General Biochemistry-II (BCH 302)

Chapter 5
Nucleic Acids

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<th>No of Weeks</th>
<th>Lectures</th>
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<td>- types of nitrogen bases,</td>
<td>0.66</td>
<td>30-31</td>
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<td>- Double helix properties, base pairing, reading, stabilizing forces.</td>
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<td>- Tertiary structure of DNA (relaxed, coiled and associated proteins; histones, protamines).</td>
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<tr>
<td>- DNA denaturation: significance and factors</td>
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</tbody>
</table>

**Genetic code, exon and introns: Gene, genome and chromosome.**

**Introduction to replication, transcription and translation and important enzymes**
Nucleic acids

Nucleic acids are macromolecules, like proteins, carbohydrates and lipids. It is essential for all known forms of life. They are found in abundance in all living things, where they function in encoding, transmitting and expressing genetic information.

Nucleic acids are divided into:
- DNA (deoxyribonucleic acid) and
- RNA (ribonucleic acid)

Nucleic acids consist of polymers nucleotides monomers.
Each nucleotide has three components:
- nitrogenous base,
- 5-carbon sugar, and
- phosphate group.

Nucleic acids *carry the genetic and hereditary information* of the cell and all the necessary information needed for cell to perform all the life processes. The ability to store and transmit genetic information from one generation to the next is a fundamental condition for life.
Structure of Nucleotides

Nucleotides are the building blocks of Nucleic Acids

- Nucleotides have three characteristic components:
  - a nitrogenous base,
  - a pentose, and
  - a phosphate.
- The molecule without the phosphate group is called a nucleoside.
The nitrogenous bases

There are two categories of nitrogenous bases in the nucleic acids:

- **Purines** (two ring structure and contain Adenine (A) and Guanine (G))
- **Pyrimidines** (one ring and contain Thymine (T), Cytosine (C) and Uracil (U))

- **DNA** contains Adenine, Guanine, **Thymine** and Cytosine
- **RNA** contains Adenine, Guanine, **Uracil** and Cytosine
PURINES

Purine

Adenine

Guanine

PYRIMIDINES

Pyrimidine

Cytosine

Uracil

Thymine

Figure 32.5
Biochemistry: A Short Course, First Edition
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The pentose sugar

Nucleic acids have two kinds of pentoses.
- The **RNA** contains ribose
- The **DNA** contains deoxyribose (ribose missing oxygen at position C2).

[Diagram of ribose and deoxyribose]
# Nomenclature

A nucleoside is a combination of a sugar and a base, while a nucleotide is a combination of a sugar, a base, and a phosphate.

## Table 8–1: Nucleotide and Nucleic Acid Nomenclature

<table>
<thead>
<tr>
<th>Base</th>
<th>Nucleoside</th>
<th>Nucleotide</th>
<th>Nucleic acid</th>
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</thead>
<tbody>
<tr>
<td><strong>Purines</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Adenine</td>
<td>Adenosine Deoxyadenosine</td>
<td>Adenylate Deoxyadenylate</td>
<td>RNA DNA</td>
</tr>
<tr>
<td>Guanine</td>
<td>Guanosine Deoxyguanosine</td>
<td>Guanylate Deoxyguanylate</td>
<td>RNA DNA</td>
</tr>
<tr>
<td><strong>Pyrimidines</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cytosine</td>
<td>Cytidine Deoxycytidine</td>
<td>Cytidylate Deoxycytidylate</td>
<td>RNA DNA</td>
</tr>
<tr>
<td>Thymine</td>
<td>Thymidine or deoxythymidine</td>
<td>Thymidylate or deoxythymidylate</td>
<td>DNA</td>
</tr>
<tr>
<td>Uracil</td>
<td>Uridine</td>
<td>Uridylate</td>
<td>RNA</td>
</tr>
</tbody>
</table>
Nucleotides

Nucleotide: Deoxyadenylate (deoxyadenosine 5'-monophosphate)
Symbols: A, dA, dAMP
Nucleoside: Deoxyadenosine

Deoxyguanylate (deoxyguanosine 5'-monophosphate)
Symbols: G, dG, dGMP
Nucleoside: Deoxyguanosine

Deoxythymidylate (deoxythymidine 5'-monophosphate)
Symbols: T, dT, dTMP
Nucleoside: Deoxythymidine

Deoxycytidylate (deoxycytidine 5'-monophosphate)
Symbols: C, dC, dCMP
Nucleoside: Deoxycytidine

Deoxyribonucleotides

Nucleotide: Adenylate (adenosine 5'-monophosphate)
Symbols: A, AMP
Nucleoside: Adenosine

Guanylate (guanosine 5'-monophosphate)
Symbols: G, GMP
Nucleoside: Guanosine

Uridylate (uridine 5'-monophosphate)
Symbols: U, UMP
Nucleoside: Uridine

Cytidylate (cytidine 5'-monophosphate)
Symbols: C, CMP
Nucleoside: Cytidine

Ribonucleotides
Abbreviations of nucleoside phosphates

<table>
<thead>
<tr>
<th>Base</th>
<th>Mono-</th>
<th>Di-</th>
<th>Tri-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adenine</td>
<td>AMP</td>
<td>ADP</td>
<td>ATP</td>
</tr>
<tr>
<td>Guanine</td>
<td>GMP</td>
<td>GDP</td>
<td>GTP</td>
</tr>
<tr>
<td>Cytosine</td>
<td>CMP</td>
<td>CDP</td>
<td>CTP</td>
</tr>
<tr>
<td>Uracil</td>
<td>UMP</td>
<td>UDP</td>
<td>UTP</td>
</tr>
</tbody>
</table>

Abbreviations of deoxyribonucleoside 5’-phosphates

<table>
<thead>
<tr>
<th>Base</th>
<th>Mono-</th>
<th>Di-</th>
<th>Tri-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adenine</td>
<td>dAMP</td>
<td>dADP</td>
<td>dATP</td>
</tr>
<tr>
<td>Guanine</td>
<td>dGMP</td>
<td>dGDP</td>
<td>dGTP</td>
</tr>
<tr>
<td>Cytosine</td>
<td>dCMP</td>
<td>dCDP</td>
<td>dCTP</td>
</tr>
<tr>
<td>Thymine</td>
<td>dTMP</td>
<td>dTDP</td>
<td>dTTP</td>
</tr>
</tbody>
</table>
Roles of functional nucleotides

Nucleotides have a variety of roles in cellular metabolism.

- They are the *constituents of DNA and RNA*.
- The structure of every protein, and ultimately of every biomolecule and cellular component, is a product of *informational codes* programmed into the nucleotide sequence of a cell’s nucleic acids.
- They are the energy currency in metabolic transactions (mostly *ATP*)
- They are essential chemical links in the *response of cells to hormones* and other *extracellular stimuli*, ex. cyclic adenosine monophosphate (cAMP)
- They are structural components of an array of *enzyme cofactors* and metabolic intermediates (ex. NAD\(^+\), FAD, FMN)
Nucleotides derivatives

- NAD⁺/ NADH
- NADP⁺/ NADPH
- FAD/ FADH₂
- FMN/ FMNH₂
- c AMP,
- c GMP
Nicotinamide adenine dinucleotide (NAD\(^+\)) has many roles in the cell:

- It is a coenzyme for many oxidoreductases. So, it carries electrons from one reactant to another.
- It acts as a precursor of the second messenger molecule cyclic ADP-ribose,
- It acts as a substrate for bacterial ligase.
- It consists of two nucleotides joined through their phosphate groups.
- One nucleotide contains an adenine base and the other nicotinamide (vitamin B\(3\)).
- NADH is the reduced form of NAD\(^+\).
- NADP\(^+\) has many functions in cell (search for its functions)
Flavin adenine dinucleotide (FAD) is a redox cofactor, for many oxidoreductases. FAD can be converted between three redox states by accepting or donating electrons. It is composed of adenine and flavin (Vitamin B2). Flavin mononucleotide (FMN) is other cofactor as FAD.
Nucleotides derivatives; cAMP, cGMP

- Cyclic adenosine monophosphate (cAMP) is a second messenger important in many biological processes.
- It is a derivative of adenosine triphosphate (ATP)
- The phosphate group attached to C5 form cyclic form with the –OH of C3, so the name cyclic AMP

Function:

It is used for intracellular signal transduction in many different organisms such as transferring the effects of hormones that cannot pass through the plasma membrane into the inside of the cell (like glucagon and adrenaline).

It is also involved in the activation of protein kinases.

It binds to and regulates the function of some ion channels.
DNA

Primary structure:
Description of Phosphodiester Bond
DNA primary structure

Phosphodiester Bonds Link Successive Nucleotides in Nucleic Acids

- The successive nucleotides of both DNA and RNA are covalently linked through phosphate-group “bridges,” in which the 5-phosphate group of one nucleotide unit is joined to the 3-hydroxyl group of the next nucleotide, creating a phosphodiester linkage.

- The backbones of both DNA and RNA are:
  - hydrophilic due to the –OH, NH, phosphate and C=O groups
  - negatively charged in neutral pH due to the phosphate groups.
Phosphodiester linkage

The DNA or RNA strands have two ends:
- 5’- phosphate end
- 3’-OH end

![Diagram of DNA and RNA strands with phosphodiester linkage]

**An ester**

![Chemical structure of an ester]

**A phosphoester**

![Chemical structure of a phosphoester]

Figure 8-7
Lehninger Principles of Biochemistry, Fifth Edition
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The covalent backbones of nucleic acids consist of alternating phosphate and pentose residues, and the nitrogenous bases may be regarded as side groups joined to the backbone at regular intervals.
DNA is the macromolecular that carries the genetic instructions for all biological processes.

Most DNA molecules consist of two strands of deoxyribonucleotides forming a double helix.

These two strands wound around the same axis in a right handed manner.

The bases forming the DNA are A, G, T and C.

All nucleotides in each strand are bound by phosphodiester bond (type of covalent bond).

The two strands bind together by hydrogen bonds.

- Adenine (A) in one strand binds Thymine (T) in the other by two hydrogen bonds.
- Guanine (G) in one strand binds Cytosin (C) in the other by three hydrogen bonds.

The two strands run in an antiparallel manner.
DNA secondary structure: (cont.)

Double helix properties, base pairing, stabilizing forces

- The DNA double helix, or duplex, is held together by two forces,
  - hydrogen bonding between complementary base pairs and
  - base-stacking interactions.
- The complementarity between the two strands of DNA is attributed to the hydrogen bonding between base pairs.
- The base-stacking interactions, which are largely nonspecific with respect to the identity of the stacked bases, make the major contribution to the stability of the double helix.
DNA secondary structure: (cont.)
In DNA
The number of purines (A+G) = The number of pyrimidines (T+C)

Chargaff’s rule
- The number of Guanine (G) = The number of Cytosine (C)
- The number of Adenine (A) = The number of Thymine (T)

So, We can calculate the ratio of three bases depending on the known ratio of any one base
Tertiary structure of DNA
The detailed structure of the double helix, the shapes of DNA, the major and minor groove triplexes and other forms

- Tertiary structure refers to the locations of the atoms in three-dimensional space, taking into consideration geometrical and steric constraints.

- The two antiparallel polynucleotide chains of double-helical DNA are complementary to each other.
  - Wherever adenine occurs in one chain, thymine is found in the other;
  - Wherever guanine occurs in one chain, cytosine is found in the other.

- The hydrophilic backbones of alternating deoxyribose and phosphate groups are on the outside of the double helix, facing the surrounding water.

- The furanose ring of each deoxyribose is in the C-2 endo conformation.

- The purine and pyrimidine bases of both strands are stacked inside the double helix, with their hydrophobic and nearly planar ring structures very close together and perpendicular to the long axis.

- The two strands creates a major groove and minor groove.
DNA

Base pairing \((A = G, T = C)\)

Anti-parallel strands \((5' \rightarrow 3', 3' \rightarrow 5')\)

Major groove is 22Å wide.

Minor groove is 13Å wide.
Tertiary structure of DNA (cont.)

There are three forms of DNA (A, B and Z)

- **The B form** DNA is the classical resolved Watson-Crick structure. It occurs at high water concentrations; and it is the most common form of DNA *in vivo*.
  - Its structure is a more narrow with elongated right-handed double helix.
  - Its wide major groove makes it more accessible to proteins.
  - The number of base pairs per helical turn is 10.5.
  - B-DNA base pairs are nearly perpendicular to the helix axis.

- **The A form** is favored in many solutions that are relatively devoid of water.
  - The DNA is still arranged in a right-handed double helix, but the helix is wider
  - The number of base pairs per helical turn is 11.
  - The plane of the base pairs in A-DNA is tilted about 20° with respect to the helix axis.

- **The Z form** is left-handed helix.
  - There are 12 base pairs per helical turn,
  - The structure appears more slender and elongated.
  - The DNA backbone takes on a zigzag appearance.
  - The number of base pairs per helical turn is 12.
  - It is prominent when pyrimidines alternate with purines, especially alternating C and G.
## Types of DNA

There are three types of DNA, as shown in the table:

<table>
<thead>
<tr>
<th></th>
<th>A form</th>
<th>B form</th>
<th>Z form</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Helical sense</strong></td>
<td>Right handed</td>
<td>Right handed</td>
<td>Left handed</td>
</tr>
<tr>
<td><strong>Diameter</strong></td>
<td>~26 Å</td>
<td>~20 Å</td>
<td>~18 Å</td>
</tr>
<tr>
<td><strong>Base pairs per</strong></td>
<td>11</td>
<td>10.5</td>
<td>12</td>
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<td><strong>helical turn</strong></td>
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<td><strong>Helix rise per base</strong></td>
<td>2.6 Å</td>
<td>3.4 Å</td>
<td>3.7 Å</td>
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<tr>
<td><strong>pair</strong></td>
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</tr>
<tr>
<td><strong>Base tilt normal to</strong></td>
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</tr>
<tr>
<td><strong>the helix axis</strong></td>
<td>20°</td>
<td>6°</td>
<td>7°</td>
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<tr>
<td><strong>Sugar pucker</strong></td>
<td>C-3’ endo</td>
<td>C-2’ endo</td>
<td>C-2’ endo for pyrimidines; C-3’ endo for purines</td>
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<tr>
<td><strong>Glycosyl bond</strong></td>
<td>Anti</td>
<td>Anti</td>
<td>Anti for pyrimidines; syn for purines</td>
</tr>
<tr>
<td><strong>conformation</strong></td>
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</tbody>
</table>
Nucleic acid quaternary structure

It refers to the interactions between separate nucleic acid molecules, or between nucleic acid molecules and proteins (like histones and protamines) to form chromatin.
Chromatin

- **Chromatin** is a complex of macromolecules found in eukaryotic cells, consisting of DNA, protein, and RNA.
- **The primary functions of chromatin are:**
  - to package DNA into a smaller volume,
  - to reinforce the DNA to allow mitosis,
  - to prevent DNA damage, and
  - to control gene expression and replication.

Chromatin is organized on three basic levels:
- primary (nucloesome)
- secondary (solenoid)
- tertiary/quaternary (final folding into chromosome shape)
A typical eukaryotic chromosome contains 1 to 20 cm of DNA. During metaphase of meiosis/mitosis, this DNA is package into a chromosome with a length of only 1 to 10 μm ($10^4$-fold smaller than the naked DNA). DNA is wrapped around some basic proteins to be packed into this small structure.

- **Histones** are the primary protein components of chromatin in eukaryotes.
- There are 5 types of histones namely H1, H2A, H2B, H3 and H4.

**Protamines** replace histones late in the haploid phase of spermatogenesis.

There are other **Non-histone protein** in the chromatin like:

- Scaffold proteins,
- DNA polymerase,
- Heterochromatin Protein 1
- Polycomb and
- numerous other structural, regulatory, and motor proteins.

Which type of protein belong histone and protamine?
DNA denaturation: significance and factors

- DNA is a remarkably flexible molecule.
- Considerable rotation is possible around a number of bonds in the sugar–phosphate (phosphodeoxyribose) backbone.
- Thermal fluctuation can produce bending, stretching, and unpairing (melting) of the strands.
- Solutions of carefully isolated, native DNA are highly viscous at pH 7.0 and room temperature (25 °C).
- When such a solution is subjected to extremes of pH or to temperatures above 80°C, its viscosity decreases sharply, indicating that the DNA has undergone a physical change.
- Heat and extremes pH cause denaturation, or melting, of double-helical DNA due to disruption of the hydrogen bonds between paired bases of the double helix to form unwind molecules.
- The covalent bonds in the DNA are NOT broken because they are strong.
- Slow cooling or neutralization of pH cause renaturation of the denatured DNA molecule.
- i.e. the unwound segments of the two strands spontaneously rewind, or anneal, to yield the intact duplex.
Types of RNA

RNAs have a broader range of functions, and several classes are found in cells.

**Ribosomal RNAs (rRNAs) are components of ribosomes**, the complexes that carry out the synthesis of proteins.

**Messenger RNAs (mRNAs) are intermediaries, carrying genetic information** from one or a few genes to a ribosome, where the corresponding proteins can be synthesized.

**Transfer RNAs (tRNAs) are adapter molecules that** carry the amino acids needed for protein synthesis in order determined by the sequence of codons in mRNA and the collaboration of r-RNA.
In RNA
In contrary to DNA,
There is no relation between the number of purines and the number of pyrimidines (T&C)

So, We can NOT predict the ratio or the number of any base if we know the ratio of any other base(s)
m-RNA

- It represents 5-10% of the total RNA%.
- It is formed in the nucleus from DNA by the process called transcription.
- It carries the genetic codes.
- Each three nucleotide is called codon.
- Each codon is translated into amino acid in the translation process.
- There are three untranslated codons called “Stop Codons”
- The number of nucleotide in mRNA is at least three times the number of amino acids to formed in translation (Why?)
- The length of the mRNA varies according to the gene it encodes.
- mRNA has a short life span (WHY?)
t-RNA

- It is the smallest type of RNA
- It is formed from 75-90 nucleotides
- It represents 10-20% from the total RNA
- There is at least one t-RNA for each amino acid.
- Some amino acids have more than one t-RNA and hence more than one codon.
- Each t-RNA has two important region:
  - 3’ amino acid attachment site that has the same sequence of codon.
  - A region complementary to the codon known as “anticodon”
- t-RNA serves as the physical link between the mRNA and the amino acid sequence of proteins.
- Each t-RNA carries the amino acids to the protein synthetic machinery of a cell (ribosome) as directed by the sequence of codons in the m-RNA.
- t-RNA are not degraded after translation.
r-RNA

- It is the largest type of RNA
- It represents 50-65% of the total RNA
- It is located in the ribosome bound to the proteins.
- r-RNA forms approximately 60% of the ribosome weight (the rest 40% is protein).
- Ribosome is the factory of protein synthesis.
- The ribosome forms two subunits:
  - the large subunit (LSU) which catalyze the peptide bond formation (ribozyme)
  - The small subunit (SSU).
- During translation, m-RNA is sandwiched between the small and large ribosome subunits, and the LSU catalyzes the formation of a peptide bond between the two amino acids that are localized in the ribosome.
- r-RNA is not degraded after translation.
Important definitions:
Genetic code, exon and introns, Gene, genome and chromosome

- **Gene** is a region of DNA which is made up of nucleotides and is the molecular unit of heredity.
- **Exon** is any part of a gene that will encode a part of the final mature RNA and is translated into proteins.
- **Introns** are untranslated segments in genomic eukaryotic DNA or pre-mRNA flanking the coding regions (exons) and is removed by RNA splicing.
- **Genetic code**, is the set of rules by which information encoded within genetic material (DNA or mRNA sequences) is translated into proteins.
- **Chromosome** is a packaged and organized structure containing most of the DNA of a living organism.
- **Genome** is the complete set of *genetic material* of an organism.
  - It consists of DNA (or RNA in RNA viruses).
  - The genome includes both the genes, (the coding regions), the noncoding DNA and the genomes of the mitochondria and chloroplasts.
Genetic code

The **codons** are three nucleotide codes, that is translated into amino acid in the protein synthesis steps. Each amino acid has one or more codons. Some codons are not translated and they called “Stop codons”. There is only one start codon. There are three stop codons.

### Table of Codons

<table>
<thead>
<tr>
<th>U</th>
<th>C</th>
<th>A</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>phe</td>
<td>ser</td>
<td>cys</td>
</tr>
<tr>
<td>U</td>
<td>leu</td>
<td></td>
<td>stop</td>
</tr>
<tr>
<td>U</td>
<td></td>
<td>stop</td>
<td>trp</td>
</tr>
<tr>
<td>CU</td>
<td>pro</td>
<td>his</td>
<td>arg</td>
</tr>
<tr>
<td>C</td>
<td>leu</td>
<td>gln</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>arg</td>
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</tr>
<tr>
<td>A</td>
<td>ile</td>
<td>thr</td>
<td>ser</td>
</tr>
<tr>
<td>A</td>
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<td>lys</td>
<td>arg</td>
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<td>asp</td>
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<tr>
<td>G</td>
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<td>glu</td>
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<tr>
<td>G</td>
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</tr>
</tbody>
</table>

Name the stop codons?

Name the start codon?
The relation between DNA, RNA & Proteins
Central Dogma of Molecular Genetics
Introduction to replication, transcription and translation and important enzymes

- **Replication**, making a copy to the all chromosome (DNA)
- **Transcription**, formation of mRNA from DNA
- **Translation**, forming protein by the translation of the genetic code in the mRNA to amino acids by the ribosome
DNA replication

- **Definition**
- DNA replication is the biological process of producing two identical replicas of DNA from one original DNA molecule.
- This process occurs in all living organisms when the cell needs to divide into two identical cells.
- During replication, the two strands are separated by breaking the week hydrogen bonds between them.

- There are three types of DNA replication
  - Semiconservative Replication
  - Bidirectional Replication
  - Semidiscontinuous replication
**Semiconservative Replication**

- Each strand of the original DNA molecule serves as a template for the production of its counterpart.
- Cellular proofreading and error-checking mechanisms ensure near perfect **fidelity** for DNA replication.
- Synthesis of DNA chain ONLY occurs in 5’ to 3’ direction
**Bidirectional Replication in Eukaryotes**

- Replication starts at site called origin of replication by the help of a protein at a point in DNA rich in adenine and thymine bases (*Why not G & C?*)
- Once the origin has been located, some other initiators are recruited and form the pre-replication complex, unzips the double-stranded DNA forming Replication Fork.
- Replication continues and the DNA pulp enlarges in two directions.
Bidirectional Replication in Prokaryotes

- Most bacterial chromosomes contain a circular DNA molecule – there are no free ends to the DNA.
- The replication occurs in two directions forming what is called **Bidirectional Replication and it forms a shape like the Greek letter Theta θ**
**Semidiscontinuous replication**

The replication occurs in the two strands. It starts in one end and propagate in two ways:

- **Leading strand** continuously from 5’ to 3’ and the new stand is rapidly synthesized.
- **Lagging strand**, it is slow and gives short segments called *Okazaki Fragments*. These fragments are joined together by ligase enzyme.
Replication fork movement

Leading strand: Continuous

Lagging strand: Discontinuous

Okazaki fragments
### Enzymes used in DNA replication

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Function in DNA replication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topoisomerase</td>
<td>relaxes the DNA from its super-coiled structure.</td>
</tr>
<tr>
<td>DNA Helicase</td>
<td>separates the two strands of DNA at the Replication Fork behind the topoisomerase.</td>
</tr>
<tr>
<td>DNA Gyrase</td>
<td>relieves strain of unwinding by DNA helicase; this is a specific type of topoisomerase</td>
</tr>
<tr>
<td>Primase</td>
<td>provides a starting point of RNA (or DNA) for DNA polymerase to begin synthesis of the new DNA strand.</td>
</tr>
<tr>
<td>DNA Polymerase</td>
<td>catalyzes the addition of nucleotide substrates to DNA in the 5' to 3' direction. It needs a piece of RNA as primer to start replication (from primase). Also performs proof-reading and error correction. There are three types of DNA polymerases: DNA polymerase I, II and III</td>
</tr>
<tr>
<td>DNA Ligase</td>
<td>joins Okazaki Fragments of the lagging strand.</td>
</tr>
<tr>
<td>Telomerase</td>
<td>lengthens telomeric DNA by adding repetitive nucleotide sequences to the ends of eukaryotic chromosomes.</td>
</tr>
</tbody>
</table>
Transcription and Translation
https://www.youtube.com/watch?v=gG7uCskUOrA
https://www.youtube.com/watch?v=-zb6r1MMTkc
Figure 10.8B

The diagram illustrates the process of gene expression. It shows the DNA sequence, which is transcribed into RNA. The RNA sequence is then translated into a polypeptide chain. The diagram highlights the start and stop codons in the RNA sequence.

- **DNA**: The top part of the diagram shows the DNA sequence with complementary bases.
- **Transcribed strand**: The middle part represents the RNA strand that is transcribed from the DNA.
- **RNA**: The RNA strand shows the start and stop codons.
- **Translation**: The bottom part of the diagram represents the polypeptide chain, showing the sequence Met-Lys-Phe.