

# Organization of prokaryotic chromosomes

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# Introduction

- ❑ The term “Prokaryotes” refers to “primitive cells” – Pro means being the first or earliest of the kind or in existence, karyon is a Greek words which means "nut or kernel (here it is nucleus since it is centrally located) “, and otes refers cytos or hollow cylinder.
- ❑ Chromosomes are thread like supercoiled structure composed of DNA as genetic material and protein molecules.
- ❑ Chromosomes are of two types on the basis of ploidy – monoploid, diploid, triploid (cultivated banana), tetraploid (common potato, *Solanum tuberosum*; Salmonoidae fish, *Gossypium hirsutum*), pentaploid (Kenai Birch, tree *Betula papyrifera*), hexaploid (Wheat, Kiwi fruit), heptaaploid or septaploid (strawberries), etc. Strawberry plants have diverse genetic makeup and can have either 2, 4, 5, 6, 7, 8, or even 10 sets of the seven strawberry chromosomes).
- ❑ Chromosomes contains genetic information in the form of genes which are responsible for appearance of characters.
- ❑ Since chromosomes are bundled with different kinds of essential genetic blocks or genetic elements, they are responsible for hereditary or flow of genetic information from one generation to others.
- ❑ Gene present in a chromosome is an unique sequence of DNA (in terms of base pairs; C:G & A:T) that carries a particular instruction for a cell.
- ❑ The genes vary in size from about 100 to 2.5 billion base pairs. The length of the sequence of DNA and the precise order of the base pairs are the critical and determining factors.

# ... Introduction

- ❑ Prokaryotes are monoploid i.e. they have single set of chromosome or gene or single set of genes are stores in single chromosome.
- ❑ The prokaryotic chromosomes are circular in shape and DNA of the circular chromosomes are packaged into a region of the prokaryotic cell known as the **nucleoid**.
- ❑ Nucleoid is not a specialized organelle and hence prokaryotic chromosomes are dispersed within the cell and is not enclosed by a separate membrane.
- ❑ Most of the information about the structure of DNA has come from studies of prokaryotes because they have simple structural organization compared to eukaryotes.
- ❑ *Escherichia coli* is taken as model organism for the study of prokaryotic chromosomes because they are simple, easily available, easily grown in culture broth, and less pathogenic.
- ❑ The DNA in *E. coli* consists of a single closed-circular DNA molecule of 4.6 million base pairs length.
- ❑ The DNA of *E. coli* contains several loop like structure called as **domain**.

# Nucleoid

- ❑ Nucleoid is a region where prokaryotic genetic materials or prokaryotic chromosomes are found.
- ❑ It occupies about one third of the volume of the cell.
- ❑ It is important for the condensation of prokaryotic chromosome in a small 3D structure. It measures ~1.5 μm in circumference when uncoiled.
- ❑ It is also important for functionality of chromosomes, such as replication, recombination, and transcription.
- ❑ It involves nucleoid-associated proteins (NAPs) essentially involved in the supercoiling of chromosomes.
- ❑ It is largely composed of about 60% DNA, plus a small amount of RNA and protein.
- ❑ It can be seen under a light microscope by staining it with the Feulgen stain, which specifically stains DNA.

# Prokaryotic chromosomes and its DNA domains

- ❑ When DNA is isolated from *E. coli* and freed from the most of the attached proteins, supercoiled loop like structures with tiny spaces are observed.
- ❑ The *E. coli* DNA consists of about 50 – 100 such domains or small loops.
- ❑ The end of loop is constrained by binding to structure which probably consists of proteins attached to part of the cell membrane.
- ❑ The loops are about 50 – 100 kb in size.



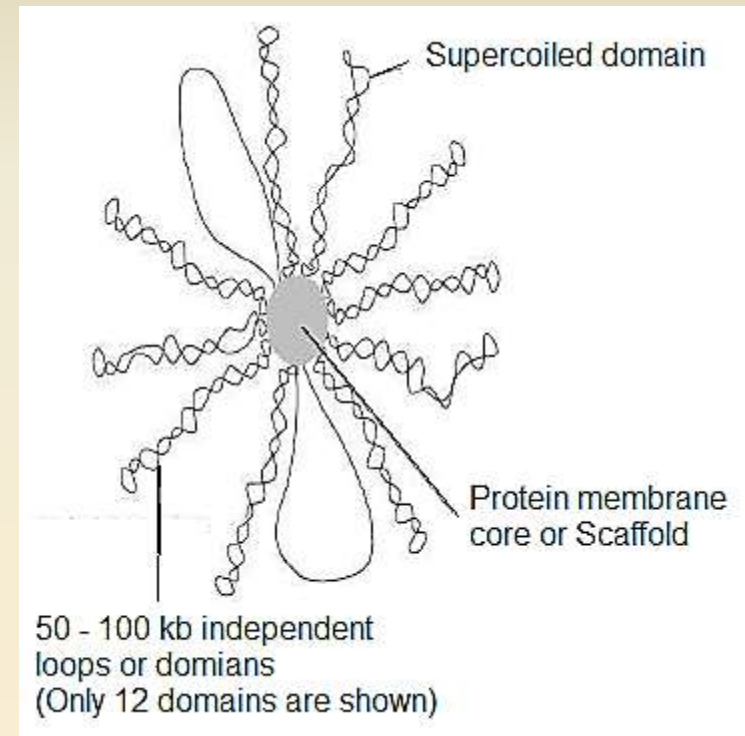
Structure of *E. coli* DNA showing its supercoiled toroidal and plectonemic structure. *Nature Education* 1(1):57

# Supercoiling of the prokaryotic chromosome

- ❑ The E. coli chromosome as a whole is negatively supercoiled i.e. DNA is twisted in the opposite direction of the double helix.
- ❑ Evidence also suggests that some domains are independently supercoiled and some are not supercoiled as shown in representative image.
- ❑ The whole chromosome with its entire loops are attached to the protein – membrane scaffold which acts as a barrier to rotation of the DNA, but domains are topologically independent.

Supercoiling of DNA is just like twisting of rubber band so that rubber band forms a tiny coils.

Lack of supercoiling in some of the domain is due to breakage of one of the strand of double helix.



Diagrammatic representation of the structure of the E. coli chromosome (4600 kb). Note the thin line in structure which is a DNA double helix.

# Supercoiling of the prokaryotic chromosome

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

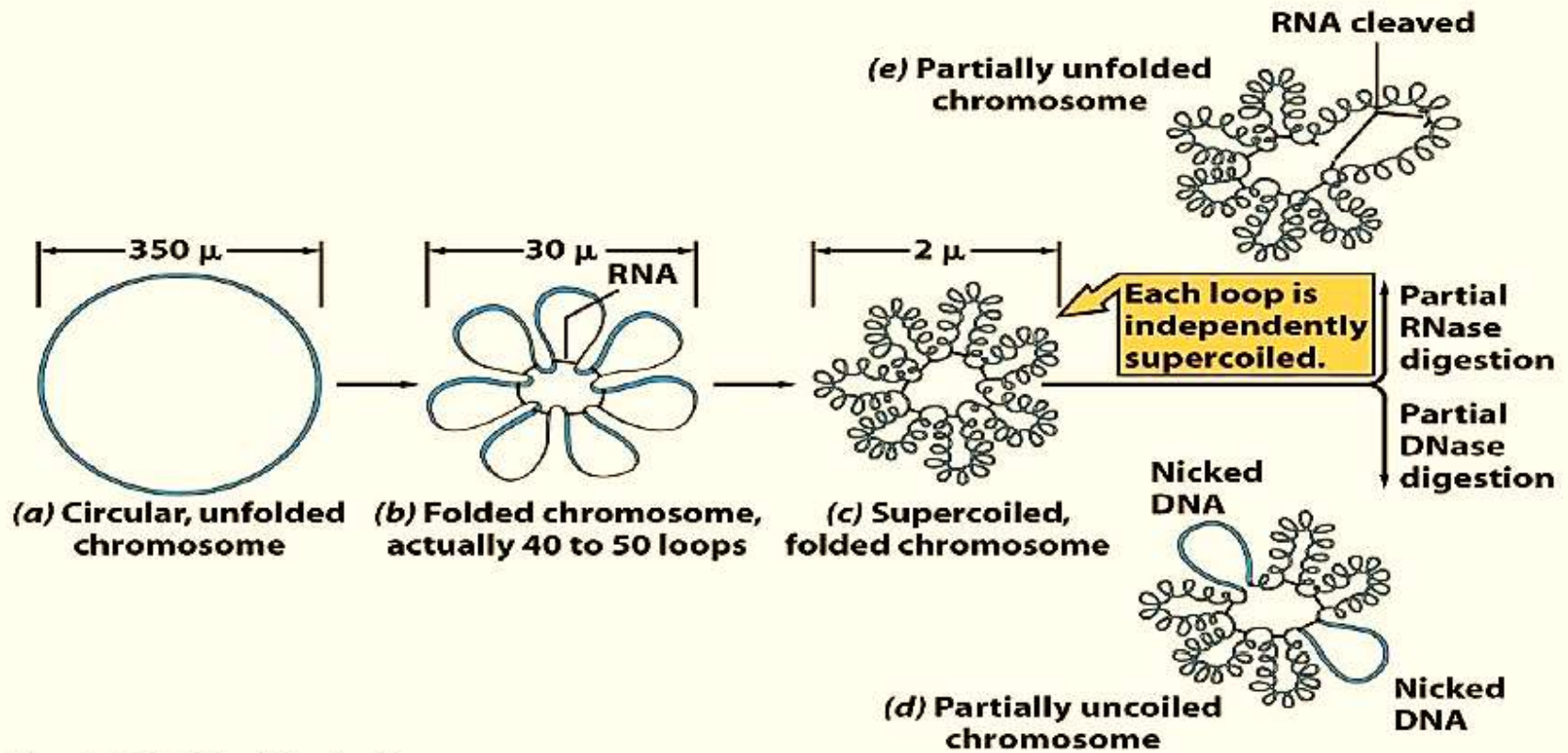


Figure 9-15 Principles of Genetics, 4/e  
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Supercoiling - One turn/100bp



# Proteins involved in the supercoiling

- ❑ Unlike to higher vertebrate or human, prokaryotic chromosome do not possess histone proteins involved in the condensation of chromatin.
- ❑ During the 1980s and 1990s, it has been discovered that multiple proteins act together to fold and condense prokaryotic DNA, one such protein is called HU.
- ❑ HU (Heat Unstable) protein is the most abundant and positively charged protein (slightly basic protein).
- ❑ Other proteins involved in the folding and condensation are integration host factor (IHF), histone-like nucleoid structuring protein (H-NS), DNA topoisomerase I, DNA gyrase, etc.
- ❑ HU and H-NS protein are sometimes referred to as **histone-like proteins**. H-NS proteins are formerly known as **H1 protein**.
- ❑ H-NS proteins are monomeric neutral proteins

*Only some of the **Archaea** have histone proteins.*



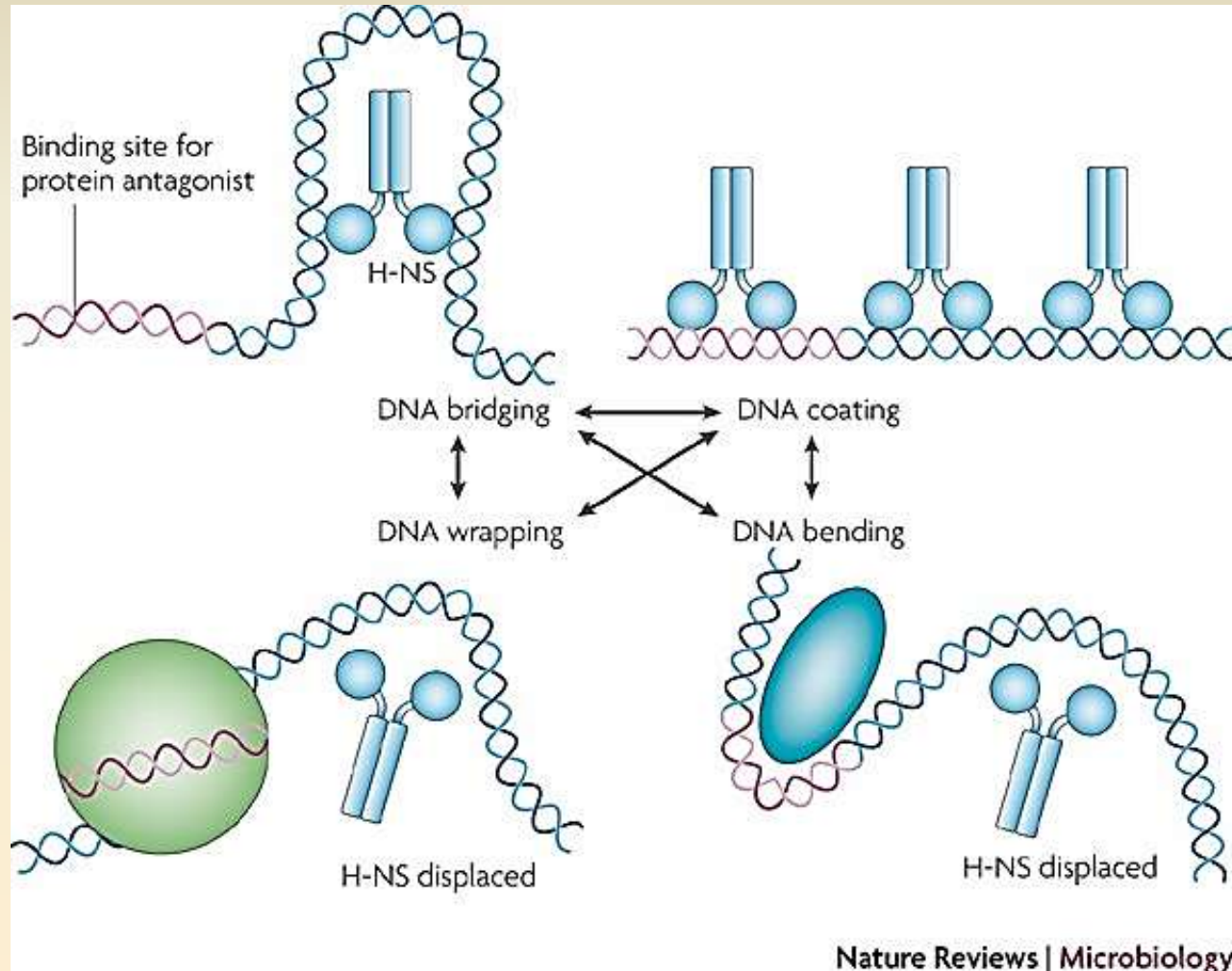
# Proteins involved in the supercoiling

## Sequential events in supercoiling

- ❑ Firstly HU protein binds DNA nonspecifically by the wrapping of the DNA around the protein with enzyme called topoisomerase I and introduce sharp bends in the chromatin, generating the tension necessary for negative supercoiling.
- ❑ H-NS proteins also bind DNA nonspecifically like HU protein thereafter.
- ❑ Half of this wrapping is **constrained** as permanent wrapping of DNA around proteins such as HU, and only about half the supercoiling is **unconstrained**.
- ❑ Unconstrained DNA is free in the medium and causing tension to the rest part of the DNA.
- ❑ Later, RNA polymerase, mRNA molecules IHF (Integration Host Factor) binds to specific sequences within the genome and introduce additional bends of about  $140^\circ$ .
- ❑ Once the supercoiled structure is formed, DNA topoisomerase I, DNA gyrase and other proteins help maintain the supercoils.
- ❑ H-NS also involved in the maintenance of supercoils and plays also an active role in transcription by modulating the expression of the genes involved in the response to environmental stimuli.
- ❑ Other maintenance protein, factor for inversion stimulation (FIS) is abundant during exponential growth and regulates the expression of more than 231 genes, including topoisomerase I.

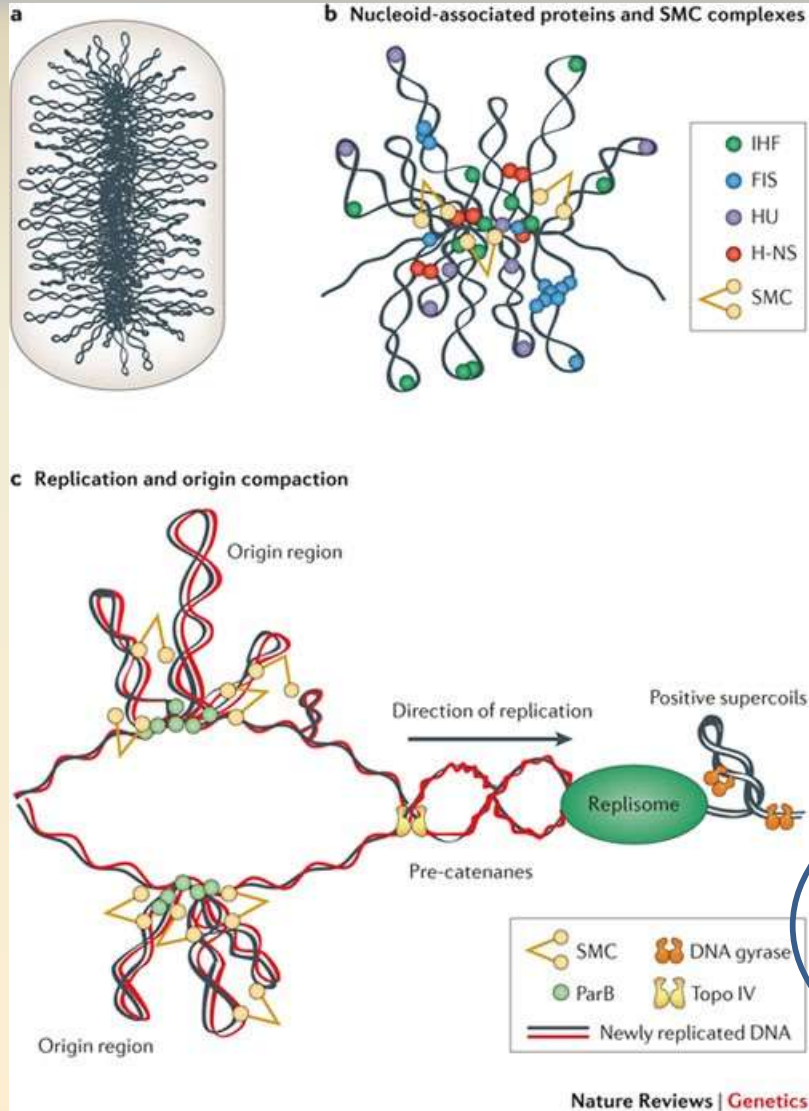
# Proteins involved in the supercoiling

## Mechanism



# Proteins involved in the supercoiling

## Mechanism



Supercoiling and uncoiling or condensation and decondensation are dynamic process.

# Difference between prokaryotic DNA and eukaryotic DNA

<b>Prokaryotic Chromosomes</b>	<b>Eukaryotic Chromosomes</b>
<ul style="list-style-type: none"><li>• Many prokaryotes contain a single circular chromosome.</li><li>• Prokaryotic chromosomes are condensed in the nucleoid via DNA supercoiling and the binding of various architectural proteins.</li><li>• Because prokaryotic DNA can interact with the cytoplasm, transcription and translation occur simultaneously.</li><li>• Most prokaryotes contain only one copy of each gene (i.e., they are haploid).</li><li>• Nonessential prokaryotic genes are commonly encoded on extrachromosomal plasmids.</li><li>• Prokaryotic genomes are efficient and compact, containing little repetitive DNA.</li></ul>	<ul style="list-style-type: none"><li>• Eukaryotes contain multiple linear chromosomes.</li><li>• Eukaryotic chromosomes are condensed in a membrane-bound nucleus via histones.</li><li>• In eukaryotes, transcription occurs in the nucleus, and translation occurs in the cytoplasm.</li><li>• Most eukaryotes contain two copies of each gene (i.e., they are diploid).</li><li>• Some eukaryotic genomes are organized into operons, but most are not.</li><li>• Extrachromosomal plasmids are not commonly present in eukaryotes.</li><li>• Eukaryotes contain large amounts of noncoding and repetitive DNA.</li></ul>

# Further reading

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