Prokaryotic & Eukaryotic genome organization

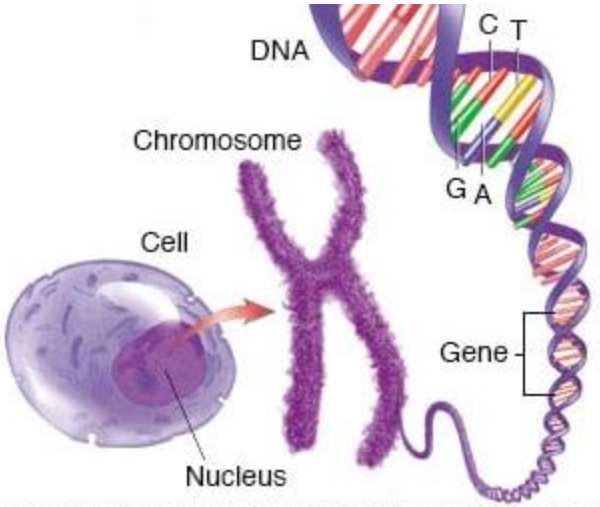
Microbiology VI

Genomes

- The word "genome," coined by German botanist Hans Winkler in 1920, was derived simply by combining *gene* and the final syllable of *chromosome*.
- The genome includes both the genes and non-coding sequences of DNA.
- An organism's **genome** is defined as the entire collection of genes and all other functional and non-functional DNA sequence in a haploid set of chromosomes.
- It includes structural genes, regulatory genes and non-functional nucleotide sequence.
- The genome is the ultimate source of information about an organism.

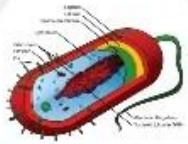
"Genes" are units of genetic information present on the DNA in the chromosomes and chromatin.

"Genome" is the entirety of an organism's hereditary organization. It is encoded either in DNA, or for many types of viruses, in RNA.



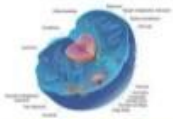
Types of Genome

There are four categories of genome according to different kinds of organisms.



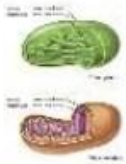
Prokaryote Genome

- ds DNA
- Circular
- 1 chromosome
- Nucleoid



Eukaryote Genome

- ds DNA
- Linear
- Many chromosomes
- Nucleus



Orgenelle Genome

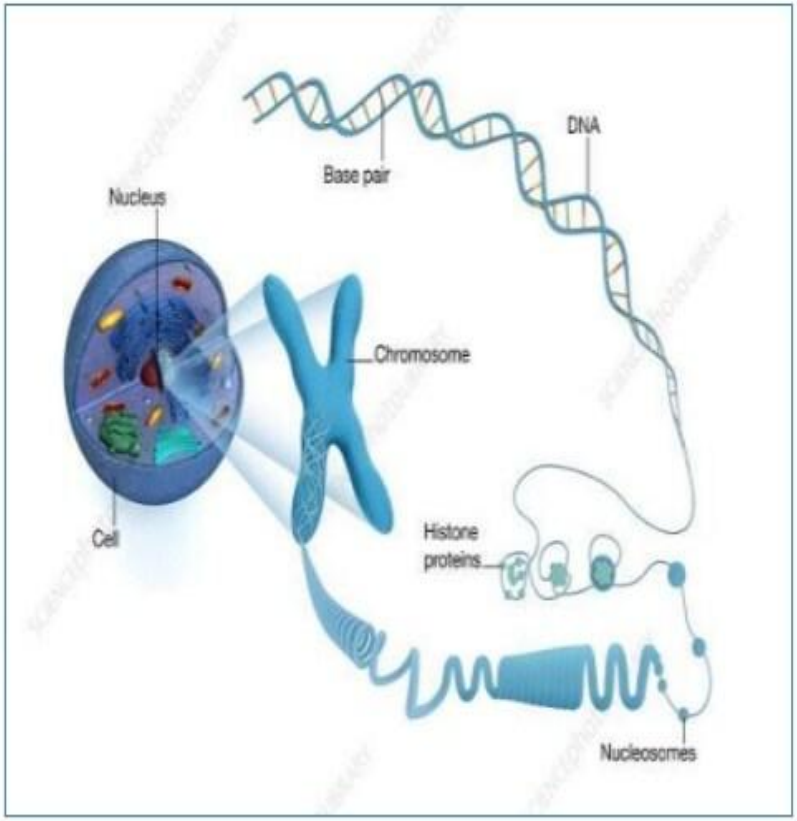
- Hereditary material present in chloroplast and mitochondria.

Virus Genome

- ss/ds DNA & RNA
- Packed under glycoprotein complex.

Genetic Organization

- In the cell, each DNA molecule associated with proteins, and each DNA molecule and its associated protein is called as chromsome.
- This organization holds true for prokaryotic and eukaryotic cells.



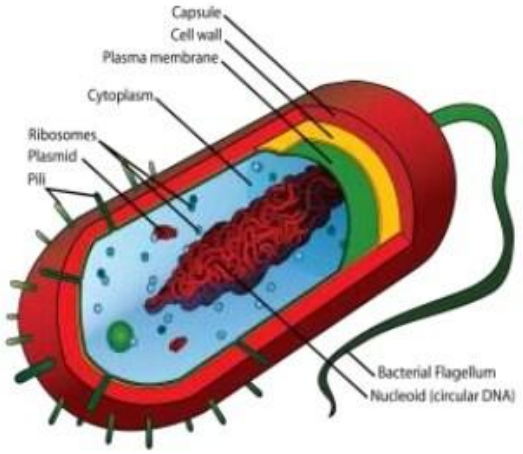
Packaging of DNA into chromosome

- **Packaging of DNA into the chromosome serves several important functions.**

1. Chromosome is compact form of DNA that readily fits inside the cell.
2. Protect the DNA from the damage.
3. Only packaged DNA can be transmitted efficiently to both daughter cells, when a cell divides.

Genome organization in prokaryotes

- They have small bodies and small genomes.
- Do not contain a nucleus or any other membrane-bound organelle.
- small, circular (sometimes linear) DNA present in the nucleoid region.
- They have a single chromosome that floats in the cytoplasm.
- The genome size ranges in between 10^4 to 10^7bp with a high gene density.
- **Apart from this single chromosome, some bacteria have extra-chromosomal DNA called plasmids.**



Plasmids

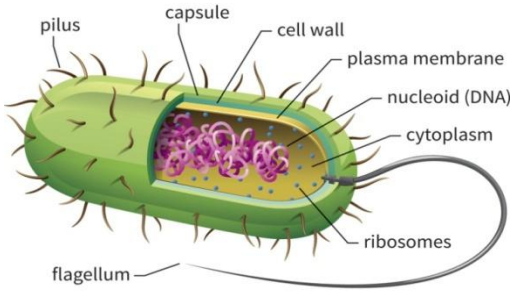
•Prokaryotes also frequently carry one or more smaller independent **extra-chromosomal DNA called plasmids.**
•Plasmids are not genomic DNA. They are accessory DNA molecules.
•Small circular DNA molecules that have the ability to self-replicate.
•Unlike the larger chromosomal DNA, plasmids typically are not essential for bacterial growth.

Importance of Plasmid

•Plasmids provide advantages to bacteria such as antibiotic resistance, herbicide resistance, etc.
•In addition, unlike chromosomal DNA, plasmids are often present in many complete copies per cell.

BACTERIAL GENOME

- Bacterial chromosomal DNA is usually a circular molecule that is a few million nucleotides in length.
  Escherichia coli :: 4.6 million base pairs
  Haemophilus influenzae :: 1.8 million base pairs
- A typical bacterial chromosome contains a few thousand different genes
- Structural gene sequences (encoding proteins) account for the majority of bacterial DNA
- The no transcribed DNA between adjacent genes are termed intergenic regions



E. coli

Prokaryotes

- The genome of E.coli contains amount of $4X10^6$ base pairs
- > 90% of DNA encode protein
- Lacks a membrane-bound nucleus.
  - Circular DNA and supercoiled domain
- Histones not present

Packaging of DNA

- Prokaryotic cells typically have smaller genomes, the need to compact their DNA is still substantial.
- *Escherichia coli* must pack its 1 mm chromosome into a cell that is only 1 µm in length.
- It is less clear how prokaryotic DNA compacted.

Nucleoid

- A prokaryotic chromosome is circular and resides in a cell region called the nucleoid.
- Only one complete copy of their chromosome that is package into a nucleoid.
- 80% DNA by mass and can be unfolded by agents that act on RNA or protein.
- Proteins - Responsible for condensing and maintain the supercoiled structure of the DNA have not been identified.
- The types of proteins found in prokaryotic chromosomes, known as the **nucleoid-associated proteins.**
- **Function:-**
  - DNA determines what proteins and enzymes an organism can synthesize and, therefore, what chemical reactions it is able to carry out.

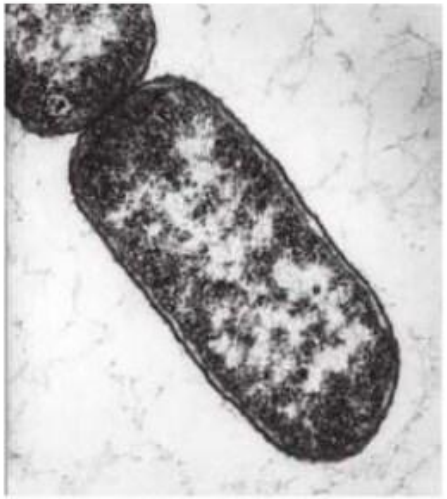
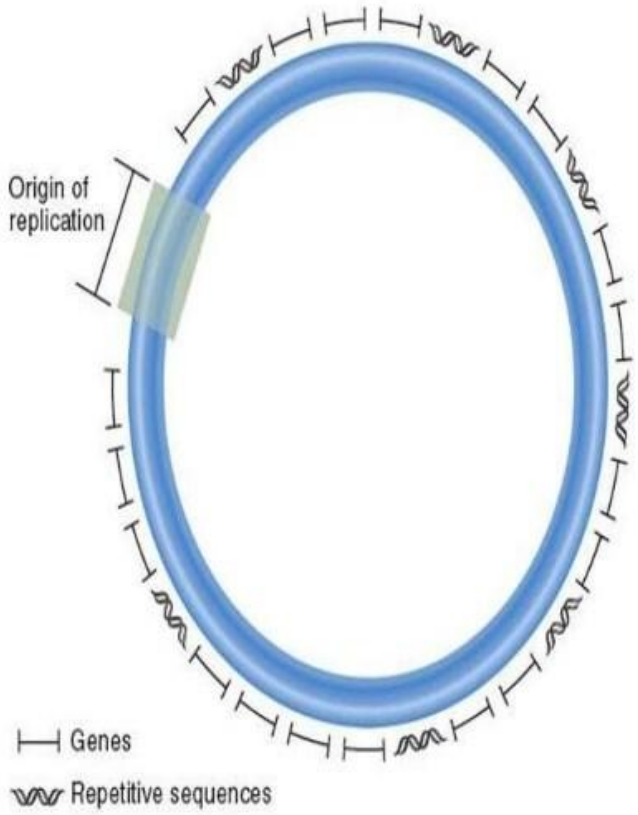


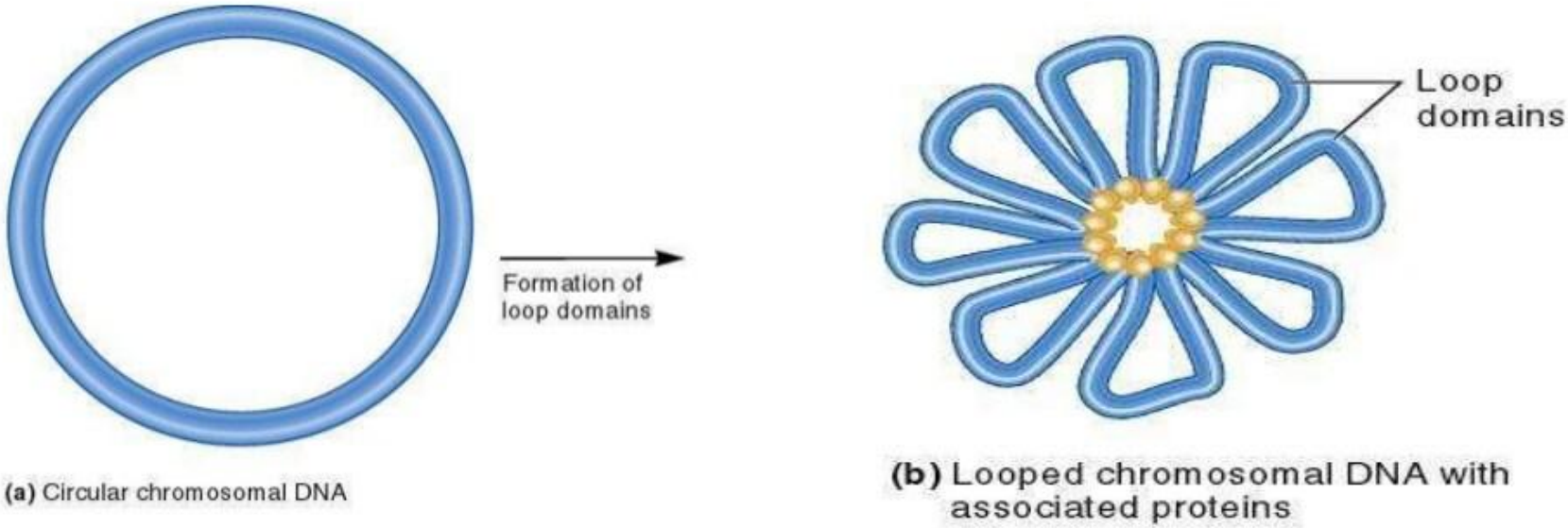
FIGURE: A thin section shows the bacterial nucleoid as a compact mass in the center of the cell.

Key features

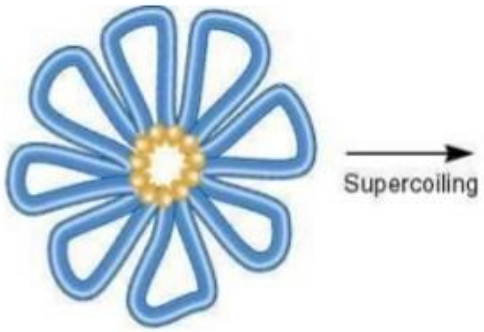
- Most, but not all bacterial species contain circular chromosomal DNA.
- A typical chromosomes is a few million base pairs in length.
- Most bacterial species contain a single type of chromosome, but it may be present in multiple copies.
- Several thousand different genes are interspersed throughout the chromosome.
- One origin of replication is required to initiate DNA replication.
- Short repetitive sequences may be interspersed throughout the chromosome.



- The chromosomal DNA must be compacted about a 1000-folds.
- The formation of loop domains.
- Number of loops varies according to the size of the bacterial chromosome and the species.
- *E. coli* has 50-100 with 40,000 to 80,000 bp of DNA in each.



- DNA super coiling



(a) Looped chromosomal DNA

(b) Supercoiled and looped DNA

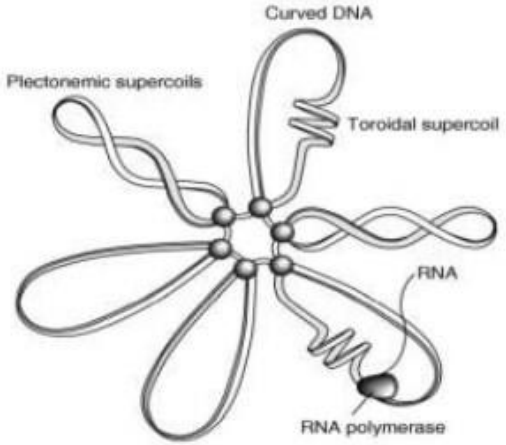


Diagram of the structure of the functional state of the *E. coli* chromosome.

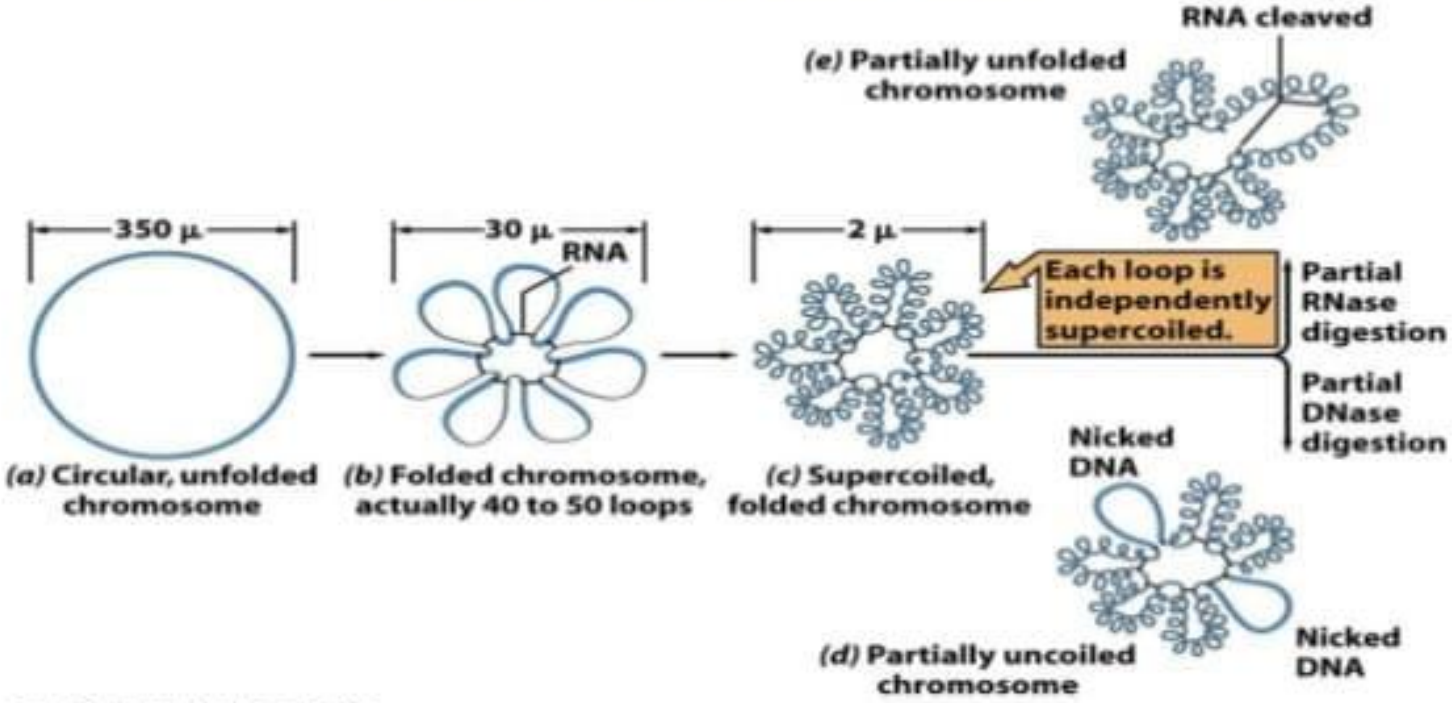
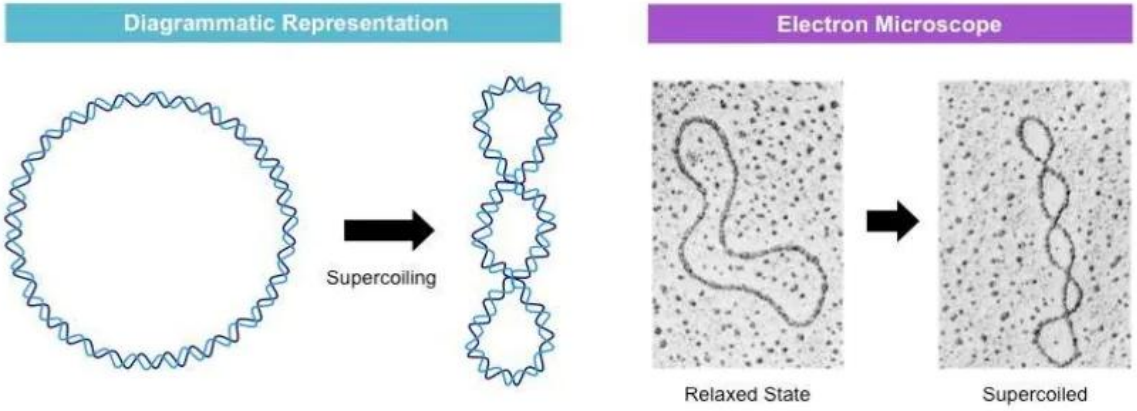


Figure 9-15 Principles of Genetics, 4/e

DNA SUPERCOILING

The term "supercoiling" means literally the coiling of a coil.

- **DNA supercoiling is generally a manifestation of structural strain.**
- **Supercoiling occurs when the molecule relieves the helical stress by twisting around itself. Overtwisting leads to positive supercoiling, while undertwisting leads to negative supercoiling.**
- **If DNA is in the form of a circular molecule, or if the ends are rigidly held so that it forms a loop, then overtwisting or undertwisting leads to the supercoiled state.**



POSITIVE AND NEGATIVE SUPERCOILING

- **Positive supercoiling is the right-handed, double helical form of DNA. It is twisted tightly in a right handed direction until the helix creates knot.**
- **Positive supercoiling is more condensed as the supercoil forms at the direction of DNA helix**

Positive supercoils

- **Negative supercoiling is the left-handed, double helical form of DNA.**
- **Prokaryotes usually have negative supercoiled DNA. It is naturally prevalent as it prepares the molecule for processes that require separation of the DNA strands without the need of additional energy.**

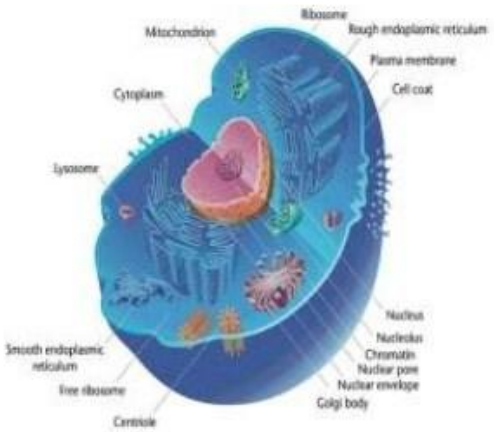
Negative supercoils

Enzyme

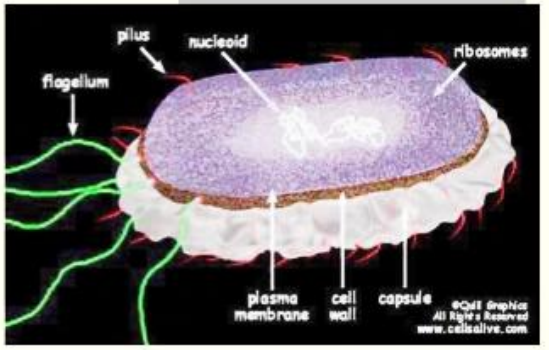
- **DNA topoisomerases -** unwinding, replication, and rewinding of the circular, supercoiled bacterial DNA
- For example, a topoisomerase called **DNA gyrase catalyzes the negative supercoiling of the circular DNA** found in bacteria
- DNA uncoiled and relaxed in order for **DNA polymerase** to bind for DNA replication and **RNA polymerase** to bind for transcription

Genome organization in eukaryotes

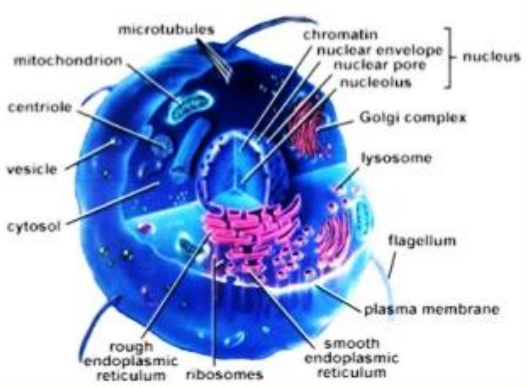
- Eukaryotic genome is linear and conforms the Watson-Crick Double Helix structural model.
- Embedded in Nucleosome-complex DNA & Protein (Histone) structure that pack together to form chromosomes.
- Eukaryotic genome have unique features of Exon - Intron organization of protein coding genes, representing coding sequence and intervening sequence that represents the functionality of RNA part inside the genome.
- A human haploid cell, consist of 23 nuclear chromosome and one mitochondrial chromosome, contains more than 3.2 billion DNA base pairs.



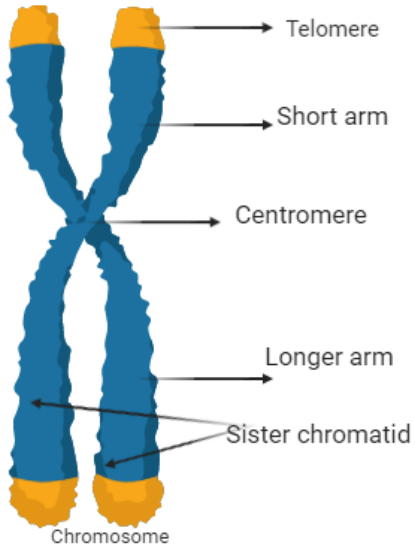
Eukaryotes



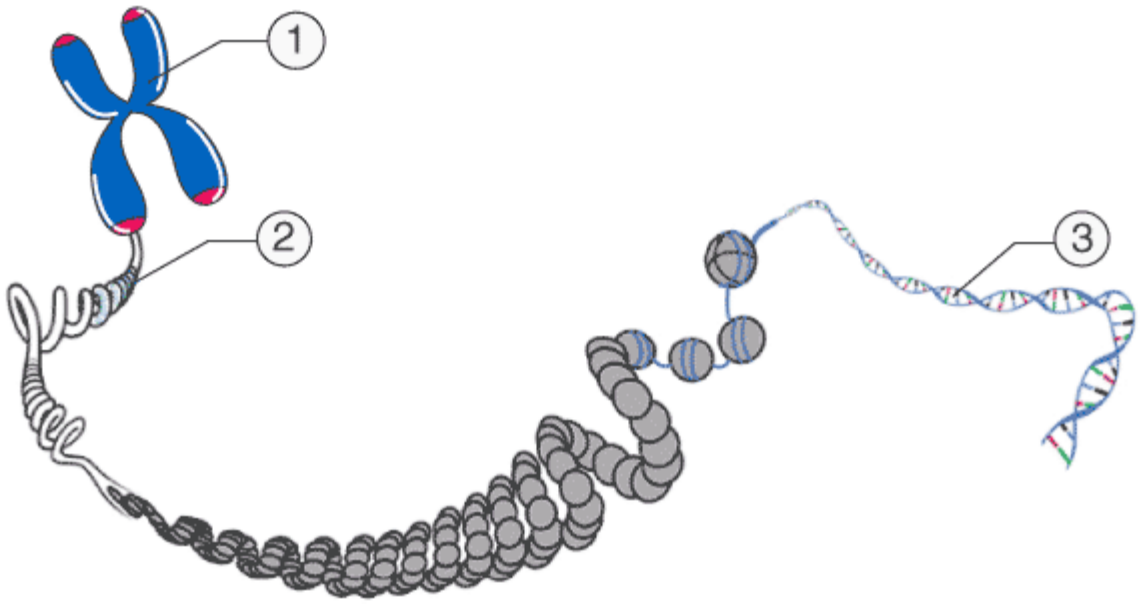
- The genome of yeast cells contains 1.35×10^7 base pairs
- A small fraction of the total DNA encodes protein.
  - Many repeats of non-coding sequences
- All chromosomes are contained in a membrane bound nucleus
  - DNA is divided between two or more chromosomes
- A set of five histones
  - DNA packaging and gene expression regulation



- Eukaryotic chromosomes are usually linear.
- A typical chromosome is tens of millions to hundreds of millions of base pairs in length.
- Eukaryotic chromosomes occurs in sets. Many species are diploid. Which means that somatic cells contains 2 sets of chromosomes.
- Each chromosome contains a centromere that forms a recognition site for the kinetochore proteins.
- Telomere contains specialized sequences located at both ends of the linear chromosomes.
- Repetitive sequences are commonly found near centromeric and telomeric regions.



Chromatin:



1 Chromosome | 2 Chromatin | 3 DNA Helix

Chromatin is a genetic material or a macromolecule comprising of DNA, RNA, and proteins which result in the formation of chromosomes within the nucleus of eukaryotic organisms is termed as chromatin.

Chemical composition of chromatin

- **DNA (20-40%)**
  - most important chemical constituent of chromatin
- **RNA (05-10%)**
  - associated with chromatin as; rRNA, mRNA, tRNA

- **Proteins (55-60%)**
  - **Histones:** very basic proteins, constitute about 60% of total protein, almost 1:1 ratio with DNA.
    - Five Types: H1, H2a, H2b, H3 and H4
  - **Non-Histones:** They are 20% of total chromatin protein:
    - Nucleosomal Assembly Proteins (NAP), Other Histone chaperones Chromosome remodeling complexes 3
    - Structural (actin, L & B tubulin & myosin) contractile proteins
    - all enzymes and

Nucleosome model.

- Most compaction in eukaryotic cells is the result of the regular association of DNA with histones to form structures called nucleosomes.
- DNA is tightly bound to histone proteins which serve to form a repeating array of DNA-Protein particles.

- The DNA is wrapped around the histone core of eight protein subunits, forming the nucleosome.
- The nucleosome is clamped by histone H1.
- About 200 base pairs (bp) of DNA coil around one histone. The coil "untwists" so as to generate **one negative superturn** per nucleosome.

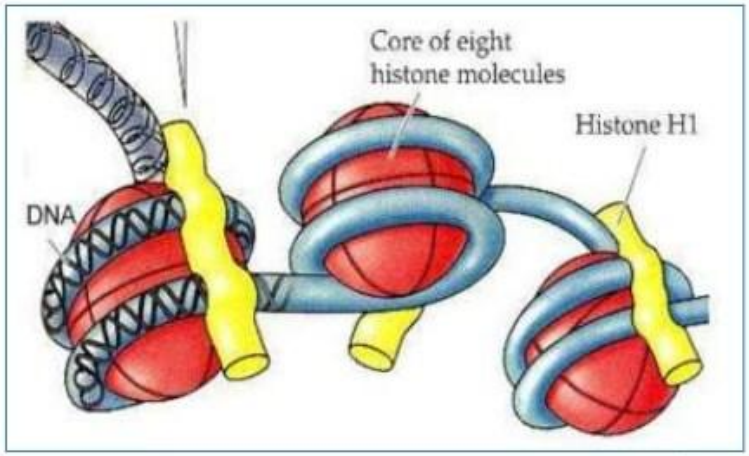
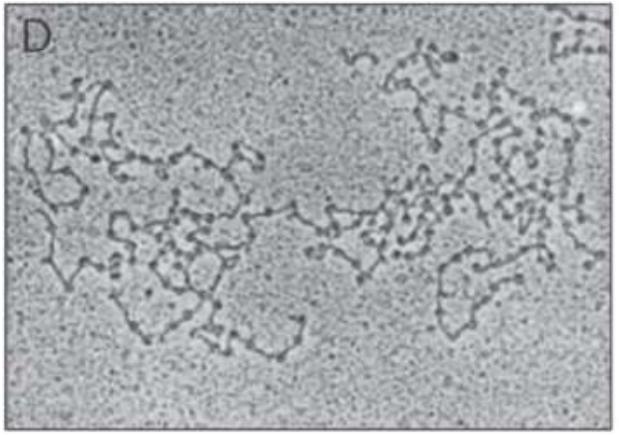
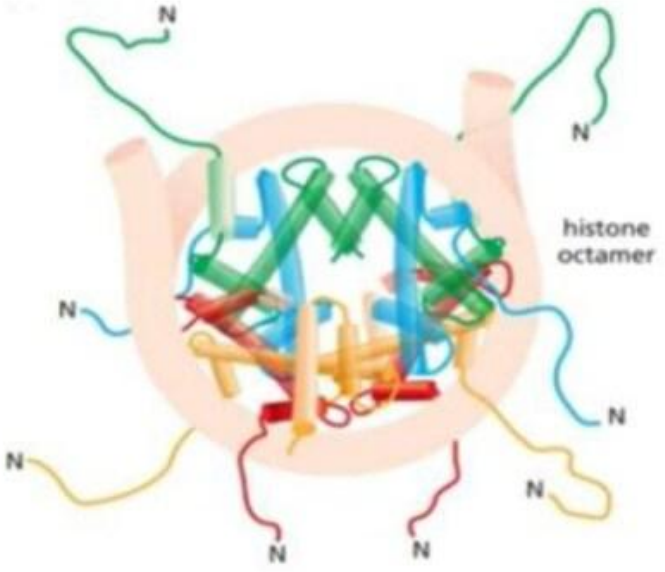


Fig. Nucleosome with histone H1



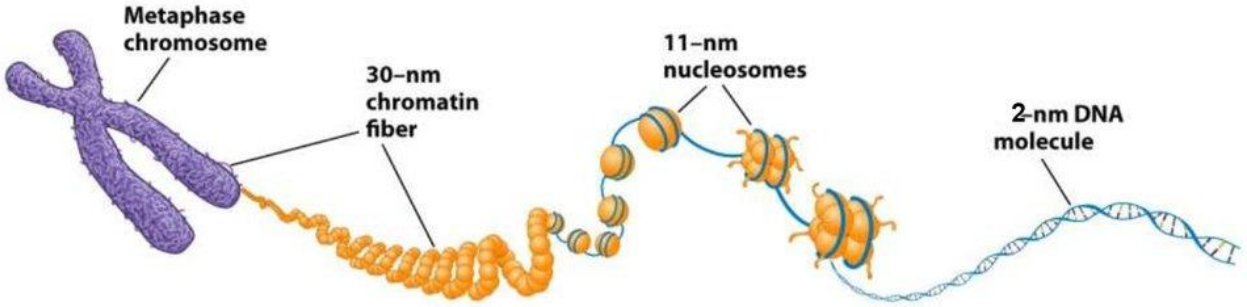
An electron microscopy image of a 10 nm chromatin fibre

- Histone tails-
  - Protein modification
  - Protein production
- When histone tails are dissociated-
  - DNA is released for the process of transcription and translation



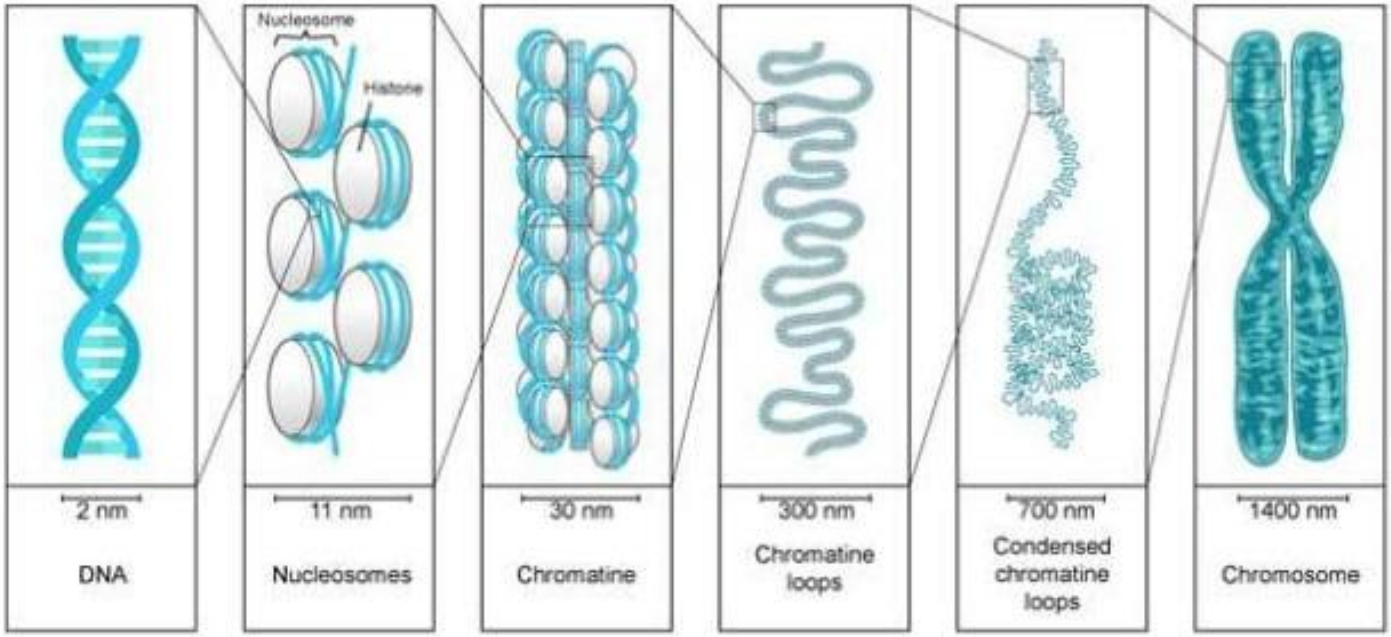
Histone octamer on DNA

Levels of DNA Packaging



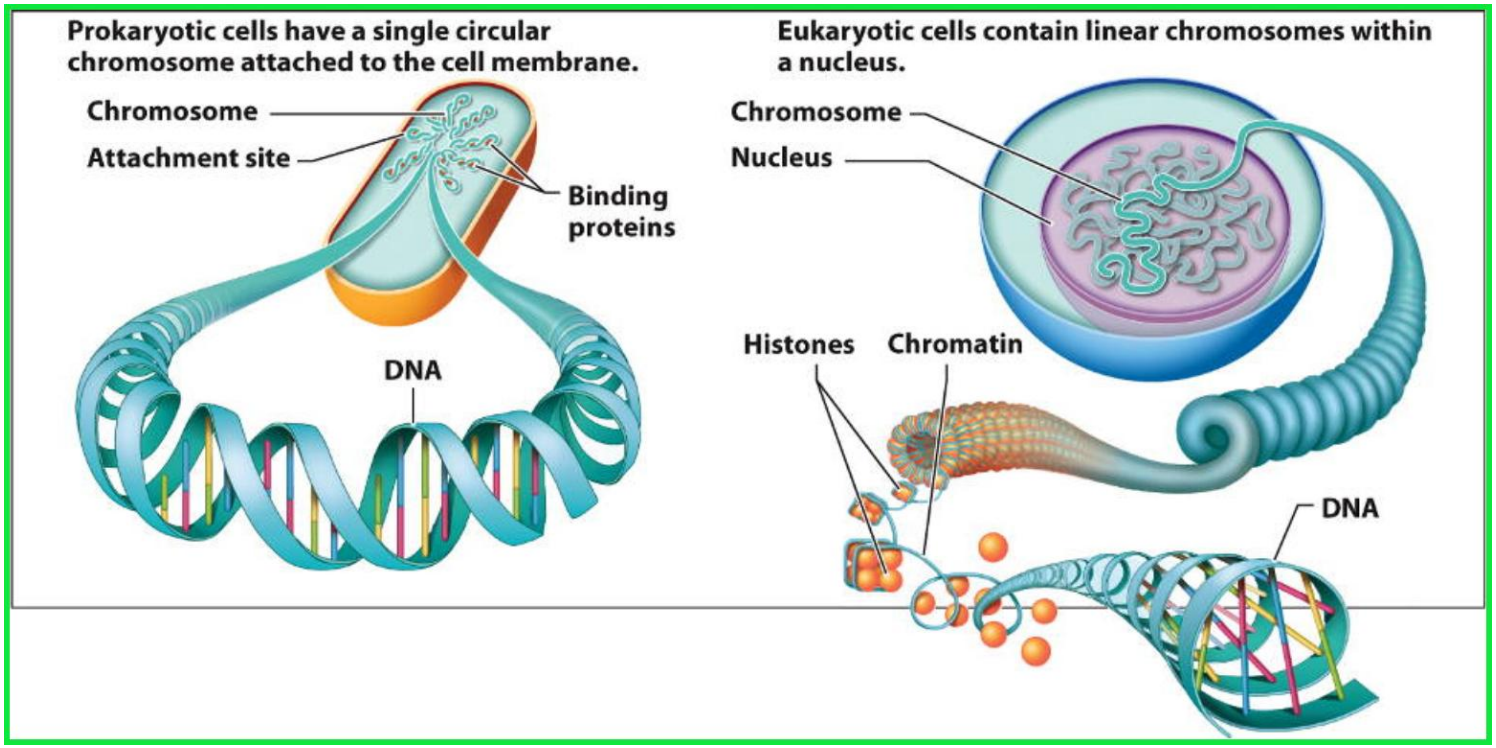
- 2-nm double-stranded DNA molecule
- 11-nm nucleosomes
- 30-nm chromatin fiber
- Organization around a central scaffold

CHROMOSOME STRUCTURE



Prokaryotic Genome v/s Eukaryotic Genome

Prokaryotic Genome	Eukaryotic Genome
Small genome, no specialization	Larger genome, cell specialization
Genome = DNA + few proteins in simple arrangement	Genome = DNA with many proteins in complex arrangement
Contain single set of chromosome	contain one or more sets of Chromosomes
Amount of DNA is smaller	typically greater than that in bacterial cells
They are polyistronic	They are monocistronic
Most of their DNA codes for protein or RNA's, very little "junk"	Most of the DNA does not code for protein or RNA's
RNA processing not an option for controlling gene expression	RNA processing allows for several opportunities to regulate genes
mRNA has a short life span (minutes)	mRNA is long lived (days to months)


Prokaryotic cells have a single circular chromosome attached to the cell membrane.
Chromosome
Attachment site
Binding proteins
DNA
Eukaryotic cells contain linear chromosomes within a nucleus.
Chromosome
Nucleus
Histones
Chromatin
DNA