Biological Chemistry Department

Biological Chemistry

# Structure and Functions of Nucleic Acids

Educational Program: Pharmacy for foreign students (Language of instructions – English)

Lecturer: ass. prof. Kravchenko G.B.

# Lecture Plan

1. Introduction.
2. The Nucleoside and Nucleotide Structure and Nomenclature.
3. Nucleic Acid Structure.
3.1. The DNA Structure.
3.2. The RNA Structure and Functions.
2.2. The basic steps in protein synthesis.
2.3. Translation. Protein Biosynthesis Stages.
3. Mechanisms of Protein Biosynthesis Regulation.
3.1. Protein Biosynthesis Inhibition. Antibiotics.
3.2. Preparations that Stimulated Protein Biosynthesis.

<u>Individual work</u>

1. Other types of RNA.
2. Structure and functions of ribosomes.

# Information Resources

*1. Biological Chemistry: Textbook / A.L. Zagayko, L.M. Voronina, G.B. Kravchenko, K.V. Strel`chenko. – Kharkiv: NUPh; Original, 2011. – 48-57 p.*

*2. Training Journal for Licensed Exam "KROK-1": Study Material in Biological Chemistry. – Kharkiv: NUPh, 2017. – 27-29 p.*

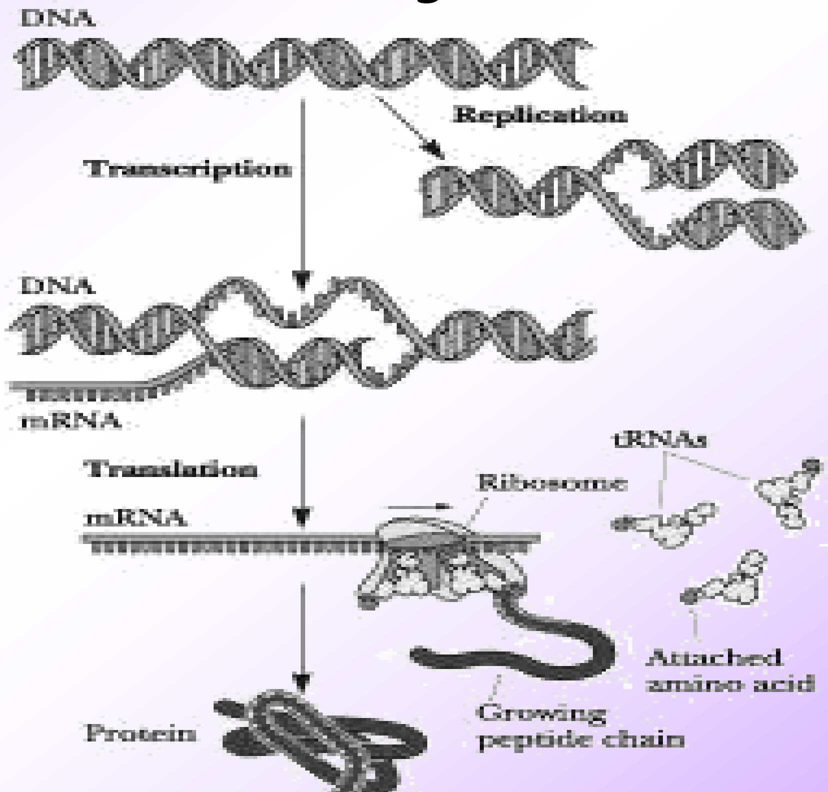
*3. Laboratory Manual on Biochemistry. Kharkiv: NUPh, 2017. - 32-35 p.*

*4. Basic Chemistry of Nucleic Acids: The Medical Biochemistry Page. Available on: https://themedicalbiochemistrypage.org/nucleic-acids.php.*


*The biochemical roles of nucleotides are numerous; they participate as essential intermediates in virtually all aspects of cellular metabolism. Serving an even more central biological purpose are the nucleic acids, the elements of heredity and the agents of genetic information transfer. Nucleic acids are linear polymers of nucleotides. The orderly sequence of nucleotide residues in a nucleic acid can encode information. The two basic kinds of nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA is the repository of genetic information in cells, while RNA serves in the transcription and translation of this information.*

# The fundamental process of information transfer in cells

*Information encoded in the nucleotide sequence of DNA is transcribed through synthesis of an RNA molecule **(transcription)** whose sequence is dictated by the DNA sequence. As the sequence of this RNA is read (as groups of three consecutive nucleotides) by the protein synthesis machinery, it is translated into the sequence of amino acids in a protein **(translation)**. This information transfer system is encapsulated in the dogma: **DNA → RNA → protein**.*

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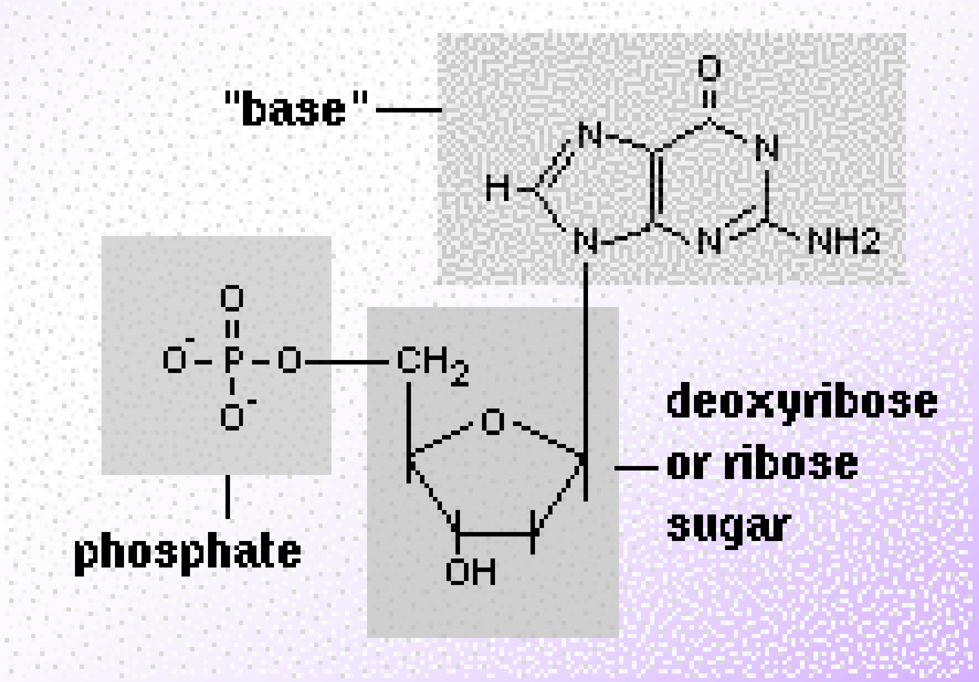
**Nucleotides** are the building blocks of all nucleic acids. Nucleotides have a distinctive structure composed of three components covalently bound together:

- ✓ a nitrogenous base - either derivative of a **pyrimidine** (one ring) or **purine** (two rings)
- ✓ a 5-carbon sugar - **ribose** or **deoxyribose**
- ✓ a phosphate group

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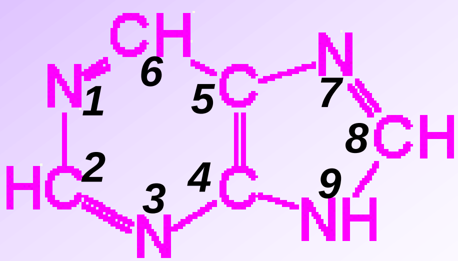
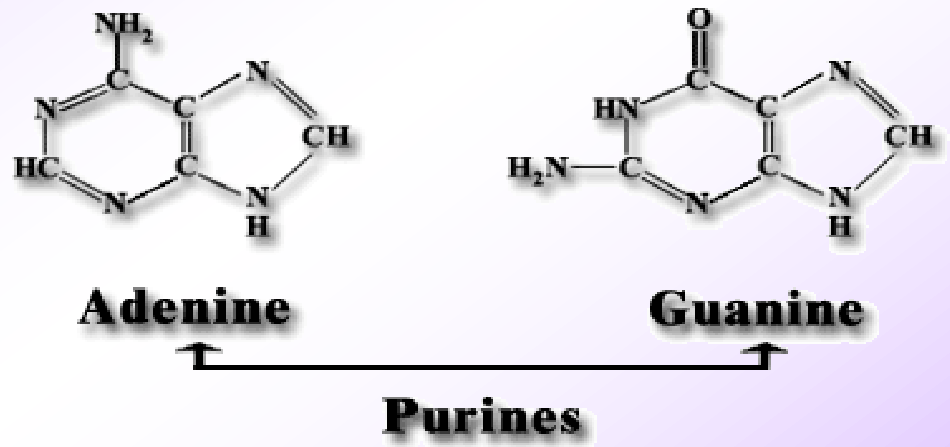
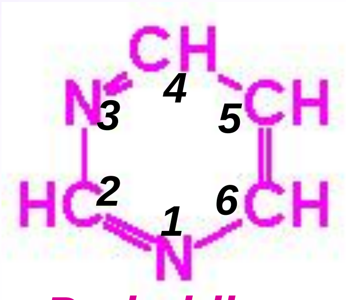
# NITROGENOUS BASES

Five bases found in nucleic acids. Two purine bases (adenine and guanine) and three pyrimidine bases (cytosine, uracil and thymine). Adenine and guanine occur in both DNA and RNA. Cytosine and thymine are the pair of pyrimidines in DNA, and cytosine and uracil are the pair in RNA.

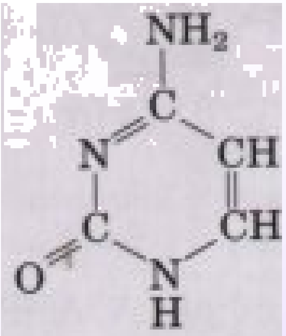


Purine

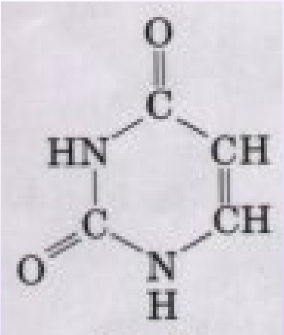


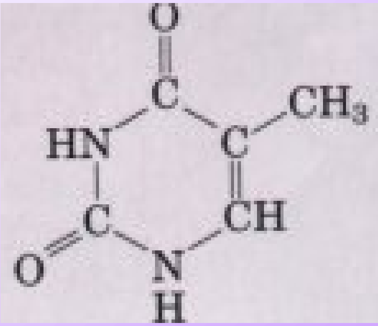
Pyrimidine



Cytosine



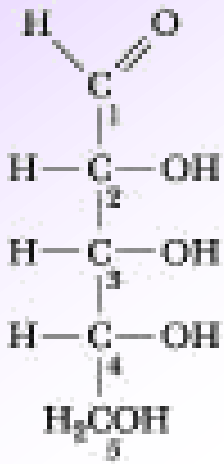
Uracil (RNA)



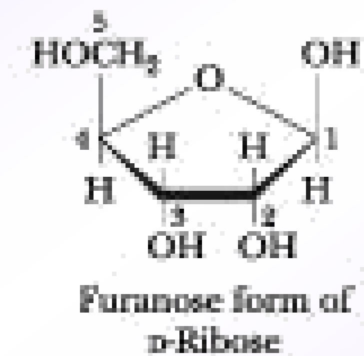
Thymine (DNA)

# PENTOSES

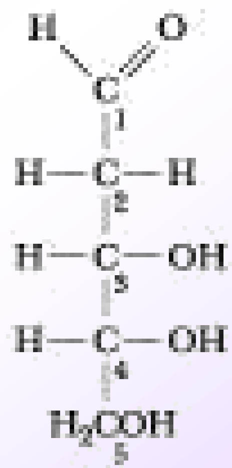
Two kinds of pentoses are found in nucleic acids. The recurring deoxyribonucleotide units of DNA contain **2'-deoxy-n-ribose**, and the ribonucleotide units of RNA contain **n-ribose**. In nucleotides, both types of pentoses are in their β-furanose (closed five-member ring) form.



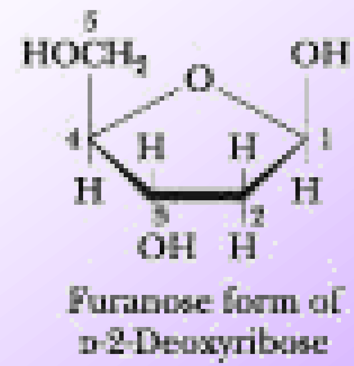
D-Ribose




β-D-Ribofuranose



D-2-Deoxyribose




β-D-Deoxyribofuranose

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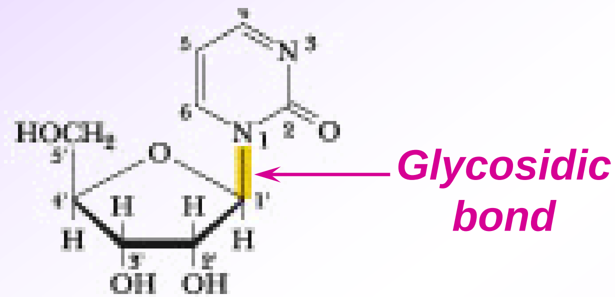
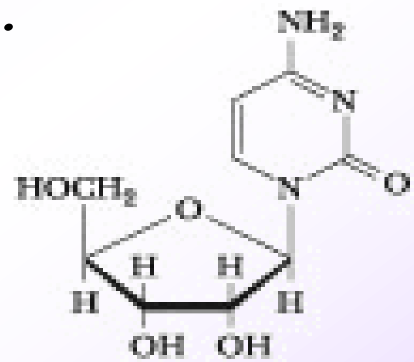
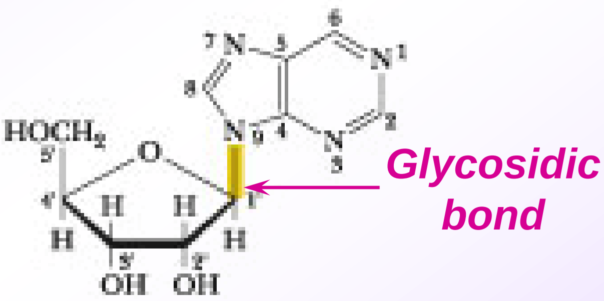
**The combination of a base and sugar is called *a nucleoside.***

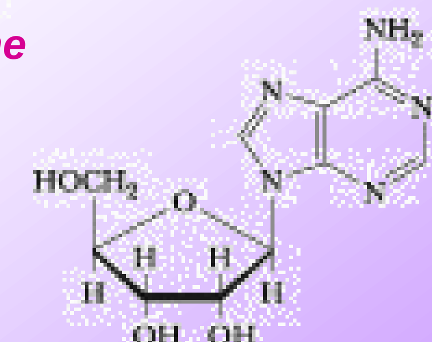
***Nucleosides are compounds formed when a base is linked to a sugar via a glycosidic bond. Glycosidic bonds by definition involve the carbonyl carbon atom of the sugar, which in cyclic structures is joined to the ring O atom. In nucleosides, the bond is an N-glycoside because it connects the anomeric C-1' to N-1 of a pyrimidine or to N-9 of a purine. Glycosidic bonds in nucleosides and nucleotides are always of the b-configuration.***



Cytidine



Adenosine

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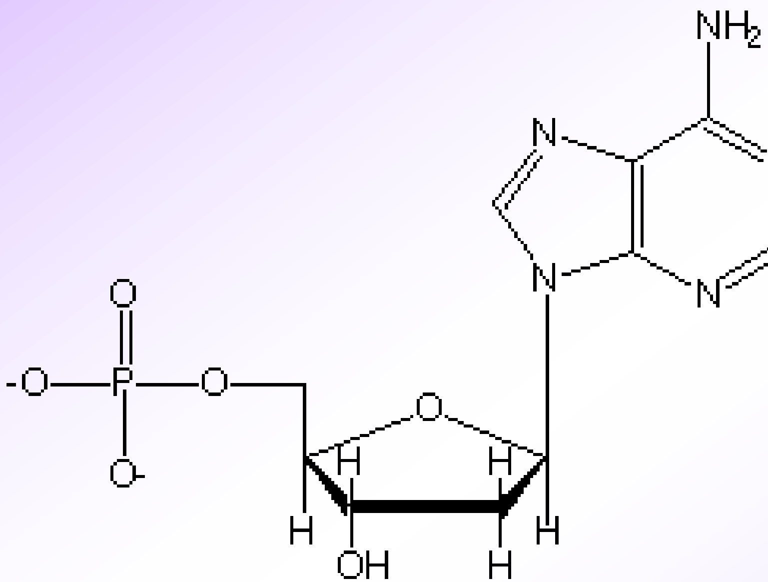
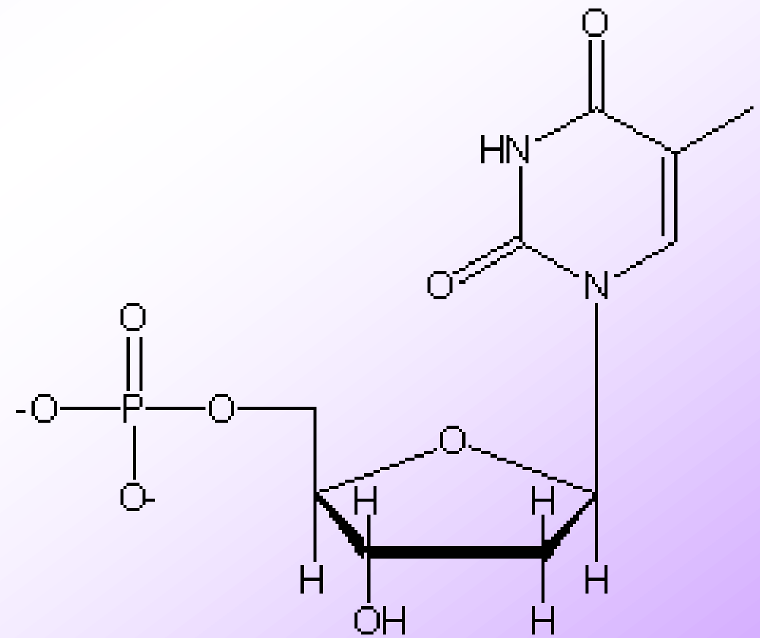
# NUCLEOTIDES

A nucleotide results when phosphoric acid is esterified to a sugar at C-3 and C-5' —OH group of a nucleoside. The vast majority of monomeric nucleotides in the cell are ribonucleotides having 5'-phosphate groups.



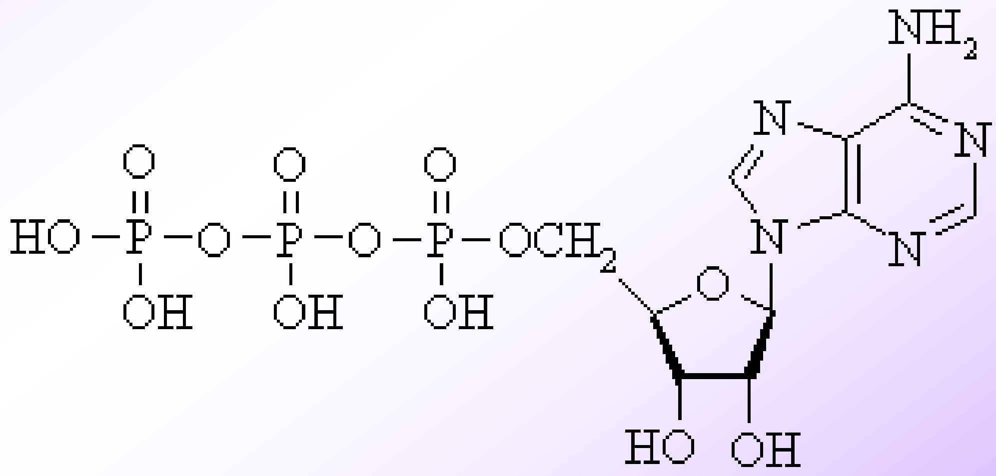
Deoxyadenosine 5' monophosphate



Deoxythymidyine 5' monophosphate

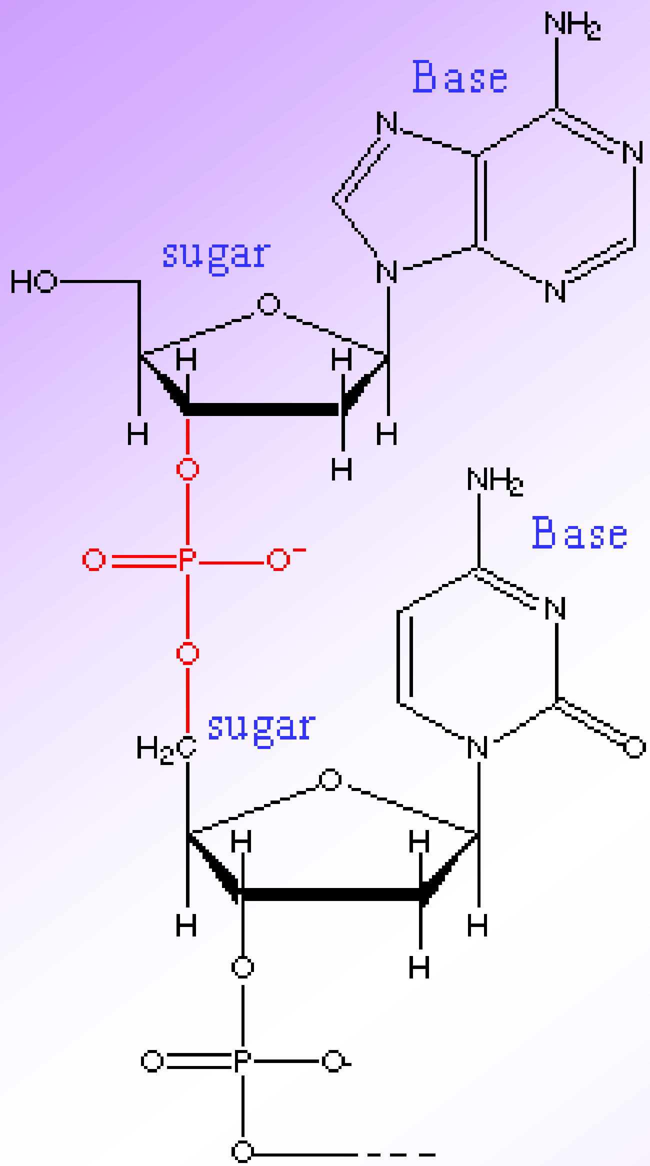
# Nucleoside 5'-Triphosphates are carriers of chemical energy

Nucleoside 5'-triphosphates are indispensable agents in metabolism because the phosphoric anhydride bonds they possess are a prime source of chemical energy to do biological work. Adenosine 5'-triphosphate (ATP) has been termed the energy currency of the cell. Guanosine 5'-triphosphate GTP is the major energy source for protein synthesis.




adenosine 5'-triphosphate (ATP)

# Nucleic Acids Are Polynucleotides




Nucleic acids are linear polymers of nucleotides linked 3' to 5' by phosphodiester bridges. They are formed as 5'-nucleoside monophosphates are successively added to the 3'-OH group of the preceding nucleotide, a process that gives the polymer a directional sense. Polymers of ribonucleotides are named **ribonucleic acid**, or **RNA**. Deoxyribonucleotide polymers are called **deoxyribonucleic acid**, or **DNA**.

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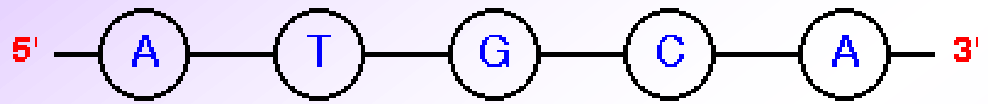
# CLASSES OF NUCLEIC ACIDS

The two major classes of nucleic acids are DNA and RNA. DNA has only one biological role, but it is the more central one. The information to make all the functional macromolecules of the cell is preserved in DNA and accessed through transcription of the information into RNA copies. Coincident with its singular purpose, there is only a single DNA molecule (or "chromosome") in simple life forms such as viruses or bacteria. Such DNA molecules must be quite large in order to embrace enough information for making the macromolecules necessary to maintain a living cell. Eukaryotic cells have many chromosomes, and DNA is found principally in two copies in the diploid chromosomes of the nucleus, but it also occurs in mitochondria and in chloroplasts, where it encodes some of the proteins and RNAs unique to these organelles.

In contrast, RNA occurs in multiple copies and various forms. Cells contain up to eight times as much RNA as DNA. RNA has a number of important biological functions, and on this basis, RNA molecules are categorized into several major types: **messenger RNA**, **ribosomal RNA**, and **transfer RNA**.

# The Primary Structure of DNA

The DNA single strand can be represented in a simple way by its base sequencing. The base sequence contains the encoded genetic information.

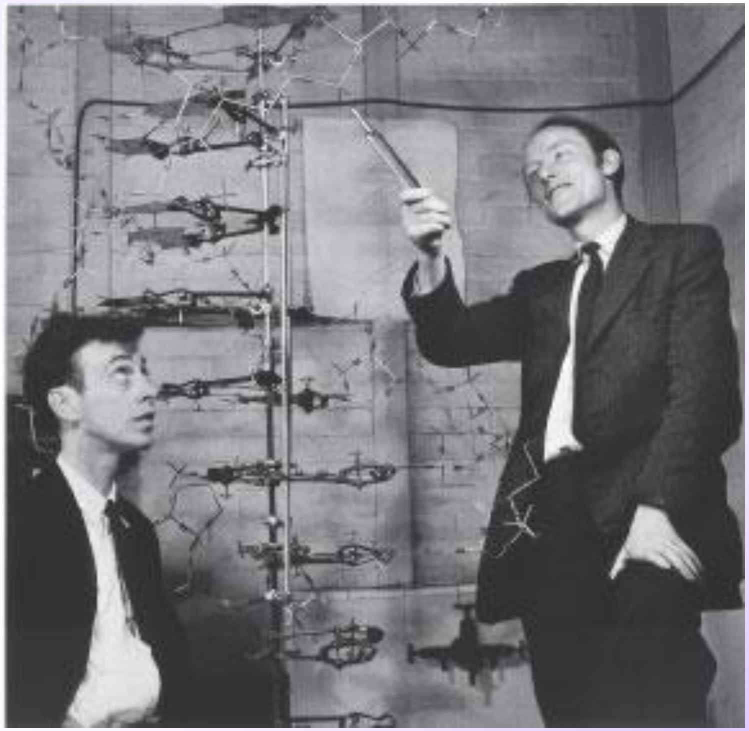



# Chargaff's Rules

A clue to the chemical basis of base pairing in DNA came from the analysis of the base composition of various DNAs by Erwin Chargaff in the late 1940s. His data showed that the four bases commonly found in DNA (A, C, G, and T) do not occur in equimolar amounts and that the relative amounts of each vary from species to species. Nevertheless, Chargaff noted that certain pairs of bases, namely, adenine and thymine, and guanine and cytosine, are always found in a 1:1 ratio and that the number of pyrimidine residues always equals the number of purine residues. These findings are known as Chargaff's rules: [A] = [T]; [C] = [G]; [pyrimidines] = [purines].

# Secondary structure of DNA

***James Watson and Francis Crick, working in the Cavendish Laboratory at Cambridge Universityin 1953, took advantage of Chargaff's results and the data obtained by Rosalind Franklin and Maurice Wilkins in X-ray diffraction studies on the structure of DNA to conclude that DNA was a complementary double helix.***



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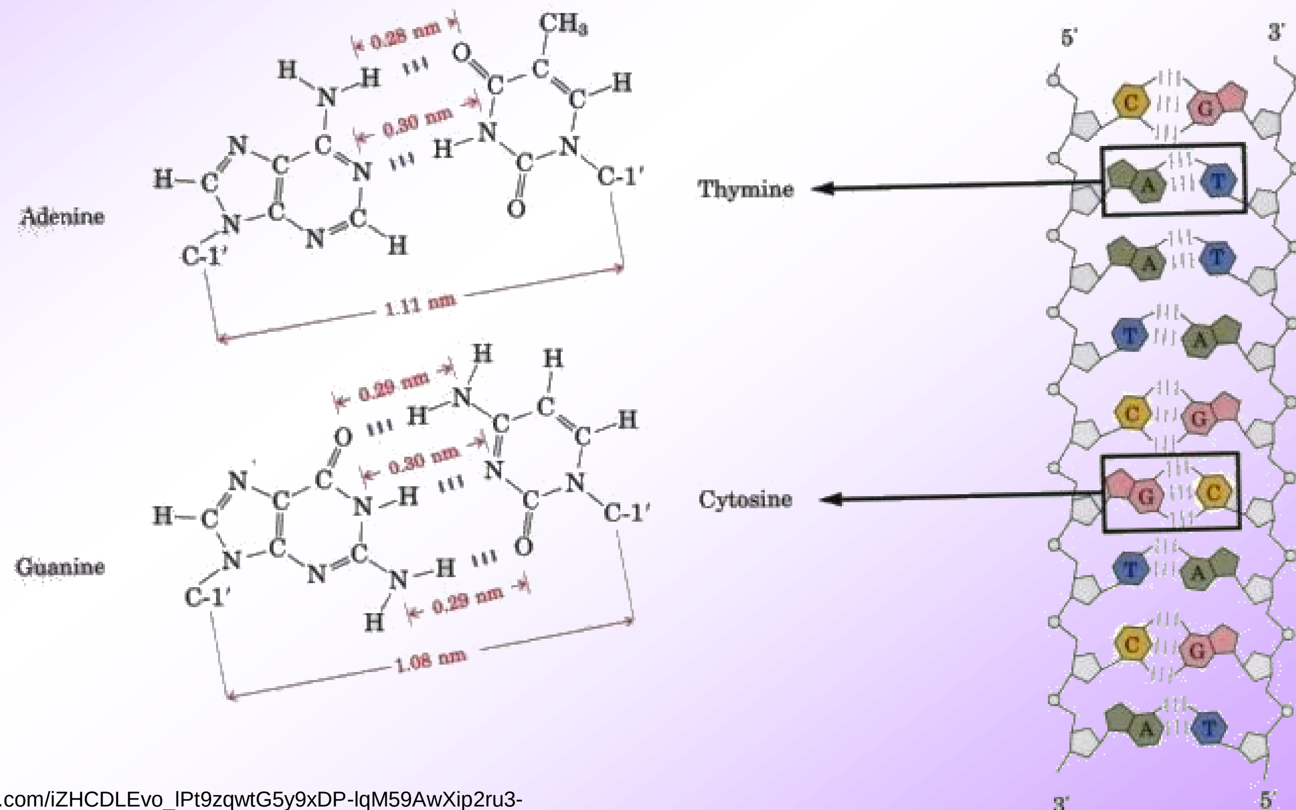
Two strands of deoxyribonucleic acid are held together by hydrogen bonds formed between unique base pairs, always consisting of a purine in one strand and a pyrimidine in the other. Base pairing is very specific: if the purine is adenine, the pyrimidine must be thymine. Similarly, guanine pairs only with cytosine. Thus, if an A occurs in one strand of the helix, T must occupy the complementary position in the opposing strand. Likewise, a G in one dictates a C in the other.

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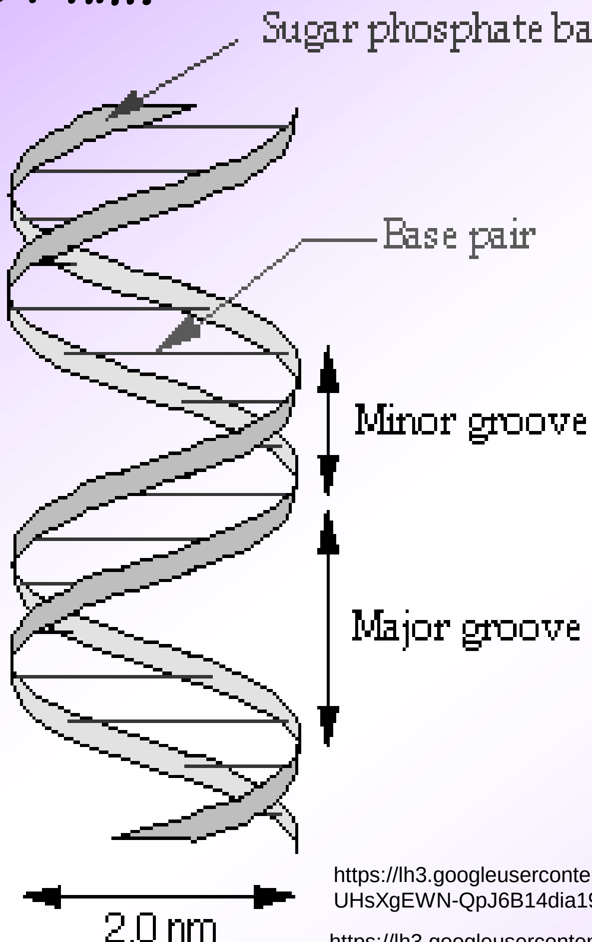
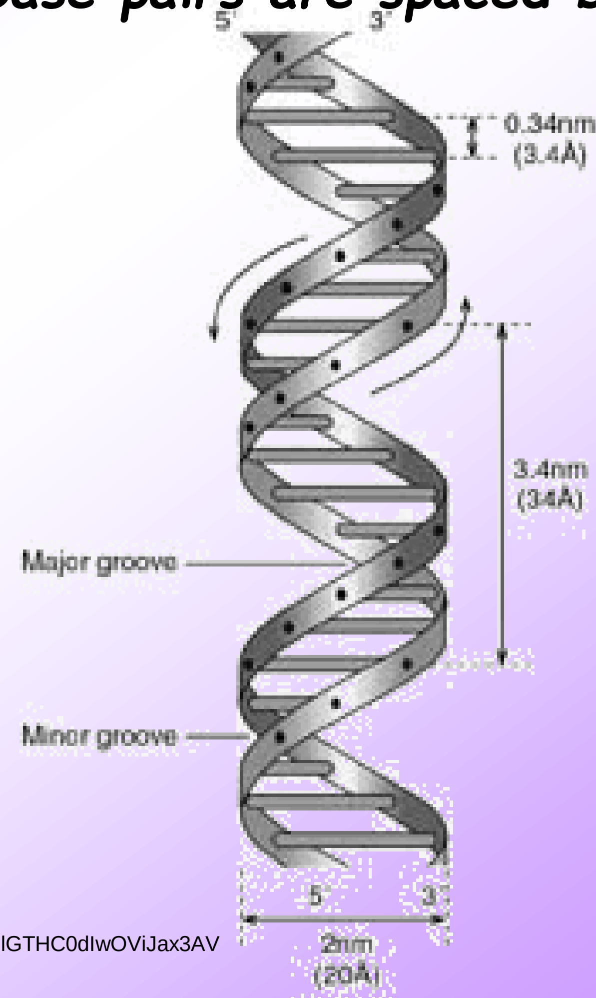
## The key features of the double helix model are as follow:

✓The two DNA strands are antiparallel and complementary

✓Sugar and phosphate groups form the outside backbone of the helix and base pairs are inside.

✓The helix diameter is 2.0 nm, adjacent base pairs are spaced by 0.34 nm.

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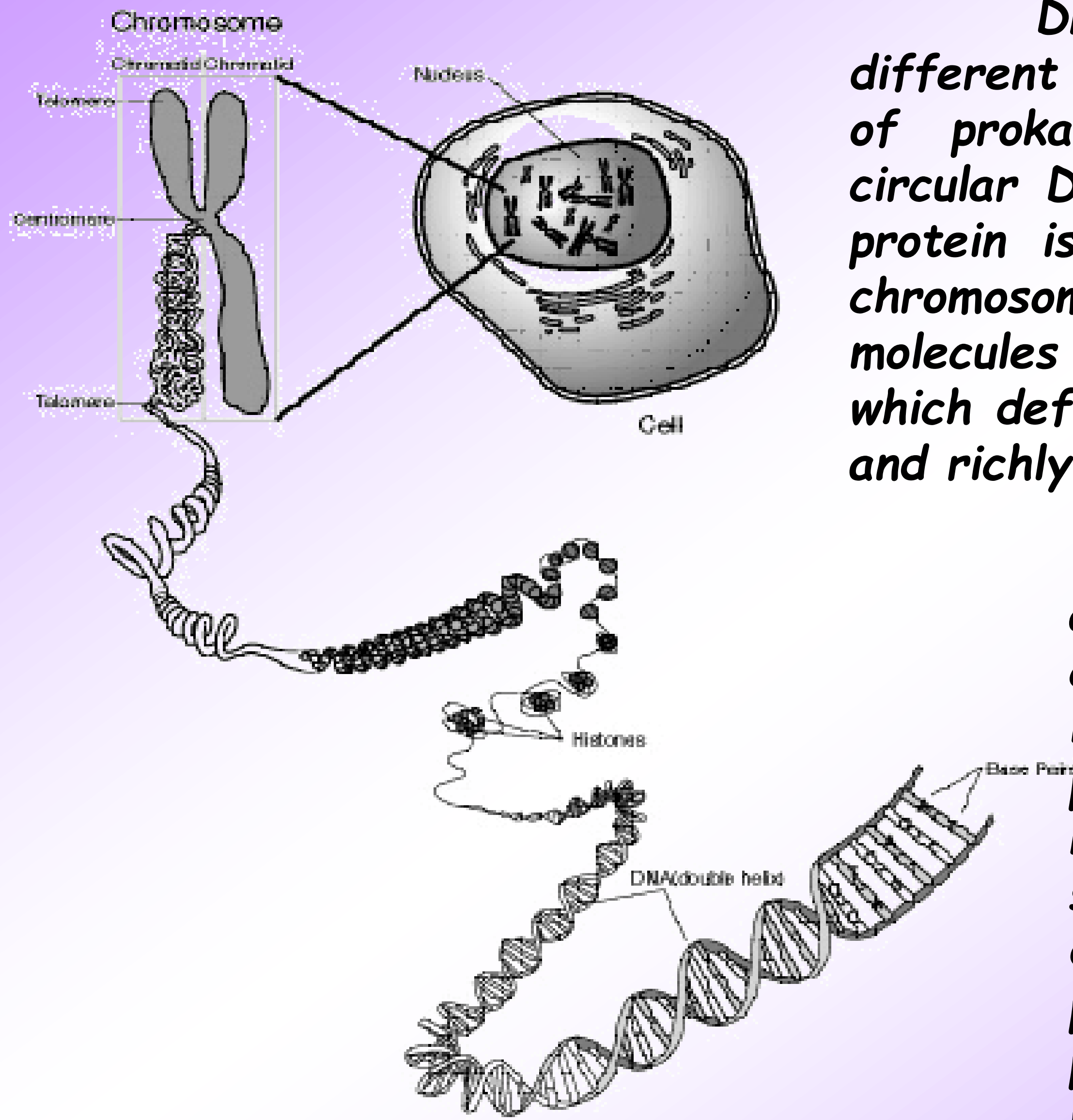
# DNA in the Form of Chromosomes




***DNA occurs in various forms in different cells. The single chromosome of prokaryotic cells is typically a circular DNA molecule. Relatively little protein is associated with prokaryotic chromosomes. In contrast, the DNA molecules of eukaryotic cells, each of which defines a chromosome, are linear and richly adorned with proteins.***

***A class of arginine- and lysine-rich basic proteins called histones interact ionically with the anionic phosphate groups in the DNA backbone to form nucleosomes, structures in which the DNA double helix is wound around a protein "core" composed of pairs of four different histone polypeptides.***

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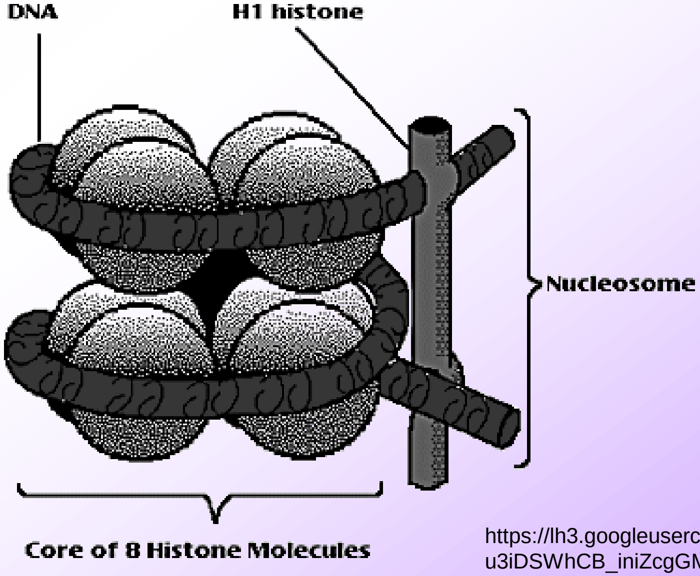
# NUCLEOSOMES

The DNA in a eukaryotic cell nucleus during the interphase between cell divisions exists as a nucleoprotein complex called chromatin. The proteins of chromatin fall into two classes: histones and nonhistone chromosomal proteins. Histones are abundant structural proteins, whereas the nonhistone class is represented only by a few copies each of many diverse proteins involved in genetic regulation. The histones are relatively small, positively charged arginine- or lysine-rich proteins that interact via ionic bonds with the negatively charged phosphate groups on the polynucleotide backbone. Five distinct histones are known: H1, H2A, H2B, H3, and H4. Pairs of histones H2A, H2B, H3, and H4 aggregate to form an octameric core structure, which is the core of the nucleosome, around which the DNA helix is wound.

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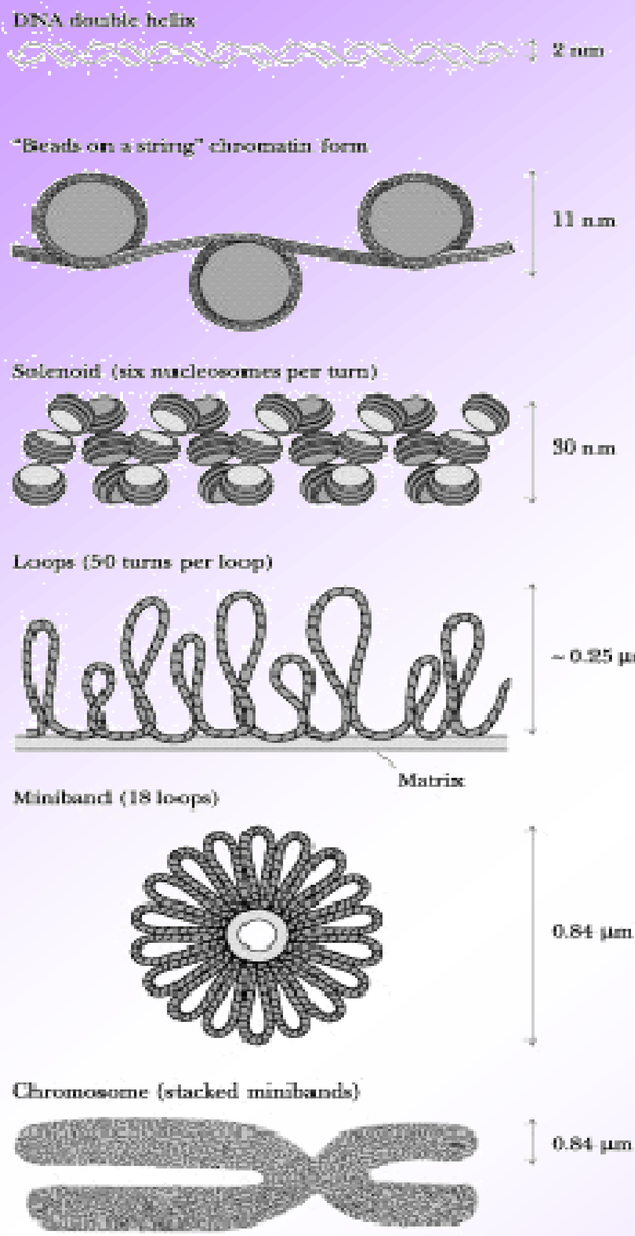
# ORGANIZATION OF CHROMATIN AND CHROMOSOMES




*A higher order of chromatin structure is created when the nucleosomes, in their characteristic beads-on-a-string motif, are wound in the fashion of a solenoid having six nucleosomes per turn. The resulting 30-nm fila-ment contains about 1200 bp in each of its solenoid turns. Interactions between the respective H1 components of successive nucleosomes stabilize the 30-nm filament. This 30-nm filament then forms long DNA loops of variable length, each containing on average between 60,000 and 150,000 bp. Electron microscopic analysis of human chromosome 4 suggests that 18 such loops are then arranged radially about the circumference of a single turn to form a miniband unit of the chromosome. According to this model, approximately 106 of these minibands are arranged along a central axis in each of the chromatids of human chromosome 4 that form at mitosis.*

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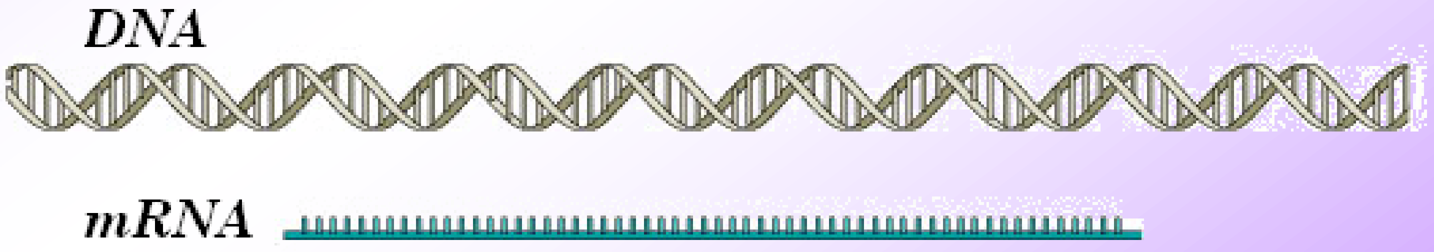
# RNA
# MESSENGER RNA

***Messenger RNA (mRNA) serves to carry the information or "message" that is encoded in genes to the sites of protein synthesis in the cell, where this information is translated into a polypeptide sequence.***

***Messenger RNA is synthesized during transcription, an enzymatic process in which an RNA copy is made of the sequence of bases along one strand of DNA. This mRNA then directs the synthesis of a polypeptide chain as the information that is contained within its nucleotide sequence is translated into an amino acid sequence by the protein-synthesizing machinery of the ribosomes.***

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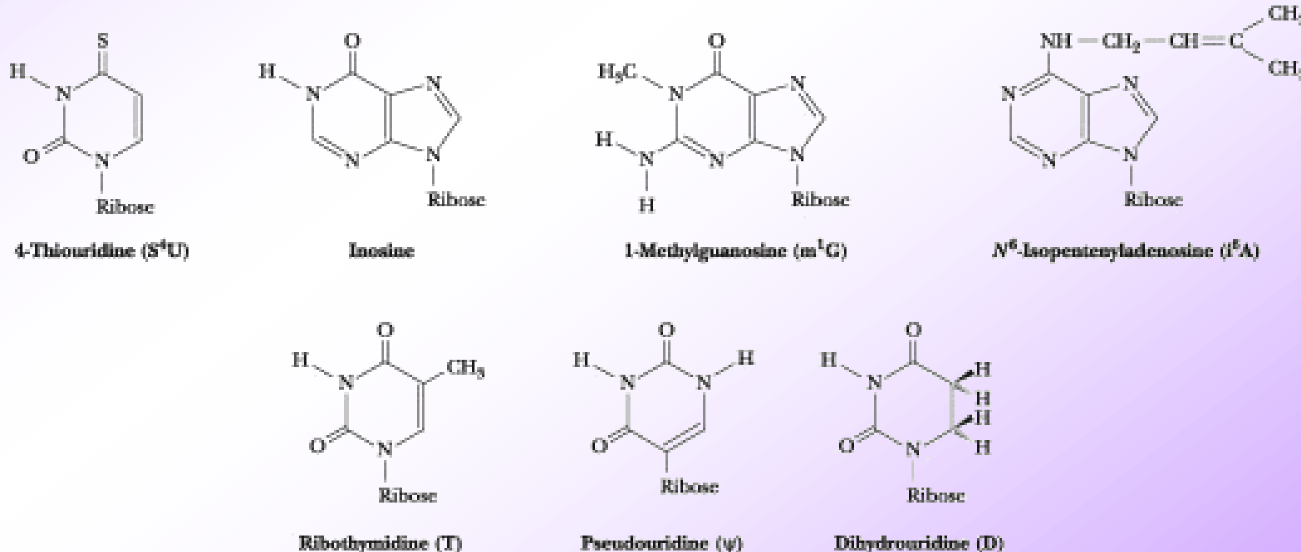
# RIBOSOMAL RNA

***Ribosomes, the supramolecular assemblies where protein synthesis occurs, are about 65% RNA of the ribosomal RNA type. Ribosomal RNA (rRNA) molecules fold into characteristic secondary structures as a consequence of intramolecular hydrogen bond interactions. The different species of rRNA are generally referred to according to their sedimentation coefficient, which are a rough measure of their relative size.***

***Ribosomal RNAs characteristically contain a number of specially modified nucleotides, including pseudouridine residues, ribothymidylic acid, and methylated bases.***




***Unusual bases of RNA—pseudouridine, ribothymidylic acid, and various methylated bases.***

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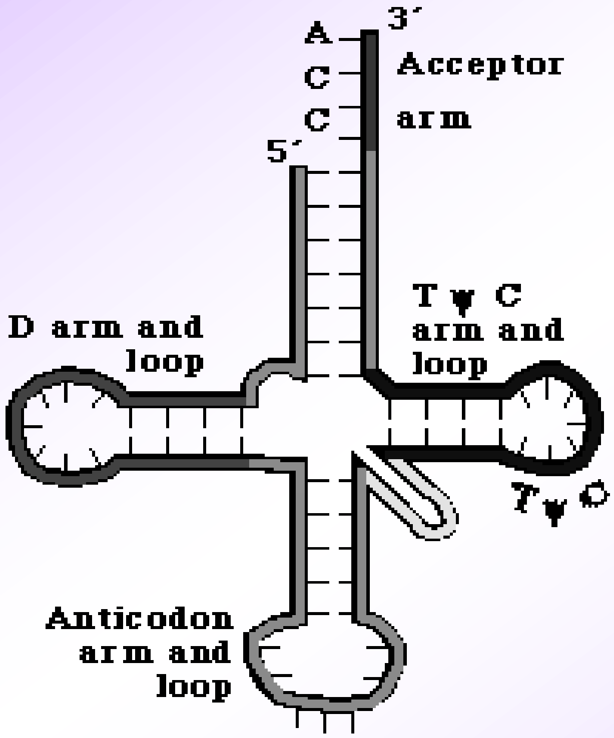
# TRANSFER RNA

***Transfer RNA (tRNA) serves as a carrier of amino acid residues for protein synthesis. Transfer RNA molecules also fold into a characteristic secondary structure (figure). The amino acid is attached as an aminoacyl ester to the 3'-terminus of the tRNA. Aminoacyl-tRNAs are the substrates for protein biosynthesis. The tRNAs are the smallest RNAs (size range—23 to 30 kD) and contain 73 to 94 residues, a substantial number of which are methylated or otherwise unusually modified.***

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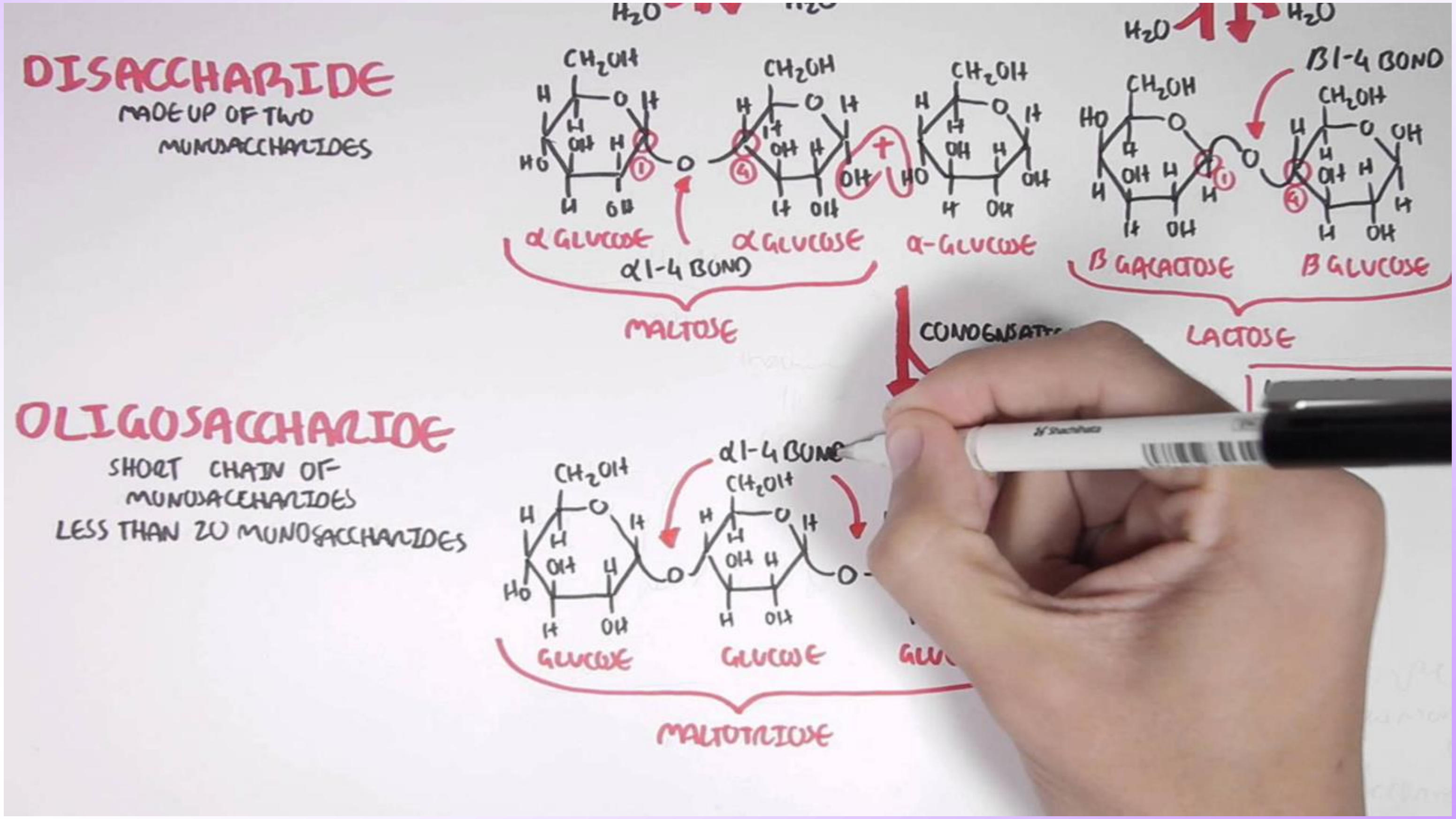
# Conclusions

1. Todays understanding of information pathways as arisen from the convergence of genetics, physics, and chemistry in modern biochemistry.
2. DNA replication is governed by a set of fundamental rules.
3. All cells have multiple DNA repair systems.
4. Three major kinds of RNA are produced.
5. RNA is synthesized by RNA polymerases.
6. All RNA molecules in eukaryotes are processed after they are synthesized.
7. Genetic code is the set of triplet code "words"  in DNA or mRNA) coding for the amino acids of proteins.
8. Translation is the process in which the genetic information present in mRNA molecular specifies the sequence of amino acids during protein synthesis.

## Do you have any questions?

## Thank you for your attention!

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