the antigen for the first pregnancy. This condition is called **erythroblastosis fetalis** (a medical condition where an Rh negative mother's antibodies attack the RBC an Rh- fetus
- Future pregnancies can be increasingly difficult, as the mother's antibodies attack the baby.

- However, it is possible to prevent Rh sensitization complications by taking anti-D vaccine.



4.7.3 Sex-linked inheritance in humans

- Males have only one X chromosome; genes that are on the chromosome are expressed because there is no similar gene on the corresponding Y chromosome that masks them.
- Hence
  - Men are far more likely to get sex-linked genetic diseases than women are.
  - Any gene on the X chromosome of male will be expressed regardless of whether it is dominant or recessive.
- Hemophilia is an example of a sex-linked genetic disease in humans.
  - This gene is carried on the X chromosome and can only be passed on to males through their mother.
- The crosses and offspring of sex-linked trait hemophilia can be shown as follows.

Parents	Male (XY)		
Female (X^HX^h)	Gametes	X	Y
	X^H	X^HX^H	X^HY
	X^h	X^HX^h	X^hY

- In this case,
  - The mother is a carrier of the sex-linked trait.
  - She does not have the diseases because her normal X chromosome masks them.

- But her son gets the disease because there is no corresponding X chromosome on Y that masks it.

4.8 Human pedigree analysis and its importance

What is pedigree?

- Line of ancestor, family tree or an organism back ground.

Importance

- To **understand how human traits and diseases are inherited.**
- It can show whether a trait is an **autosomal dominant**, **autosomal recessive** or **X-linked trait.**

Pedigree analysis

- A typical pedigree that consists of squares and circles.
  - Square_ represents males
  - Circles_ represents females.
- Rows show generations
  - The oldest generation at the top row
  - Subsequent generation on separate rows.
- A **horizontal line** connecting two parents is called a “marriage line”.
- A **vertical line** connects children to couples.

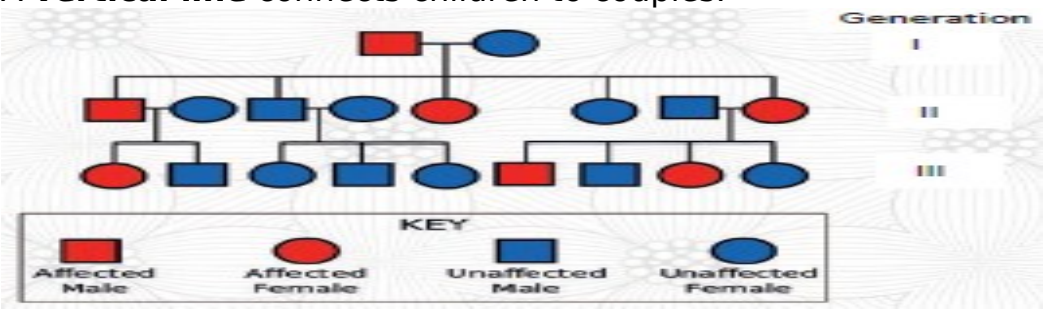
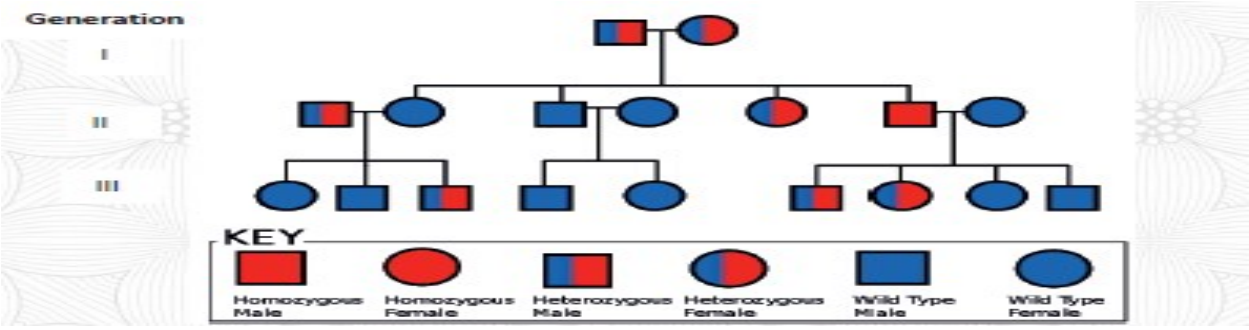


Figure 4.34 above is an example of a pedigree of an autosomal dominant trait. This pedigree begins with an affected male and an unaffected female.

- The first child (on the left) is an affected male, who married an unaffected female and produced two children (an affected female and an unaffected male).
- The second child is an unaffected male married to an unaffected female and produced three unaffected children (1 male and 2 females).
- The third child is an affected female who is not married.
- The fourth child is an unaffected female who is not married.
- The fifth child is an affected female married to an unaffected male and produced four children (an affected male, an unaffected male, an affected female, and an unaffected female).

- Figure 4.35 below is an example of a pedigree of an autosomal recessive trait. In this pedigree, individuals that are half-shaded are heterozygous and therefore do not show the trait).

- The example shows two heterozygous individuals who have four children.
  1. The first child (on the left) is an unaffected female, married to a heterozygous male who produced three children (an unaffected female, an unaffected male, and a heterozygous male.
  2. The second child is an **unaffected male** married to an **unaffected female** who produced two unaffected children (1 male and 1 female).
  3. The third child is a heterozygous female, not married.
  4. The fourth child is an **affected** male married to an **unaffected** female and produced four children: one heterozygous male, one heterozygous female, and one unaffected male and one unaffected female).
- 

Pedigree analysis can provide information about:

- Trait inheritance by examining the presence and absence of a trait throughout the history of a family.
- Give important clues about the risk of disease inheritance and propagation.

- In general analyzing pedigrees can reveal the following:
  1. Whether a trait is dominant or recessive
  2. The type of chromosome, autosomal or sex, a trait is linked to
  3. The genotypes of family members, and
  4. The probabilities of phenotypes in the future generations.

4.9. Genetic disorders

- It is a disease that is caused by a change, or mutation, in an individual's DNA.
- This disease can be further categorized as autosomal dominant, autosomal recessive, x-linked, chromosomal and multifactorial disorders in human being.
- For Example:

- Diabetes
- Cancer
- Down syndrome
- Turner syndrome

Hemophilia
Cystic fibrosis
albinism

- **Mutation** is a change in the DNA sequence of an organism due to:
  - Either error that occur during DNA replication or environmental factors**.**
- **Parents pass genes on to their children, and some of** these genes may contain genetic disorders.
- Genetic disorders can be grouped into **three main categories**.

4.9.1 Single-gene disorders/Monogenetic disorder

- It is defects in **one particular gene due to changes or mutations** that occur in the DNA. These disorders are known as **monogenetic disorders.**
- **There are many** well-known single-gene disorders.
- The pattern of inheritance depends on whether they are controlled by genes on autosomes or by genes on sex chromosomes.
- The three major patterns of Mendelian inheritance for genetic disorders and diseases are **autosomal dominant, autosomal recessive,** and **X-linked.**

A. Autosomal dominant

- It expressed in the **heterozygous condition**.
- Controlled by genes on one of human autosomes (22 pairs of non sex chromosomes) that do not differ between males and females.
- Inherited in the same way regardless of the sex of the parent or offspring.
- Example
- **Huntington's disease_** A hereditary disorder of the nervous system that manifests as jerky involuntary movements.

B. Autosomal recessive

- It expressed in homozygous conditions.
- It most commonly occurs when both parents carry the trait and the offspring receives the defected gene from each parent.
- Although both parents are the carriers off the trait, they are unaffected.
- A child with cystic fibrosis or albinism has inherited a defective gene from each parent.
- Example: Cystic fibrosis and Albinism

C. X-linked disorders

- It controlled by genes on the sex chromosomes.
- Females have two X chromosomes that have two alleles (XX) for any X-linked disorder.

- Therefore, they must inherit two copies of the recessive allele to express an X-linked recessive disorder.
- This explains why X-linked recessive disorders are less common in females than in males.
- Example: Hemophilia
  - The blood-clotting disorder that is characterized by the blood's inability to clot normally.

4.9.2 Chromosome disorders

- It is disorders resulting from changes in the number or structure of chromosomes.
- Chromosomal abnormalities typically occur due to errors during cell division.
- Example:
  - Down syndrome or trisomy 21(2n+1), three copies of chromosome 21).
- The most common types of chromosomal disorders occur due to the following (Figure 4.36):

1. **Aneuploidy: wrong number of chromosomes**
   - (2n_1, 2n_2, 2n+1, 2n+2, search the type of disorder for each).
2. **Deletion: a part of a chromosome is** missing.
3. **Inversion: occurs when there are two** breaks on a chromosome and the segment between the breakpoints flips around and reinserts back into the chromosome**;**
4. **Translocation: is a rearrangement of a** chromosomal segment from one location to another

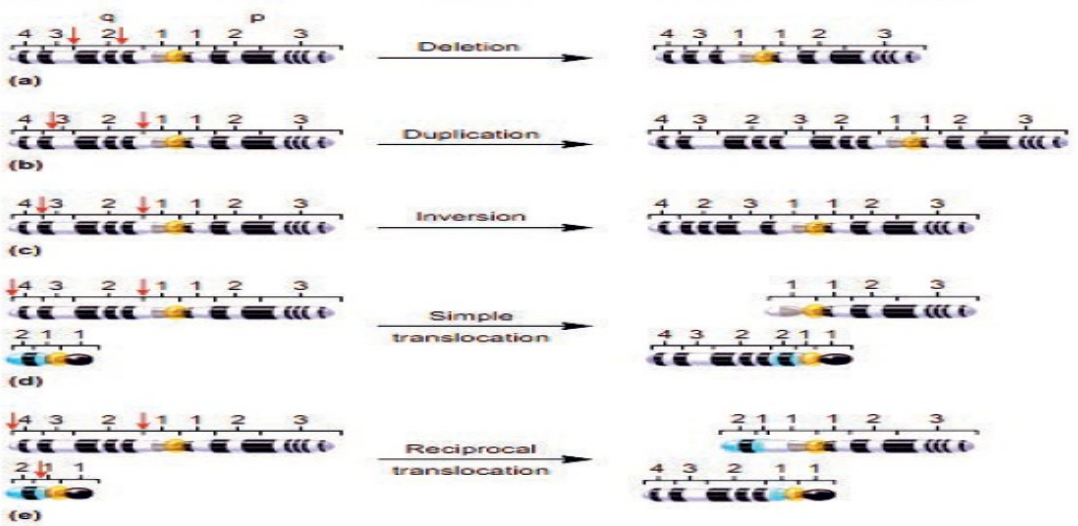


Figure 4.36 Types of changes in chromosome structure

4.9.3 Multifactorial disorders

- Disorders caused by changes in the combination of multiple genes, complex interaction with environmental and lifestyle factors.
- Life style factors such as smoking, drinking alcohol, eating an unhealthful diet, not getting enough sleep and living in an area that has high levels of air pollution.
    - Examples: Diabetes and Cancer.