Introductory lecture:

Genetics is defined as the science that deals with heredity and variation in organisms, including the genetic features and constitution of a single organism, species, or group, and with the mechanisms by which they are affected.

The term genetics was proposed by the English biologist William Bateson in 1906. The classical principles of genetics were deduced by Gregory Mendel in 1865, on the basis of the results of breeding experiments with peas. Mendel studied the inheritance of a number of well-defined traits, such as seed color, and was able to deduce general rules for their transmission. In all cases, he could correctly interpret the observed patterns of inheritance by assuming that each trait is determined by a pair of inherited factors, which are now called **genes**.

These factors are transmitted from one plant generation to the next in a predictable pattern, each factor being responsible for an observable trait. The trait one can observe is the **phenotype**. The underlying genetic information is the **genotype.**

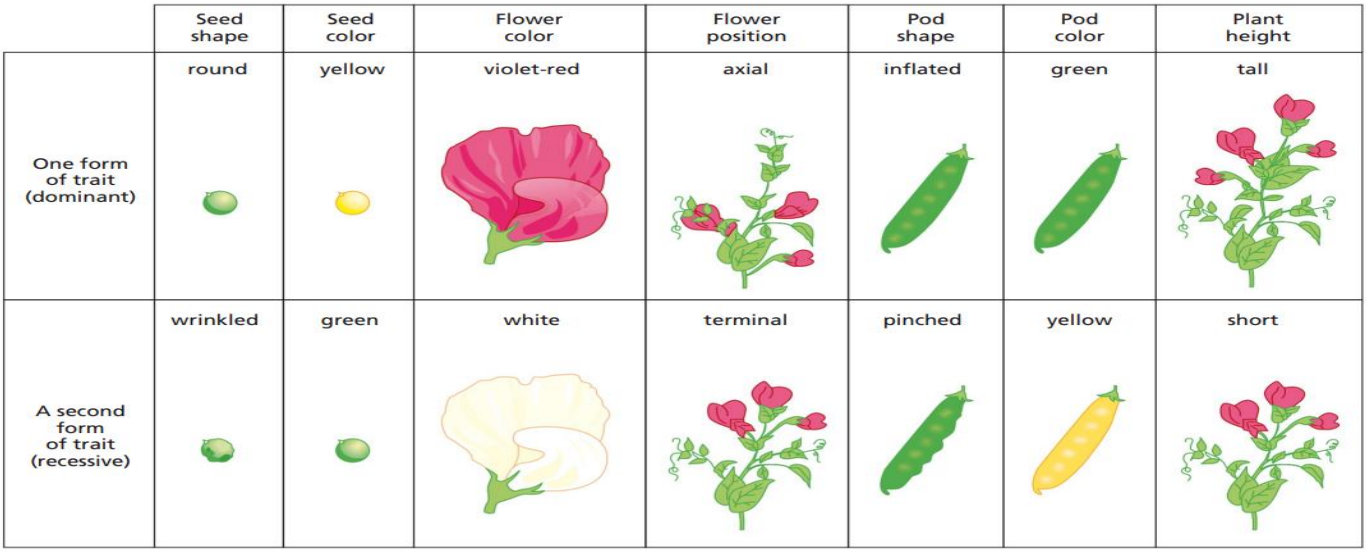

Figure (1): Phenotype of several traits in pea. (Weinberg, R A, 2014, The biology of cancer, 2nd edition)

The term gene for this type of a heritable factor was introduced in 1909 by the Danish biologist Wilhelm Johannsen (1857–1927). Theodor Boveri (1862–1915), is the scientist who recognized the genetic individuality of chromosomes in 1902 when he was studying the embryonic development of the sea urchins. Walter Sutton found same results when he studied the reduction

division (meiosis) in grasshopper in 1902-1903. **The chromosome theory of inheritance** was proposed by Sutton and Boveri.

Genetics became an independent scientific field in 1910 when Thomas H. Morgan studied the fruit fly (*Drosophila melanogaster*) in his systematic genetic studies and showed that **genes are arranged on chromosomes in sequential order**. Morgan summarized "**the chromosome theory of inheritance" that hereditary factors (sequential ordered genes) responsible for Mendelian inheritance are located on the chromosomes within the nucleus**. leading to foundation of Mendelian (Classic) genetics

This theory is based on a few fundamental principles:

1. Chromosomes contain the genetic material that is transmitted from parent to offspring and from cell to cell.

2. Chromosomes are replicated and passed along, generation after generation, from parent to offspring. They are also passed from cell to cell during the development of a multicellular organism. Each type of chromosome retains its individuality during cell division and gamete formation.

3. The nuclei of most eukaryotic cells contain chromosomes that are found in homologous pairs they are diploid. One member of each pair is inherited from the mother, the other from the father. At meiosis, one of the two members of each pair segregates into one daughter nucleus, and the homolog segregates into the other daughter nucleus. Gametes contain one set of chromosomes they are haploid.

4. During the formation of haploid cells, different types of (nonhomologous) chromosomes segregate independently of each other.

5. Each parent contributes one set of chromosomes to its offspring. The maternal and paternal sets of homologous chromosomes are functionally equivalent; each set carries a full complement of genes.

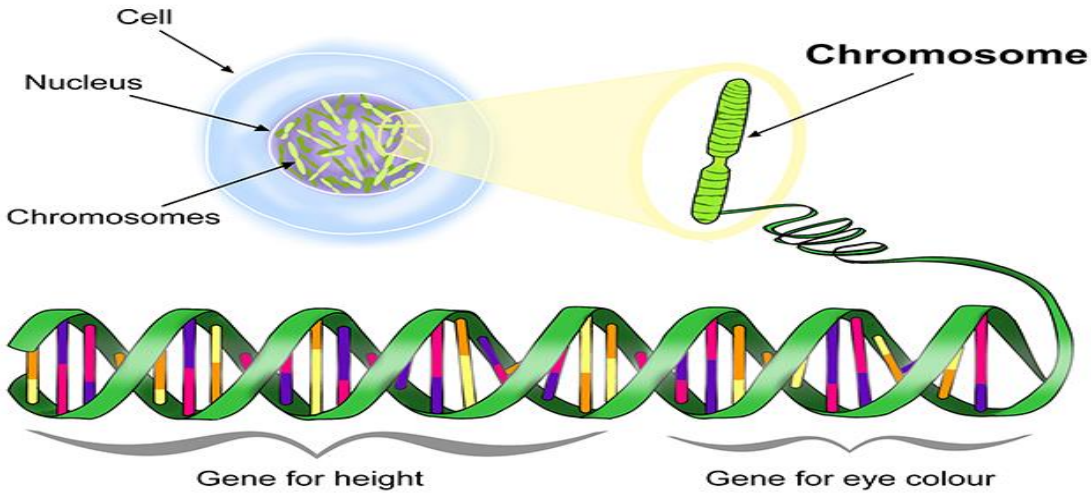

Figure (2): The genetic material as a sequential ordered gene located on the chromosome within the nucleus of an animal cell.

What did Morgan do?

Morgan used to inbreed the fruit fly in his lab to improve the chromosome theory of inheritance. He did many test crosses between white eye drosophila males and red eyes drosophila females, as a result he noticed that, there were no while eye females at all (as in table 1).

Table 1: Expected Mendelian Ratios versus Morgan's Actual Results

Cross	Outcome	
	Expected Phenotypes	**Observed Phenotypes**
P_1 Red ♀ × P_1 White ♂	F_1 = All Red	F_1 = All Red*
F_1 Red ♀ × F_1 Red ♂	75% Red ♀ and ♂ 25% White ♀ and ♂	50% Red ♀ 25% Red ♂ 25% White ♂

So, he investigated the frequencies of the phenotypes of the offspring. Morgan considered the evidence and proposed that a process of crossing over, or recombination, might explain his results. Specifically, he proposed that the two paired chromosomes could "cross-over" to exchange information. Furthermore, Morgan hypothesized that the frequency of recombination was related to the distance between the genes on a chromosome, and that the interchange of

genetic information broke the linkage between genes. The closer two genes were to one another on a chromosome, the greater their chance of being inherited together. In contrast, genes located farther away from one another on the same chromosome were more likely to be separated during recombination. Therefore, Morgan correctly proposed that the strength of linkage between two genes depends upon the distance between the genes on the chromosome. This proposition became the basis for construction of the earliest maps of the human genome. The map unites and measured by centimorgan and its represented 1% crossing over between two linkage genes. (for further reading click the links: https://www.nature.com/scitable/topicpage/thomas-hunt-morgan-genetic-recombination-and-gene-496/ , https://www.nature.com/scitable/topicpage/thomas-hunt-morgan-and-sex-linkage-452/). Also, for the first time there were a linkage between the inherited trait and the sex which led foundation of new genetic concepts (sex determination and sex linkage inheritance).

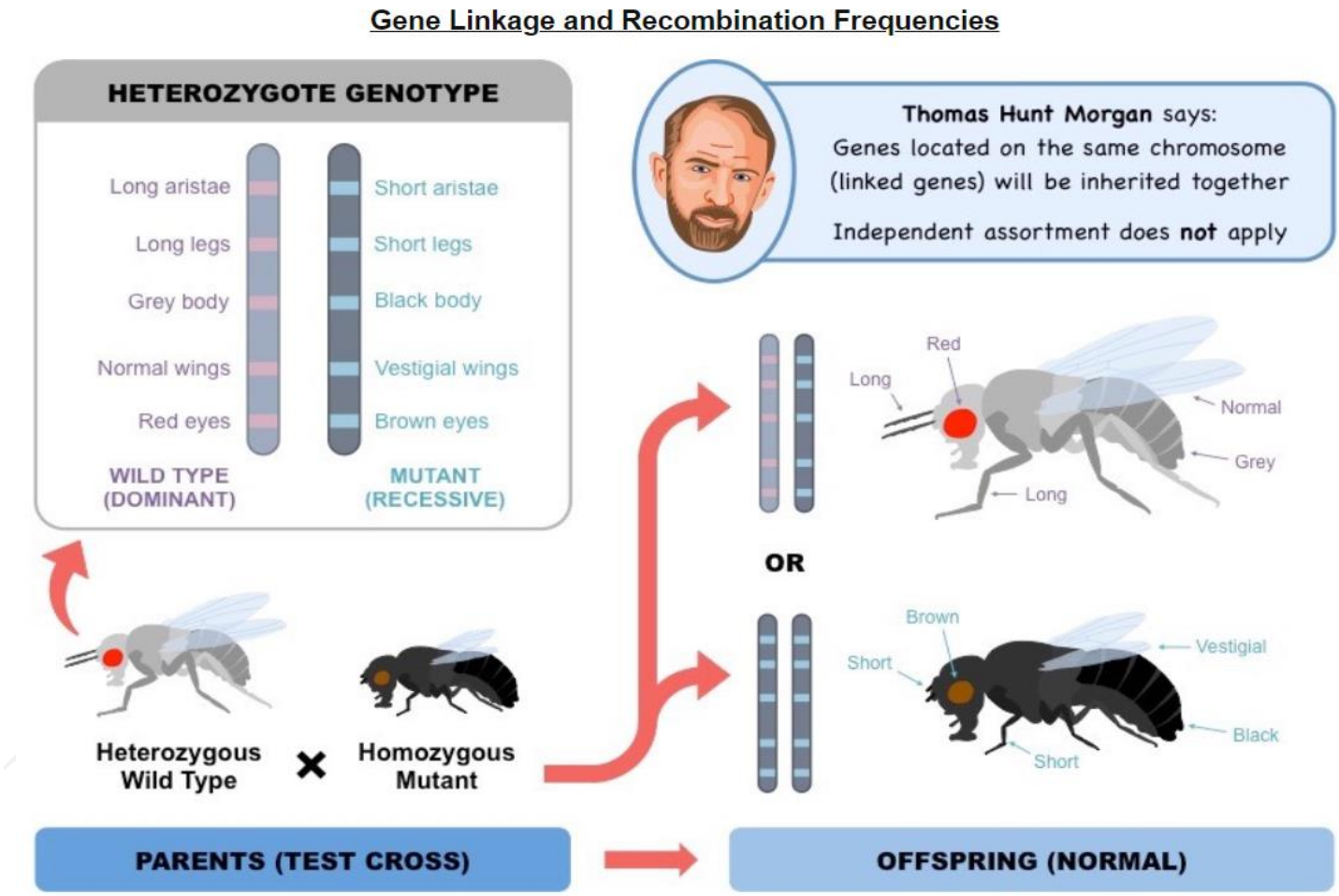

Figure (3): The linkage and recombination frequencies

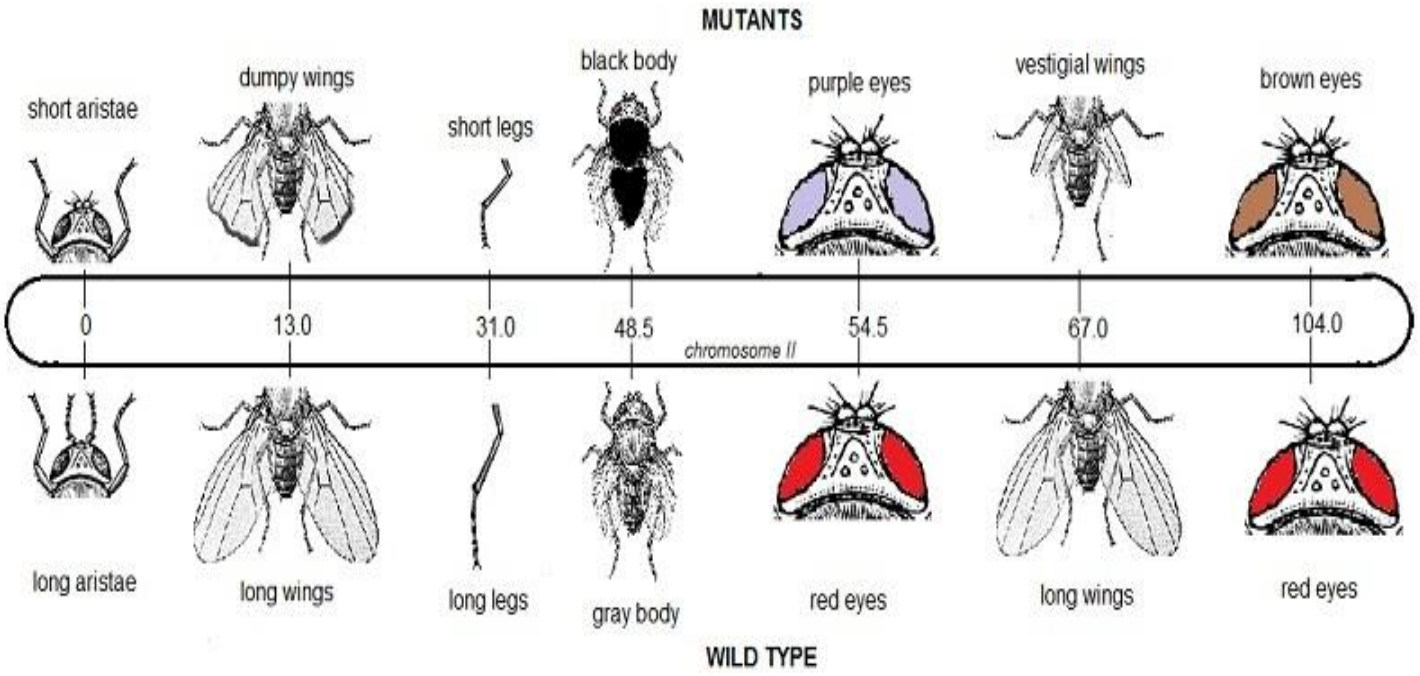

Figure (4): The distance among the genes located on Chromosome 2 on Drosophila Melanogaster (fruit fly), the wild type traits and the mutants.

Importance of genetics

In the last century, genetics has become an important biological tool, using mutants to gain an understanding of specific processes. This work has included:

a. Analyzing heredity in populations.

b. Analyzing evolutionary processes.

c. Identifying genes that control steps in processes.

d. Mapping genes.

e. Determining products of genes.

F. Analyzing molecular features of genes and regulation of gene expression

Basic Concepts of Genetics

1. Genetic material of both eukaryotes and prokaryotes is DNA (deoxyribonucleic acid). Many viruses also have DNA, but some have RNA genomes instead.

2. DNA has two chains, each made of nucleotides composed of a deoxyribose sugar, a phosphate group and a base. The chains form a double helix.

3. There are four bases in DNA: A (adenine), G (guanine), C (cytosine) and T (thymine).

a. In RNA, U (uracil) replaces T.

b. The sequence of bases determines the genetic information.

c. Genes are specific sequences of nucleotides that pass traits from parents to offspring.

4. Genetic material in cells is organized into chromosomes (literally "colored body" because it stains with biological dyes).

a. Prokaryotes generally have one circular, super coiled chromosome.

b. Eukaryotes generally have:

i. Linear chromosomes in their nuclei, with different species having different numbers of chromosomes.

ii. DNA in organelles (e.g., mitochondria and chloroplasts) that is usually a circular molecule.

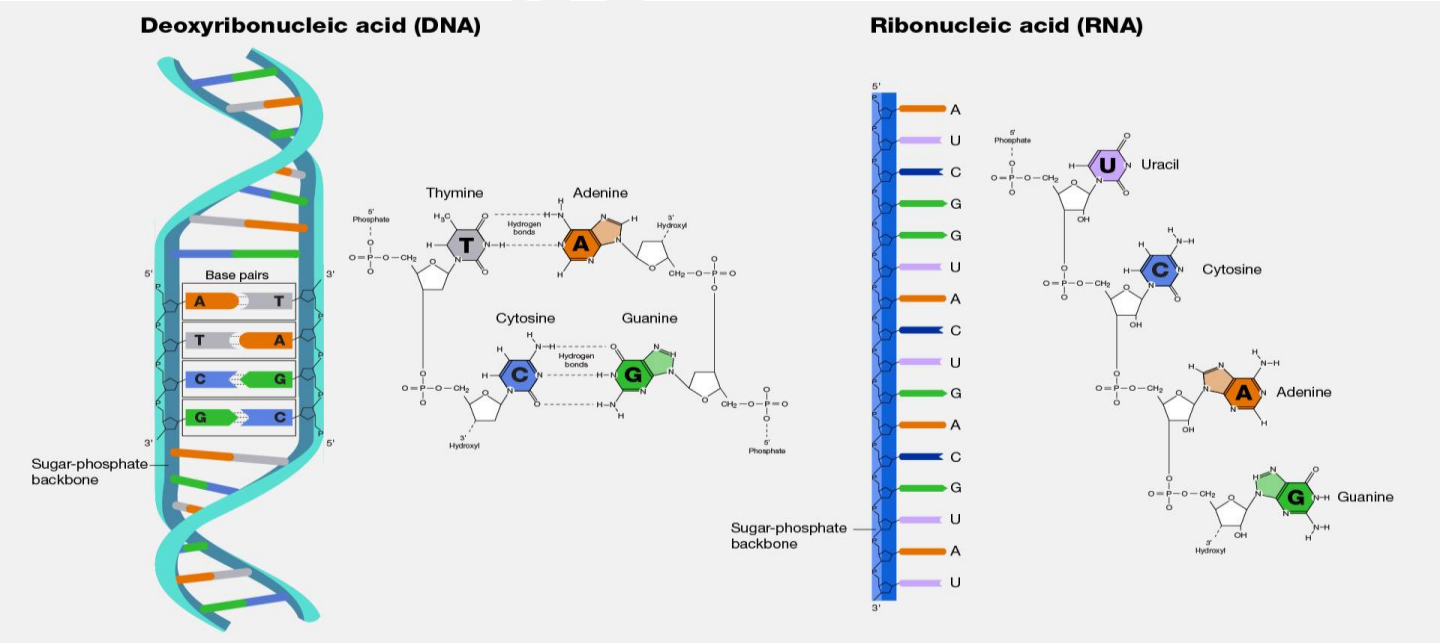

Figure (5): the structure of DNA and RNA.

Branches of genetics

1- **Mendelian (classic) genetics:** deals with transmission (movement) of genes and genetic traits from parents to offspring, and with genetic recombination.
2- **Population genetics:** studies heredity in groups for traits determined by one or a few genes. It was found as a result of the work of the English mathematician G.H. Hardy and the German physician W. Weinberg independently who recognized, in 1908 that Mendelian inheritance accounts for certain regularities in the genetic structure of populations. Their work contributed to the successful introduction of genetic concepts into plant and animal breeding.
3- **Quantitative genetics:** studies group hereditary for traits determined by many genes simultaneously.
4- **Human genetics:** is the study of inheritance as it occurs in human beings.
5- **Medical genetics** is the branch of medicine that involves the diagnosis and management of hereditary disorders.
   a- **Cytogenetic** is the study of the structure, the behavior of the chromosomes and chromosome abnormalities.
   b- **Biochemical genetics**: Metabolic (or biochemical) genetics involves the diagnosis and of inborn errors of metabolism in which patients have enzymatic deficiencies that involved in metabolism of carbohydrates, amino acids, and lipids.
   c- **Cancer genetics:** the study of genetic changes in the chromosomes and genes leading to cancer initiation and progression.
   d- **Mitochondrial genetics**: its deal with the diagnosis of mitochondrial disorders, which have a molecular basis but often result in biochemical abnormalities due to deficient in energy production.
   e- **Developmental genetics**: is the study of the process by which animals and plants grow and develop.
   f- **Genetic counseling:** Genetic counseling is the process of providing information about genetic conditions, diagnostic testing, and risks in other family members.
6- **Molecular genetics:** deals with the molecular structure and function of genes. It is a branch of genetics is stated when the double helix structure of deoxy ribonucleic acid (DNA) molecule was suggested by Watson and Crick in 1953, this structure explain the model of DNA replication and how could the DNA store the genetic information.
7- **Microbial genetics.** It studies the genetics of very small (micro) organisms; bacteria, archaea, viruses and some protozoa and fungi. This involves the study of the genotype of microbial species the phenotypes.

8- **Genetic engineering**: is the direct manipulation of an organism's genome using biotechnology.
9- **Epigenetics:** branch of genetics that deal with post transcriptional modifications of gene products without changing the DNA sequence, leading to change the gene expression.
10- **Forensic genetics:** The branch of genetics that deals with the application of genetic in the legal problems and legal proceedings. To find and analysis biological evidences in the crimes. Forensic genetics is also a branch of forensic medicine which deals more broadly with the application of medical knowledge to legal matters.

In the Lab:

Characteristics of Model Organisms suitable for genetic studies: Many organisms are used in genetic research. Desirable qualities for an experimental organism include:

a. A well-known genetic history.
b. A short life cycle so generations can be studied in a relatively.
c. A large number of offspring from each mating.
d. Ease of growing and handling the organism.
e. Marked genetic variation within the population.

Prokaryotic cells:

Prokaryotic cells (bacteria) are typically rod shaped or spherical with few micrometers in diameter, with plasmid cleus or special internal structures. Within a cell wall consisting of a bilayer cell membrane, most of bacteria contain an average 1000–5000 genes tightly packed in a single super-coiled circular molecule of DNA. In addition, they usually contain small circular DNA molecules named plasmids.

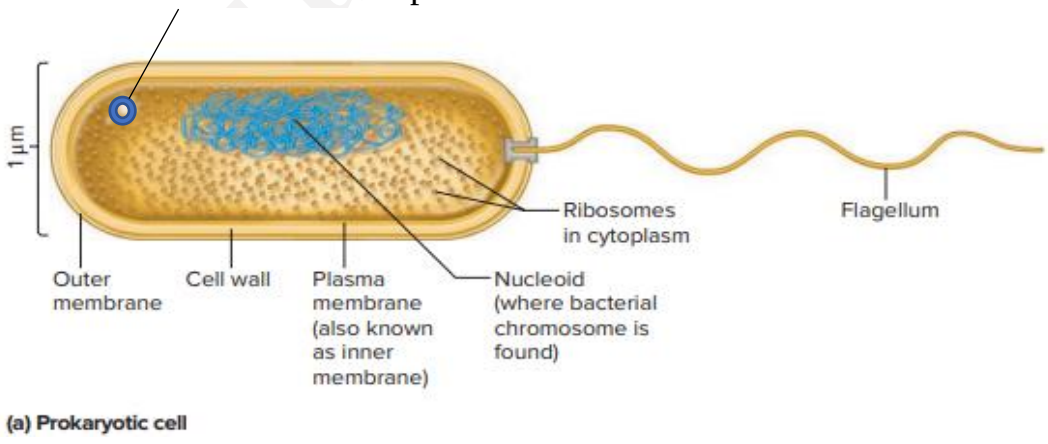

Figure (6): The basic organization of cells. (a) A prokaryotic cell. The example is a typical bacterium, (*Escherichia coli*), (Brooker, RJ, 2018, Genetics: Analysis & Principles, 6th Edi. McGraw-Hill Education, US).

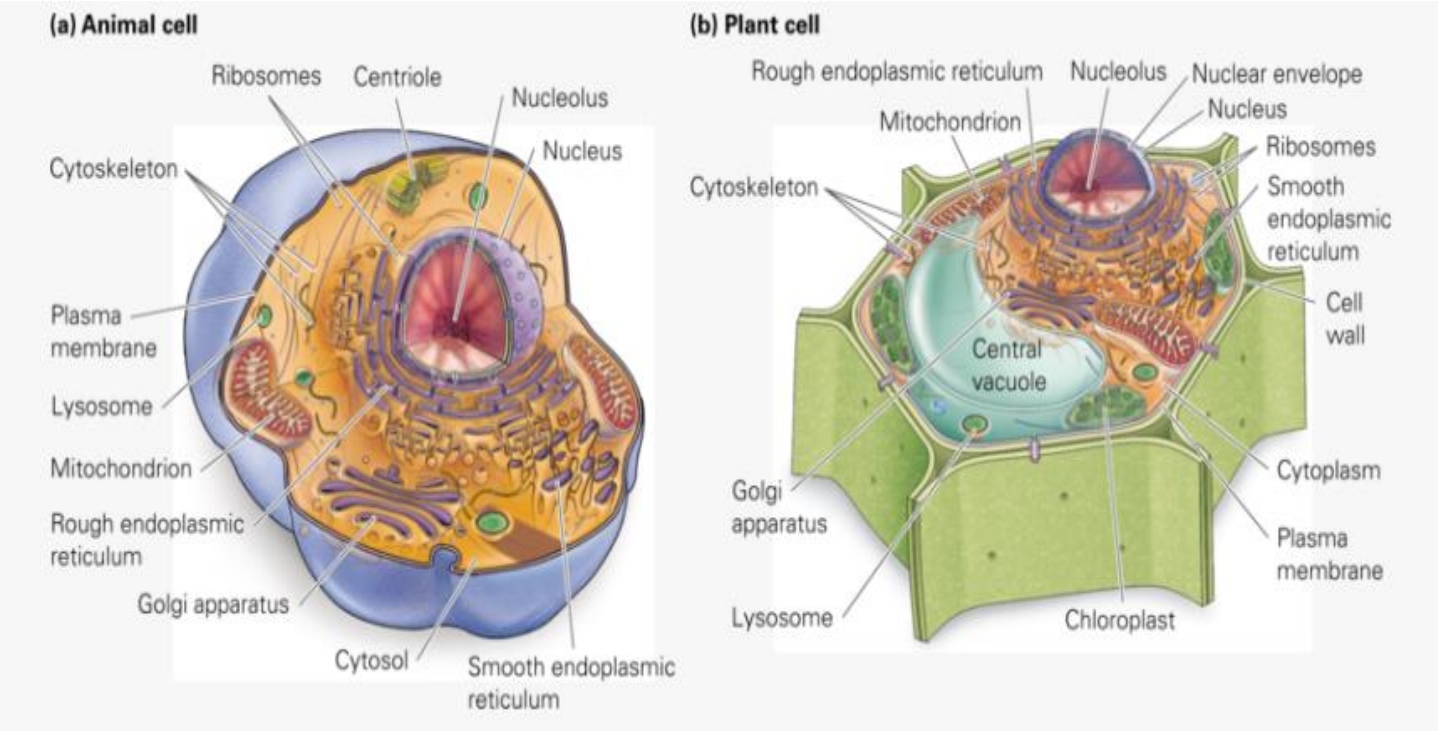

Figure (7): The basic organization of cells. A eukaryotic cell. (a) The example is a typical animal cell, (b) typical plant cell.

Eukaryotic Cells:

The cytoplasm contains many materials and organelles. Important in genetics are:

i. Centrioles (basal bodies) are in cytoplasm of nearly all animals, but not in most plants. In animals, a pair of centrioles is associated with the centrosome region of the cytoplasm where spindle fibers are organized in mitosis or meiosis.

ii. The endoplasmic reticulum (ER) is a double membrane system that runs through the cell. ER, with ribosome attached, collects proteins that will be secreted from the cell or localized to an organelle.

iii. Ribosome synthesizes proteins, either free in the cytoplasm or attached to the cytoplasmic side of the ER.

iv. Mitochondria are large organelles surrounded by double membrane that play a key role in energy processing for the cell. They contain their own DNA encoding some mitochondrial proteins, rRNAs and tRNAs.

v. Chloroplasts are photosynthetic structures that occur in plants. The organelle has a triple membrane layer, and includes a genome encoding some of the genes needed for organelle functions.

Eukaryotes have multiple linear chromosomes in a number characteristic of the species. These chromosomes located in the nucleus which surrounded by the nuclear membrane. Most have two versions of each chromosome, and so are diploid (2N).

a. Diploid cells are produced by haploid (N) gametes that fuse to form a zygote. The zygote then undergoes development, forming a new individual.

b. Examples of diploid organisms are humans (23 pairs) and Drosophila melanogaster (4 pairs). The yeast Saccharomyces cerevisiae is haploid (16 chromosomes).